Solar Tracking: High precision solar position algorithms, programs, software and source-code for computing the solar vector, solar coordinates & sun angles in Microprocessor, PLC,...

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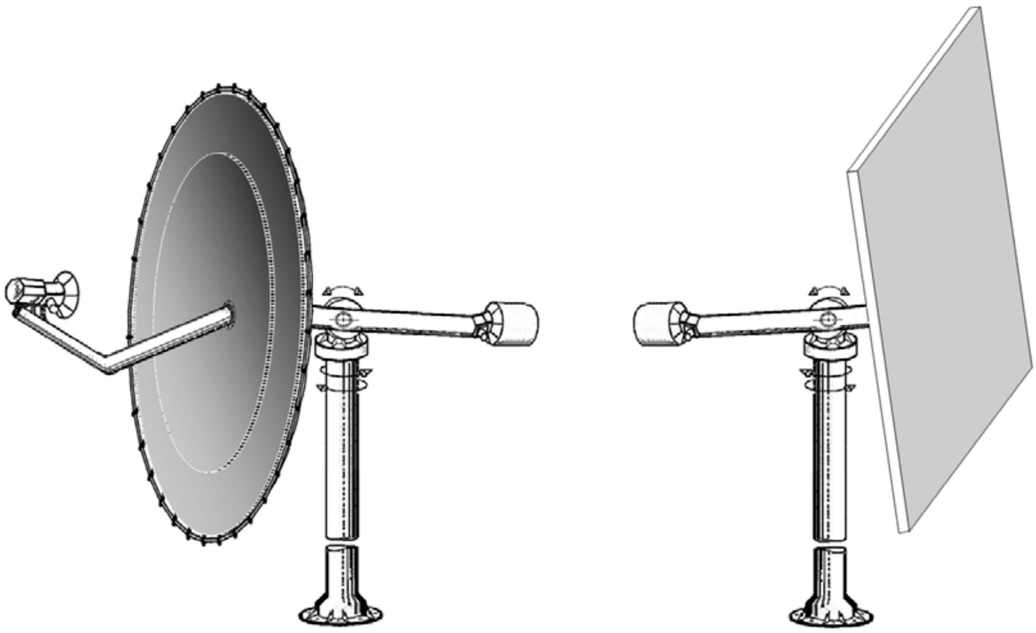
High precision solar position algorithms, programs, software and source-code for computing the solar vector, solar coordinates & sun angles in Microprocessor, PLC, Arduino, PIC and PC-based sun tracking devices or dynamic sun following hardware



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FOREWORD

Your research led to the design of your mechanical platform for your solar positioning system, but you need to know more about the technology and processes in order to track and follow the sun ?. Your internet searches for the term ”solar tracking” or ”sun tracking” led to millions of pages that reference complex scientific papers on astronomical angles and complex formulas. If not this, then on the other end of the spectrum you found hundreds of spreadsheets for calculating the position of the sun. You ask, how do I get these angles in the spreadsheet to get my mechanical system moving ?
In this research support book, we will get you a little closer to realising your concentrating solar research invention, idea or patent. We will make your work a little simpler by giving you straightforward and practical direction on how to get you mechanical system or electronics to follow the sun. If you dont know anything about electronics or programming, we will show you simple ways on how to get started on this also, just enough so that you are able to get your tracker to automatically follow the sun throughout the day. For the professionals who wants to harness power from the sun through a solar tracking system, many algorithms have already been programmed to perform these functions and are available on open-source. An on-axis sun tracking system such as the altitude-azimuth dual axis solar tracker uses a sun track-ing algorithm to ensure high precision sun tracking in automated solar tracker applications. In short, this book is all about helping technicians, scientists and engineering on solutions to solar tracking and sun following technology principles for solar collecting and solar harvesting systems.

Keywords and Tags:

SunPos algorithm Microsoft Windows, Macintosh, iOS, MS-DOS, Android, Palm OS, Unix/Linux actuator automation azimuth and elevation battery calculated camera carbon footprint closed-loop cloud cogeneration components computed concentrated solar power configuration control system DC motor devices diagram Dobson dual-axis efficiency electrical electronic elevation angle encoder ensure equation example illustrated input installation interface irradiation mechanical microcontroller maximum power point Mppt solar tracking monitoring movement NREL open-loop control operation optical optimization output parabolic dish parameters Trimble Platform Gimbal photo-voltaic power budget power conversion encyclopaedia remote satellite slew drive solar cells solar collector solar concentrator solar dish solar energy solar harvesting solar position algorithm solar power system solar radiation solar receiver solar reflector system solar resource solar thermal energy solar tracking applications solar tracking control solar tracking error solar tracking platform solar tracking system solar vector stand-alone stepper motor Stirling engine sun path sun position sun sensor sun tracking sun vector sunlight tracker solar trigeneration triple generation solar polygeneration solar quadgeneration vision Wii remote weather station weather center wind Solar lighting Concentrated solar energy Fibre optic bundle solar simulation Matlab Simulink Matlab Simulink Modelica TRNSYS EnergyPlus EnergyPlan BeOpt DView solar energy portal Gridlab-D Simergy Exergy solar synthesis Energy analysis Efficiency Green buildings Efficient buildings automatic solar tracking system solar tracking system using microcontroller solar tracking mechanism solar tracking system circuit diagram solar tracking system project solar tracking circuit solar navigation systems sun navigation systems Inertial navigation system solar tracker orientation and attitude measurements automatic dish positioner automatic camera positioner automatic solar collector positioner sola tracking GPS tracking Stirling micro-CHP micro-CCHP co-generation combined cycle micro combined heat and power

CONTENTS IN BRIEF

PREFACE

This book details Automatic Solar-Tracking, Sun-Tracking-Systems, Solar-Trackers and Sun Tracker Systems. An intelligent automatic solar tracker is a device that orients a payload toward the sun. Such programmable computer based solar tracking device includes principles of solar tracking, solar tracking systems, as well as microcontroller, microprocessor and/or PC based solar tracking control to orientate solar reflectors, solar lenses, photovoltaic panels or other optical configurations towards the sun. Motorized space frames and kinematic systems ensure motion dynamics and employ drive technology and gearing principles to steer optical configurations such as mangin, parabolic, conic, or cassegrain solar energy collectors to face the sun and follow the sun movement contour continuously.

In harnessing power from the sun through a solar tracker or practical solar tracking system, renewable energy control automation systems require automatic solar tracking software and solar position algorithms to accomplish dynamic motion control with control automation architecture, circuit boards and hardware. On-axis sun tracking system such as the altitude-azimuth dual axis or multi-axis solar tracker systems use a sun tracking algorithm or ray tracing sensors or software to ensure the sun's passage through the sky is traced with high precision in automated solar tracker applications, right through summer solstice, solar equinox and winter solstice. A high precision sun position calculator or sun position algorithm uses a software program routine to align the solar tracker to the sun and is an important component in the design and construction of an automatic solar tracking system.

From sun tracing software perspective, the sonnet Tracing The Sun has a literal meaning. Within the context of sun track and trace, this book explains that the sun's daily path across the sky is directed by relatively simple principles, and if grasped/understood, then it is relatively easy to trace the sun with sun following software. Sun position computer software for tracing the sun are available as open source code, sources that is listed in this book. Ironically there was even a system called sun chaser, said to have been a solar positioner system known for chasing the sun throughout the day.

Using solar equations in an electronic circuit for automatic solar tracking is quite simple, even if you are a novice, but mathematical solar equations are over complicated by academic experts and professors in text-books, journal articles and internet websites. In terms of solar hobbies, scholars, students and Hobbyist's looking at solar tracking electronics or PC programs for solar tracking are usually overcome by the sheer volume of scientific material and internet resources, which leaves many developers in frustration when search for simple experimental solar tracking source-code for their on-axis sun-tracking systems. This booklet will simplify the search for the mystical sun tracking formulas for your sun tracker innovation and help you develop your own autonomous solar tracking controller.

By directing the solar collector directly into the sun, a solar harvesting means or device can harness sunlight or thermal heat. In order to track the sun as the earth rotates (or as the sun moves across the sky) the help of sun angle formulas, solar angle formulas or solar tracking procedures is required in the calculation of sun's position in the sky. Automatic sun tracking system software includes algorithms for solar altitude azimuth angle calculations required in following the sun across the sky. In using the longitude, latitude GPS coordinates of the solar tracker location, these sun tracking software tools supports precision solar tracking by determining the solar altitude-azimuth coordinates for the sun trajectory in altitude-azimuth tracking at the tracker location, using certain sun angle formulas in sun vector calculations. Instead of follow the sun software, a sun tracking sensor such as a sun sensor or webcam or video camera with vision based sun following image processing software can also be used to determine the position of the sun optically. Such optical feedback devices are often used in solar panel tracking systems and dish tracking systems.

Dynamic sun tracing is also used in solar surveying, DNI analyser and sun surveying systems that build solar infographics maps with solar radiance, irradiance and DNI models for GIS (geographical information system). In this way geospatial methods on solar/environment interaction makes use use of geospatial technologies (GIS, Remote Sensing, and Cartography). Climatic data and weather station or weather center data, as well as queries from sky servers and solar resource database systems (i.e. on DB2, Sybase, Oracle, SQL, MySQL) may also be associated with solar GIS maps. In such solar resource modelling systems, a pyranometer or solarimeter is normally used in addition to measure direct and indirect, scattered, dispersed, reflective radiation for a particular geographical location. Sunlight analysis is important in flash photography where photographic lighting are important for photographers. GIS systems are used by architects who add sun shadow applets to study architectural shading or sun shadow analysis, solar flux calculations, optical modelling or to perform weather modelling. Such systems often employ a computer operated telescope type mechanism with ray tracing program software as a solar navigator or sun tracer that determines the solar position and intensity.

The purpose of this booklet is to assist developers to track and trace suitable source-code and solar tracking algorithms for their application, whether a hobbyist, scientist, technician or engineer. Many open-source sun following and tracking algorithms and source-code for solar tracking programs and modules are freely available to download on the internet today. Certain proprietary solar tracker kits and solar tracking controllers include a software development kit SDK for its application programming interface API attributes (Pebble). Widget libraries, widget toolkits, GUI toolkit and UX libraries with graphical control elements are also available to construct the graphical user interface (GUI) for your solar tracking or solar power monitoring program.

The solar library used by solar position calculators, solar simulation software and solar contour calculators include machine program code for the solar hardware controller which are software programmed into Micro-controllers, Programmable Logic Controllers PLC, programmable gate arrays, Arduino processor or PIC processor. PC based solar tracking is also high in demand using C++, Visual Basic VB, as well as MS Windows, Linux and Apple Mac based operating systems for sun path tables on Matlab, Excel. Some books and internet webpages use other terms, such as: sun angle calculator, sun position calculator or solar angle calculator. As said, such software code calculate the solar azimuth angle, solar altitude angle, solar elevation angle or the solar Zenith angle (Zenith solar angle is simply referenced from vertical plane, the mirror of the elevation angle measured from the horizontal or ground plane level). Similar software code is also used in solar calculator apps or the solar power calculator apps for IOS and Android smartphone devices. Most of these smartphone solar mobile apps show the sun path and sun-angles for any location and date over a 24 hour period. Some smartphones include augmented reality features in which you can physically see and look at the solar path through your cell phone camera or mobile phone camera at your phone's specific GPS location.

In the computer programming and digital signal processing (DSP) environment, (open source) program code are available for Gambas, VB, .Net, Delphi, Python, C, C+, C++, PHP, Swift, ADM, F, Flash, Basic, QBasic, GBasic, KBasic, SIMPL language, Squirrel, Solaris, Assembly language on operating systems such as MS Windows, Apple Mac, DOS, Unix or Linux OS. Software algorithms predicting position of the sun in the sky are commonly available as graphical programming platforms such as Matlab (Mathworks), Simulink models, Java applets, TRNSYS simulations, Scada system apps, Labview module, Beckhoff TwinCAT (Visual Studio), Siemens SPA, mobile and iphone apps, Android or iOS tablet apps, and so forth. At the same time, PLC software code for a range of sun tracking automation technology can follow the profile of sun in sky for Siemens, HP, Panasonic, ABB, Allan Bradley, OMRON, SEW, Festo, Beckhoff, Rockwell, Schneider, Endress Hauser, Fudji electric. Honeywell, Fuchs, Yokonawa, or Muthibishi platforms. Sun path projection software are also available for a range of modular IPC embedded PC motherboards, Industrial PC, PLC (Programmable Logic Controller) and PAC (Programmable Automation Controller) such as the Siemens S7-1200 or Siemens Logo, Beckhoff IPC or CX series, OMRON PLC, Ercam PLC, AC500plc ABB, National Instruments NI PXI or NI cRIO, PIC processor, Intel 8051/8085, IBM (Cell, Power, Brain or Truenorth series), FPGA (Xilinx Altera Nios), Intel, Xeon, Atmel megaAVR, MPU, Maple, Teensy, MSP, XMOS, Xbee, ARM, Raspberry Pi, Eagle, Arduino or Arduino AtMega microcontroller, with servo motor, stepper motor, direct current DC pulse width modulation PWM (current driver) or alternating current AC SPS or IPC variable frequency drives VFD motor drives (also termed adjustable-frequency drive, variable-speed drive, AC drive, micro drive or inverter drive) for electrical, mechatronic, pneumatic, or hydraulic solar tracking actuators.

The above motion control and robot control systems include analogue or digital interfacing ports on the processors to allow for tracker angle orientation feedback control through one or a combination of angle sensor or angle encoder, shaft encoder, precision encoder, optical encoder, magnetic encoder, direction encoder, rotational encoder, chip encoder, tilt sensor, inclination sensor, or pitch sensor. Note that the tracker's elevation or zenith axis angle may measured using an altitude angle-, declination angle-, inclination angle-, pitch angle-, or vertical angle-, zenith angle- sensor or inclinometer. Similarly the tracker's azimuth axis angle be measured with a azimuth angle-, horizontal angle-, or roll angle- sensor. Chip integrated accelerometer magnetometer gyroscope type angle sensors can also be used to calculate displacement. Other options include the use of thermal imaging systems such as a Fluke thermal imager, or robotic or vision based solar tracker systems that employ face tracking, head tracking, hand tracking, eye tracking and car tracking principles in solar tracking.

With unattended decentralised rural, island, isolated, or autonomous off-grid power installations, remote control, monitoring, data acquisition, digital datalogging and online measurement and verification equipment becomes crucial. It assists the operator with supervisory control to monitor the efficiency of remote renewable energy resources and systems and provide valuable web-based feedback in terms of CO2 and clean development mechanism (CDM) reporting. A power quality analyser for diagnostics through internet, WiFi and cellular mobile links is most valuable in frontline troubleshooting and predictive maintenance, where quick diagnostic analysis is required to detect and prevent power quality issues.

Solar tracker applications cover a wide spectrum of solar applications and solar assisted application, including concentrated solar power generation, solar desalination, solar water purification, solar steam generation, solar electricity generation, solar industrial process heat, solar thermal heat storage, solar food dryers, solar water pumping, hydrogen production from methane or producing hydrogen and oxygen from water (HHO) through electrolysis. Many patented or non-patented solar apparatus include tracking in solar apparatus for solar electric generator, solar desalinator, solar steam engine, solar ice maker, solar water purifier, solar cooling, solar refrigeration, USB solar charger, solar phone charging, portable solar charging tracker, solar coffee brewing, solar cooking or solar dying means. Your project may be the next breakthrough or patent, but your invention is held back by frustration in search for the sun tracker you require for your solar powered appliance, solar generator, solar tracker robot, solar freezer, solar cooker, solar drier, solar pump, solar freezer, or solar dryer project. Whether your solar electronic circuit diagram include a simplified solar controller design in a solar electricity project, solar power kit, solar hobby kit, solar steam generator, solar hot water system, solar ice maker, solar desalinator, hobbyist solar panels, hobby robot, or if you are developing professional or hobby electronics for a solar utility or micro scale solar powerplant for your own solar farm or solar farming, this publication may help accelerate the development of your solar tracking innovation.

Lately, solar polygeneration, solar trigeneration (solar triple generation), and solar quad generation (adding delivery of steam, liquid/gaseous fuel, or capture food-grade CO_2) systems have need for automatic solar tracking. These systems are known for significant efficiency increases in energy yield as a result of the integration and re-use of waste or residual heat and are suitable for compact packaged micro solar powerplants that could be manufactured and transported in kit-form and operate on a plug-and play basis. Typical hybrid solar power systems include compact or packaged solar micro combined heat and power (CHP or mCHP) or solar micro combined, cooling, heating and power (CCHP, CHPC, mCCHP, or mCHPC) systems used in distributed power generation. These systems are often combined in concentrated solar CSP and CPV smart microgrid configurations for off-grid rural, island or isolated microgrid, minigrid and distributed power renewable energy systems. Solar tracking algorithms are also used in modelling of trigeneration systems using Matlab Simulink (Modelica or TRNSYS) platform as well as in automation and control of renewable energy systems through intelligent parsing, multi-objective, adaptive learning control and control optimization strategies.

Solar tracking algorithms also find application in developing solar models for country or location specific solar studies, for example in terms of measuring or analysis of the fluctuations of the solar radiation (i.e. direct and diffuse radiation) in a particular area. Solar DNI, solar irradiance and atmospheric information and models can thus be integrated into a solar map, solar atlas or geographical information systems (GIS). Such models allows for defining local parameters for specific regions that may be valuable in terms of the evaluation of different solar in photovoltaic of CSP systems on simulation and synthesis platforms such as Matlab and Simulink or in linear or multi-objective optimization algorithm platforms such as COMPOSE, EnergyPLAN or DER-CAM.

A dual-axis solar tracker and single-axis solar tracker may use a sun tracker program or sun tracker algorithm to position a solar dish, solar panel array, heliostat array, PV panel, solar antenna or infrared solar nantenna. A self-tracking solar concentrator performs automatic solar tracking by computing the solar vector. Solar position algorithms (TwinCAT, SPA, or PSA Algorithms) use an astronomical algorithm to calculate the position of the sun. It uses astronomical software algorithms and equations for solar tracking in the calculation of sun's position in the sky for each location on the earth at any time of day. Like an optical solar telescope, the solar position algorithm pin-points the solar reflector at the sun and locks onto the sun's position to track the sun across the sky as the sun progresses throughout the day. Optical sensors such as photodiodes, light-dependant-resistors (LDR) or photoresistors are used as optical accuracy feedback devices. Lately we also included a section in the book (with links to microprocessor code) on how the PixArt Wii infrared camera in the Wii remote or Wiimote may be used in infrared solar tracking applications.

In order to harvest free energy from the sun, some automatic solar positioning systems use an optical means to direct the solar tracking device. These solar tracking strategies use optical tracking techniques, such as a sun sensor means, to direct sun rays onto a silicon or CMOS substrate to determine the X and Y coordinates of the sun's position. In a solar mems sun-sensor device, incident sunlight enters the sun sensor through a small pin-hole in a mask plate where light is exposed to a silicon substrate. In a web-camera or camera image processing sun tracking and sun following means, object tracking software performs multi object tracking or moving object tracking methods. In an solar object tracking technique, image processing software performs mathematical processing to box the outline of the apparent solar disc or sun blob within the captured image frame, while sun-localization is performed with an edge detection algorithm to determine the solar vector coordinates.

An automated positioning system help maximize the yields of solar power plants through solar tracking control to harness sun's energy. In such renewable energy systems, the solar panel positioning system uses a sun tracking techniques and a solar angle calculator in positioning PV panels in photovoltaic systems and concentrated photovoltaic CPV systems. Automatic on-axis solar tracking in a PV solar tracking system can be dual-axis sun tracking or single-axis sun solar tracking. It is known that a motorized positioning system in a photovoltaic panel tracker increase energy yield and ensures increased power output, even in a single axis solar tracking configuration. Other applications such as robotic solar tracker or robotic solar tracking system uses robotica with artificial intelligence in the control optimization of energy yield in solar harvesting through a robotic tracking system.

Automatic positioning systems in solar tracking designs are also used in other free energy generators, such as concentrated solar thermal power CSP and dish Stirling systems. The sun tracking device in a solar collector in a solar concentrator or solar collector Such a performs on-axis solar tracking, a dual axis solar tracker assists to harness energy from the sun through an optical solar collector, which can be a parabolic mirror, parabolic reflector, Fresnel lens or mirror array/matrix. A parabolic dish or reflector is dynamically steered using a transmission system or solar tracking slew drive mean. In steering the dish to face the sun, the power dish actuator and actuation means in a parabolic dish system optically focusses the sun's energy on the focal point of a parabolic dish or solar concentrating means. A Stirling engine, solar heat pipe, thermosyphin, solar phase change material PCM receiver, or a fibre optic sunlight receiver means is located at the focal point of the solar concentrator. The dish Stirling engine configuration is referred to as a dish Stirling system or Stirling power generation system. Hybrid solar power systems (used in combination with biogas, biofuel, petrol, ethanol, diesel, natural gas or PNG) use a combination of power sources to harness and store solar energy in a storage medium. Any multitude of energy sources can be combined through the use of controllers and the energy stored in batteries, phase change material, thermal heat storage, and in cogeneration form converted to the required power using thermodynamic cycles (organic Rankin, Brayton cycle, micro turbine, Stirling) with an inverter and charge controller.

AUTHORS

November, 2014

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PART IX GENERAL SOLAR TRACKING RESOURCES

PART I

SUN CONTOUR AND TRACKING MECHANISMS

CHAPTER 1

THE SUN PATH AND SUN TRAJECTORY

1.1 Introduction

Grasping the concept of the sun's movement will assist any hobbiest, technician, engineer or system developer to understand the formulas that one need to use in programming of micro-controllers, programmable logic controllers or to write a simple PC program that could automatically steer your solar tracking system. The discussion around the movement of the sun is thus made within the context of orientating a solar tracker with respect to the sun at any location on the earth and on any given time of the day.

This chapter is aimed at helping readers to conceptualise the movement of the sun and presents some basic theoretical models around the movement of the sun as it progresses through the sky during the day. The conceptualization of the movement of the sun (or rather relative and apparent movement of the sun) is of utmost importance in the development of a solar tracking system and this chapter is intended to help the reader understand the basic principles behind the sun's movement in simple and understandable terms.

1.2 Solar Trajectory

The sun radiates energy in the form of electromagnetic energy and the amount of electromagnetic radiation that reaches the earth from the sun in referred to as solar radiation. The term *irradiance* is normally used to define the amount of solar energy per unit area received over a given time. As the solar electromagnetic energy passes through the atmosphere of the earth, while the solar energy levels is around 1367 W/m^2 when it reaches the surface of the earth (Duffie and Beckman, 2006).

In Figure 1.1 there is shown an illustration of the solar irradiation on the surface of the earth as a plot that shows the cyclic nature of the radiation variations between the years 1975 and 2005 (Chiamiov, 2014). In terms of solar tracking applications, this means that the radiation level can be assumed relatively stable around the average levels of 1366 W/m^2, or rounded as 1 kW/m^2 (see detailed discussion of the electromagnetic spectral composition of solar radiation in the chapter "Solar Energy as a Natural Resource" in Section 18.2 of this book).

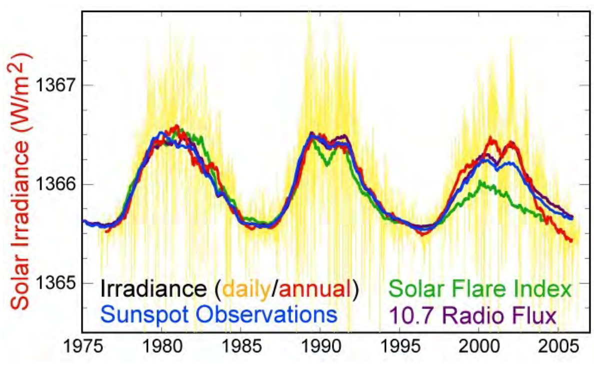


Figure 1.1 Illustration of the solar irradiation on the surface of the earth as a plot of radiation variations between 1975 and 2005 (Chiamiov, 2014).

Thus, for every square meter of surface area on your solar collecting platform that faces the sun, the system will at most be able to collect around 1000 W of solar energy (assuming

100% efficiency). This energy from the sun can be harvested using an optical means such as a parabolic dish or photovoltaic panels. Either way, to improve the efficiency of the energy yield, one requires a simple yet accurate sun following mechanism, called a solar tracking mechanism.

We know that the solar geometry in relation to particular location is such that the sun rises in the eastern sky and sets in the western sky. As illustrated in Figure 1.2, the sun follows a certain path when viewed from a certain geographical location (GPS position). A sun tracking mechanism then use information about the position of the sun at that location to continuously direct a solar concentrator dish or solar panels to point towards the sun. For this purpose, the location of the sun and its trajectory of movement from a given geographical perspective needs to be carefully studied, analysed and understood.

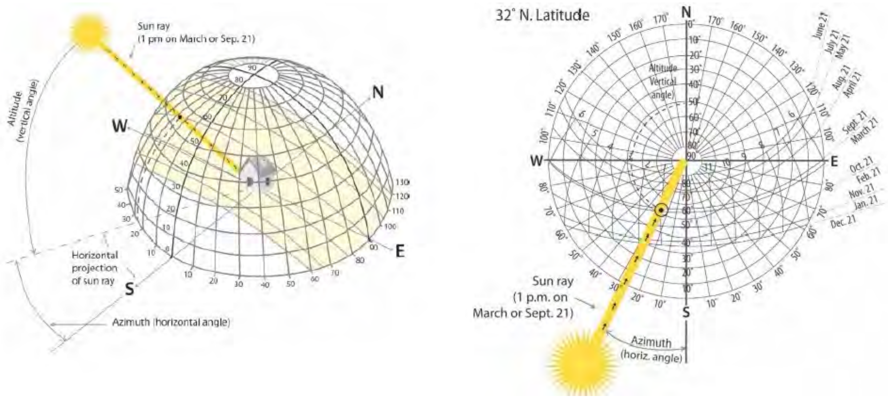


Figure 1.2 Solar geometry illustrated with the help of an imaginary sky dome at the solar tracker location, with the curves in the sky dome representing the sun's location and paths broken up as vertical (altitude) and horizontal (azimuth) components (Lechner, 2014).

Since the earth travels around the sun and rotates daily about its own polar axis, it is important for any solar harvesting system to mathematically determine or optically locate the position of the sun. This can for example be done by calculating sun vector altitude and azimuth angles (Duffie and Beckman, 2006) or by way of using an optical sensor means to optically measure the sun angles (SolarMEMS, 2013).

To establish a frame of reference, the graphical illustration in Figure 1.3 shows the sun's location from a given global positioning system (GPS) location (Rockwell Automation, 2012). In this frame of reference, the solar altitude is the angle between the horizontal plane and the acting line of the sun, this angle varies throughout the day and it is zero during the sunset and 90° when the sun is totally overhead, usually at the solar noon. The solar azimuth is the angular displacement from the north of the projection beam radiation on the horizontal plane. In the northern hemisphere (northern half of the earth), the sun is directly south at solar noon, and north in the southern hemisphere at solar noon.

According to the Astronomy Notes of Schombert Mueller (Mueller, 2014) "The horizontal coordinate system (commonly referred to as the alt-az system) is the simplest coordinate system as it is based on the observer's horizon. The celestial hemisphere viewed by an observer on the Earth is shown (Figure 1.3). The great circle through the zenith Z and the north celestial pole P cuts the horizon NESYW at the north point (N) and the south point (S). The great circle WZE at right angles to the great circle NPZS cuts the horizon at the west point (W) and the east point (E). The arcs ZN, ZW, ZY, etc, are known as verticals.

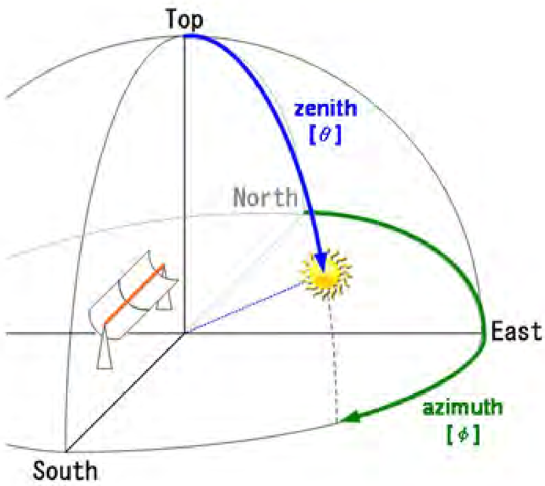


Figure 1.3 Typical solar vector showing the azimuth and elevation of the sun from an arbitrary location on the earth (Yokogawa, 2014).

The two numbers which specify the position of a star, X, in this system are the azimuth, A, and the altitude, a. The altitude of X is the angle measured along the vertical circle through X from the horizon at Y to X. It is measured in degrees. An often-used alternative to altitude is the zenith distance, z, of X, indicated by ZX. Clearly, z = 90 - a. Azimuth may be defined in a number of ways. For the purposes of this course, azimuth will be defined as the angle between the vertical through the north point and the vertical through the star at X, measured eastwards from the north point along the horizon from $0 - 360°$. This definition applies to observers in both the northern and the southern hemispheres". More information on `http://abyss.uoregon.edu/~js/ast122/lectures/lec02.html`.

As the sun moves across the sky, the path of the sun (as calculated by the solar position algorithm for any GPS location on the earth) can be viewed as if the sun is apparently moving along the circumference of a disc which is displaced from the observer at various angles, as illustrated in Figure 1.4. This illustration presents a geometric view of the sun path as seen by an observer at Q during Winter solstice, Equinox, and Summer solstice season intervals (Stine and Geyer, 2001).

The solar discs in Figure 1.4 are known as *Diurnal Circles*, as it describes the apparent path followed by the sun due to the earth's rotation on its axis (Strobel, 2014). The sun thus appears to move on the celestial sphere/disc in concentric circular paths centered at the celestial poles, and as the earth rotates west to east, the sun appears to move from east to west along their diurnal circles - for more reading see also this link `http://www.physics.csbsju.edu/astro/CS/CS.07.html`.

The centre axis of the seasonal solar discs are always orientated along a fixed axis, namely the polar axis. This linear axis points from the location of the observer towards the Northern Star (Stine and Geyer, 2001).

The position/location of the sun disc on the linear polar axis depends on the season of the year. It moves in incremental steps every day of the year, and is thus a function of the calendar date.

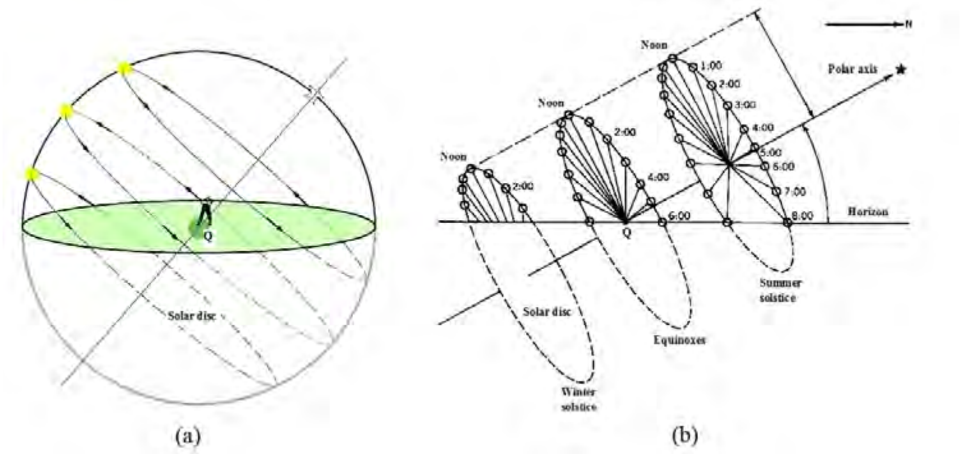


Figure 1.4 A geometric view of the sun path as seen by an observer at Q during Winter solstice, Equinox, and Summer solstice season intervals (Stine and Geyer, 2001).

From the perspective of the observer (or sun tracker), the sun's disc like motion thus appears shift in annual cycles up and down the Polar axis. The shifts are always at a fixed angle of incline with respect to the observer and solar dish changes position in daily increments, as a function of the calendar date.

The solar discs, shown in Figure 1.4, thus represents the geometric view of the sun's apparent path from the perspective of any observer (or sun tracker) located on the surface of the earth. The sun also appears to be travelling about the disc circumferences at a constant rate of around 15° per hour. This rate gives a first indication of the relatively slow rate of movement of a solar tracking system.

Figure 1.5 presents illustrations of the celestial sphere and motion of celestial bodies when viewed by an observer located at Fairbanks Alaska (top left), Seattle USA (top right), Los Angeles USA (bottom left) and on the Equator (bottom right) (Strobel, 2014). This will give the reader of the changes in solar tracking angles from the perspective of different locations on the earth.

The images in Figure 1.5 was copied from `http://www.astronomynotes.com`, Nick Strobel's Astronomy Notes (Strobel, 2014). This link for more detail and updates `http://www.astronomynotes.com/nakedeye/s4.htm` and for updated and corrected version. University of Oregon lecture notes on the subject Astronomy 122 (Mueller, 2014) about the Birth and Death of Stars will make interesting read for those readers interested to lean more about the movement of celestial bodies `http://abyss.uoregon.edu/~js/ast122/lectures/lec02.html`.

Note that, from the perspective of an observer (solar tracker location), the celestial sphere is an imaginary sphere of arbitrarily large radius, concentric with a particular celestial body, meaning all bodies in the observer sky (such as the sun for example) appears to be projected upon the inside surface of the celestial sphere (underside of a dome or a hemispherical screen). The celestial sphere is visual representation, allowing observers to plot positions of objects such as the sun in the sky when their distances are unknown or unimportant.

In the beginning of this chapter, we stressed the importance of conceptualizing the movement or relative and apparent movement of the sun to understand any solar tracking

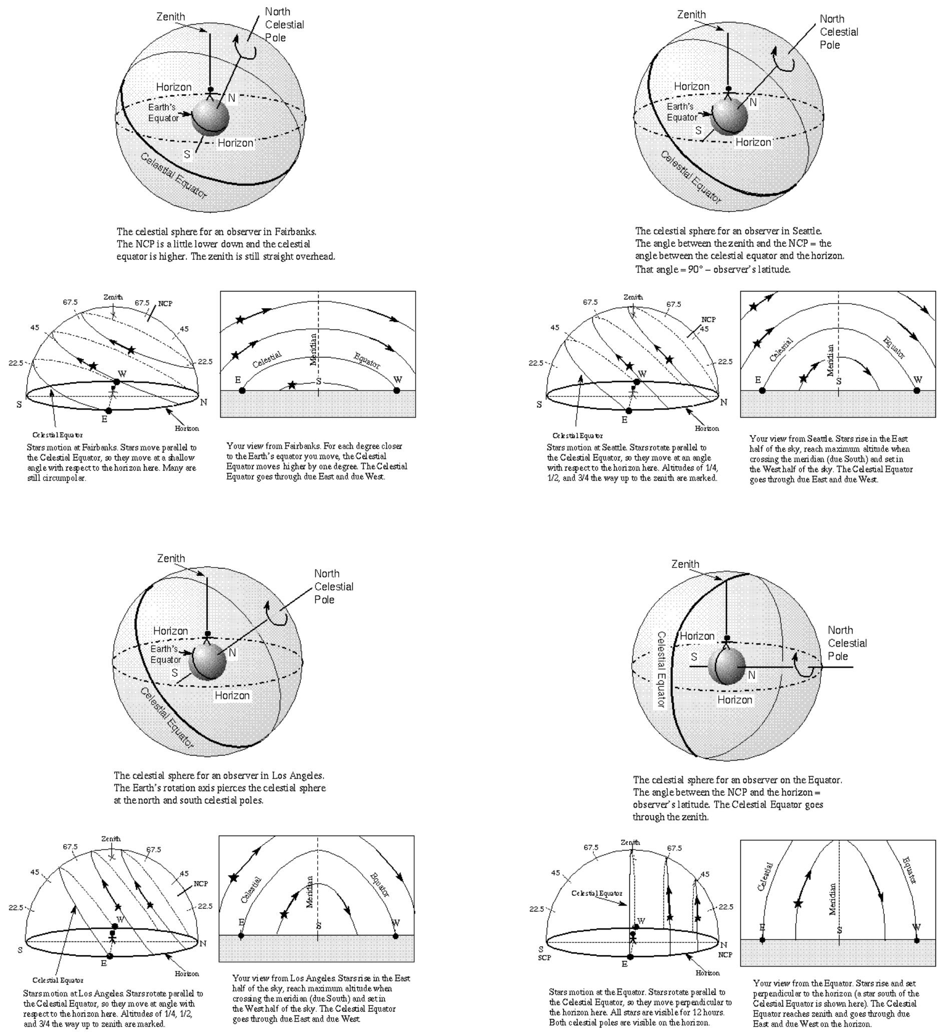


Figure 1.5 Celestial sphere and motion of celestial bodies when viewed by an observer located at Fairbanks Alaska (top left), Seattle USA (top right), Los Angeles USA (bottom left) and on the Equator (bottom right) (Strobel, 2014).

system. In this regard, the company GreenEnergyStar (`http://www.greenergystar.com/shop/content/14-optimizing-pv-array`) presents a color graphic illustration on their website (shown in Figure 1.6 with permission) that will further imprint an understanding of the orientation of their solar tracker with respect to the sun at any location on the earth and on any given time of the day and season of the year (Greenenergy Star, 2010).

Figure 1.6 once again shows the inclined solar disc-like diurnal circle movement of the sun, wherein the green disc depicts the path of the sun during the spring and fall equinoxes. The red disc depicts the path of the sun during the summer solstice, while the blue disc depicts the path of the sun during the winter solstice for a particular location in California (Greenenergy Star, 2010).

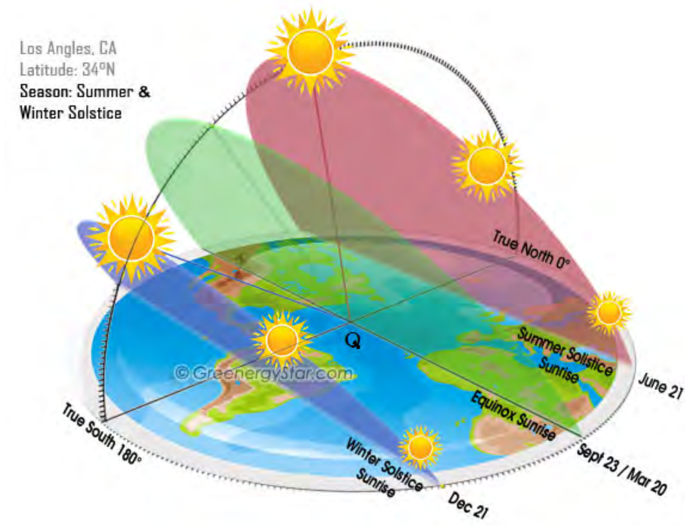


Figure 1.6 Artist impression of the sun path as seen by an observer at Q during winter solstice, equinox, and summer solstice diurnal solar circle courses viewed from a location in California (Greenenergy Star, 2010).

The Stanford Solar Center developed physical model that simulates the sun's tracks across the sky at summer solstice (longest track), winter solstice (shortest track), as well as the fall and spring equinoxes (medium track) using beads (`http://solar-center.stanford.edu/AO/Sun-Track-Model.pdf`) (Scherrer and Scherrer, 2014). Thanks to such models, students and scholars can simulate the sun moving from rising of the sun along the eastern horizon to the setting of the sun on the western horizon. The sun path modelling beads can be physically moved by hand on rails that represent the diurnal circles of the course of the sun and the model can be adapted to accurately represent the latitude and geographical location of the scholar (preview from the solar tracker location).

The next section describes the basis of computer modelling of the sun's apparent trajectory in the sky and serves as an introduction to solar tracking mechanisms (described in the next chapter) required to optically harvest solar thermal energy from the sun as it moves across the sky.

1.3 Solar Tracking with Algorithms

The framework behind the cosmic motion of objects in the universe is a first resource provides that a fairly reliable base to enable programmers in modelling the sun path trajectory (Stine and Geyer, 2001). The coordinates of the location of the sun at any instant of time, as well as the trajectory of the sun-path throughout the day, can be obtained from this mathematical framework and is of primary importance steering and energy harvesting reflector. The use of such mechanisms in hybrid combination with electronic feedback devices.

This leads us to the introduction of the so-called *sun vector*. The *sun vector* is an imaginary line/arrow running from the location of the solar tracker system (or any point of observation on the surface of the earth) directly into the centre of the sun. This sun vector and sun path is of primary importance since it is required for steering a parabolic dish or photovoltaic panels to continuously face the sun directly (to attain maximum solar energy harvesting yield).

The coordinates of the sun from the solar tracking system as well as the trajectory of the daily sun path from the tracker's location can be calculated at any instance of time using certain mathematical algorithms (Stine and Geyer, 2001). The sun's coordinates can for example be calculated as a vector $S_Q(\gamma_s, \theta_s)$ from mathematical astronomical frameworks.

If the mathematical symbols sound a little complicated or begins to scare you, just pretend you understand the maths for now. For those who do not understand a vector, a vector is simply an arrow that points from your solar tracker directly into the sun. We give this arrow or vector a name $S_Q(\gamma_s, \theta_s)$, where Q is the GPS location of the solar tracker, θ_s is the sun's elevation angle or angle between the tracker's location on the surface of the earth to the sun (in the vertical direction), and γ_s) is the sun's azimuth angle or angle between sun tracker's true north direction and the direction of the sun (in the horizontal plane).

The term Sun-vector, or sun-pointing vector, stems from algebraic grounds associated with an earth surface based coordinate system through which an observer at location Q is illuminated by a central sun ray, observed along direction vector S, where this vector points towards the sun at solar azimuth angle ϕ, and the solar altitude angle α (solar zenith angle θ) (Stine and Geyer, 2001). Figure 1.7 shows a typical figure of a sun vector and the angles to be considered when tracking the sun.

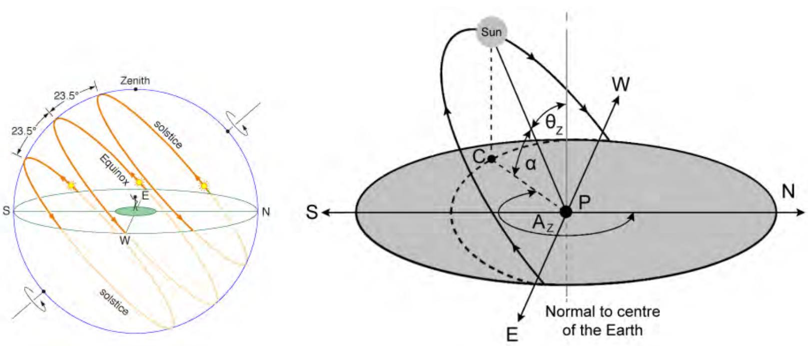


Figure 1.7 Solar vector showing the azimuth and elevation components of the sun vector (right) within the context of the diurnal circle course of movement of the sun in the sky and through the various seasons (left) (Rockwell Automation, 2012)(Schroeder, 2011).

The notation of the earth surface based vector system used in this study is depicted in Figure 1.7. Although some conventions measure the azimuth angle from the south-pointing coordinate, this study uses the general convention through which the azimuth angle is measured from the north-pointing coordinate, with a positive increase in the clockwise direction.

One of the most accurate algorithms for computing the location of the sun using an algebraic astronomical base was developed under contract at the National Renewable Energy Laboratory of the Department of Energy in the United States (NREL) by Andreas (Reda and Andreas, 2008*a*). This algorithm is known as the NREL Solar Position Algorithm (SPA) and calculates the position of the sun with great certainty. From a programmer's perspective, this and similar algorithms are valuable tools in solar tracking systems and their use will be described in more detail in the next section and in the rest of this book.

Depending on the GSP location of the observer or your sun tracking system (Q= GPS location) and season of the year, the sun's movement relative to the observer Q can be calculated from the SPA for every second of movement along the circumference of a disc. Figure 1.8 illustrates the solar vectors $S_Q(\gamma_s, \theta_s)$ calculated for a particular geographical location (Wood, 2010).

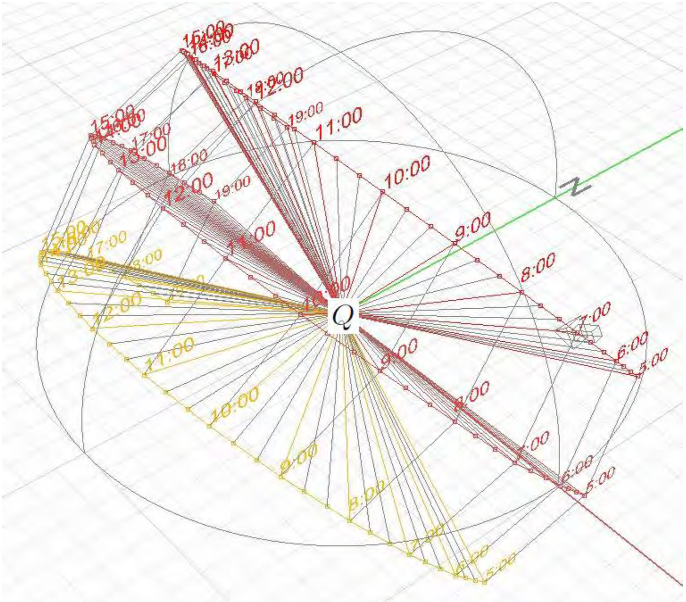


Figure 1.8 Computed sun vectors and sun path as seen by an observer at Q during winter solstice, equinox, and summer solstice (Wood, 2010).

With the SPA, the position of the sun in the sky is expressed as sun vectors, denoted in terms of an azimuth angle and elevation angle of the sun. Such SPA algorithm is formulated to take the date and time as well as the GPS coordinates of the location as input, and to compute the solar altitude angle and azimuth angle as output for that particular geographical location. It uses astronomical principles that takes the daily as well as the seasonal variations of the solar path into consideration.

The discrete time solar vectors computed by a discrete or digital solar position algorithm in Figure 1.8 confirms an earlier statement. The sun do appear to move along the circumference of the celestial disc on any given day, but follows different circles/discs at different times of the year. In the southern/northern hemisphere respectively, the disc is located most northerly/southerly at the winter solstice and most southerly/northerly at the summer solstice (Stine and Geyer, 2001).

Thus far most illustrations helped the reader to conceptualise the sun path movement in terms of a celestial perspective, but how does this underlying sun path translate in the real world of solar tracking. In other words, what is the appearance and mechanics of the sun path when viewed from a particular spot on the ground, the sun path that a solar tracking device needs to follow.

By way of example, Figure 1.9 shows the computed solar path (azimuth and elevation angle contours) for a particular site in the UK (Manfred, 2012). In this representation, the sun path/contour is mapped or projected onto the horizon in an augmented reality fashion. It helps the reader to visualise the projection on the disc-like solar movement of the sun around the earth from the perspective of a particular spot on the earth, in this case what appears to be on the edge of a park or sport field (more information (Manfred, 2012)).

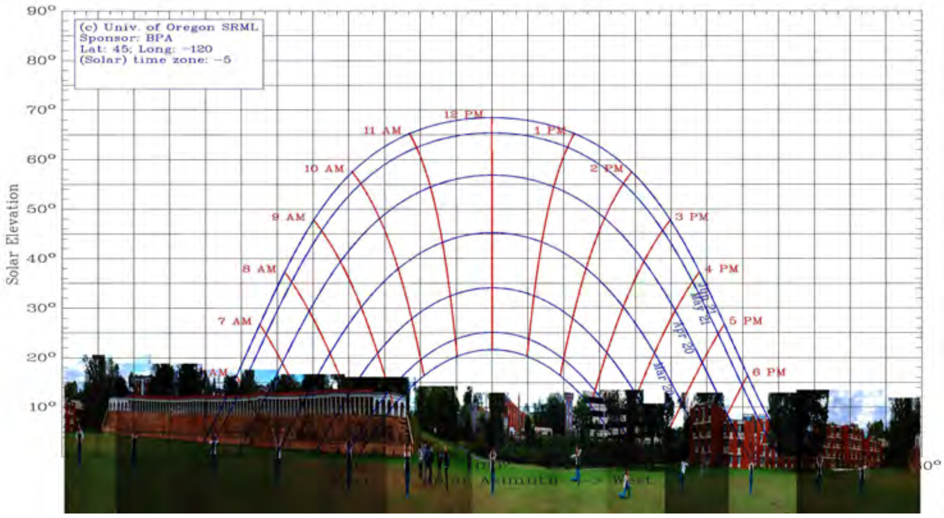


Figure 1.9 Typical sun path diagram in Cartesian coordinates, showing the azimuth/elevation of the sun daytime path at a given location (Manfred, 2012).

The first observation that can be made about the solar path contour(s) in Figure 1.9, is that the actual disc like contour(s) of the sun, shown from a celestial perspective in Figure 1.8, looks vastly different from a ground perspective. From this perspective at a particular spot on the earth, these solar circle contours of the sun appears to translate itself into odd-looking ellipses (Figure 1.9). The shape of these ellipses vary from location to location on the earth, while seasonal changes in the movement of the sun also translates into different (larger/smaller) ellipses as the season varies.

Secondly, from a solar tracking perspective, the solar tracking platform needs follow the sun as it moves across the sky based upon the sequence of solar vectors computed in Figure 1.9. For this purpose, the set of sun-paths in Figure 1.9 can be calculated as solar vector using the solar position algorithm SPA (described in more detail in the rest of this book). The sun path contours in Figure 1.9 (location, site, track) thus donates the track of the sun path or sequence of sun vectors (sometimes also referred to as the solar arc in the sky) that needs to be tracked by a solar tracking system to harvest solar energy at that location.

With the task of the solar tracking platform in mind, Ray (Ray, 2012) used a Matlab algorithm to generate a certain general graphical illustration that we will use to finally help the reader with the visualisation of the sun path, in particular from the perspective of azimuth and elevation angle movement. In his publication on the calculation of sun position and tracking of the path of the sun for a particular geographical location, the graphical plots in Figure 1.10 represent the solar azimuth and elevation angles of the daytime sun path as viewed from a particular geographical location.

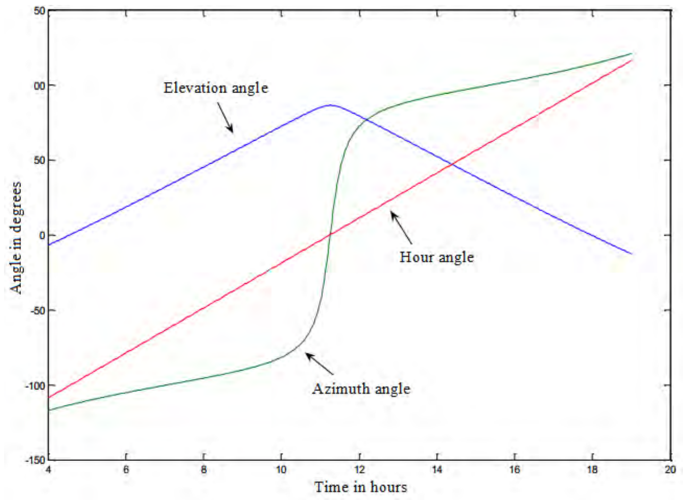


Figure 1.10 Solar azimuth and elevation angles of the daytime sun path for a given geographical location (Ray, 2012).

In this representation, the sun patch contour mapped onto the horizon in an augmented reality fashion in Figure 1.9 is presented as angles over a 24 hour period. For a given date, the PC, PLC or microcontroller can thus compute the solar vector as an azimuth and elevation angle required to follow the sun at a particular location. The solar tracking platform has the task of tracking the profile of the solar arc in the sky in terms the azimuth and elevation angles shown in the plots.

Ray also showed a comparison of the plots for the azimuth angle, elevation angle and hour angle for the summer solstice (left) and the winter solstice (right) in the plots in Figure 1.11. It illustrates the angle variations required for the solar tracking operation, while the partial differential of the angle curves (slope at each point) equates to the solar tracking speed (degrees per minute).

While the plots in Figure 1.11 represent the day of summer solstice (left) and the day of winter solstice (right) solar tracking angles, the solar azimuth and elevation angles for the other days of the year will result in angle values in between the values of these two days (Ray, 2012). The two plots in Figure 1.11 thus also represent the extreme angle values in terms of solar tracking following capabilities to follow the sun path at different dates and times of the year. By knowing the geographical location in terms of latitude and longitude, the SPA can compute the path followed by the sun, and can be used by a PC, PLC, or microcontroller to track the sun at any location on the earth.

In conclusion, the coordinates of the same sun path at the solar concentrator location site (Q) presented in Figure 1.8, Figure 1.9 and Figure 1.10 can be calculated using an astronomical based solar position algorithm. The NREL solar position algorithm uses an algebraic astronomical base for computing the location of the sun (sun vector $S_Q(\gamma_s, \theta_s)$) (Reda and Andreas, 2008*a*). The NREL SPA calculates the position of the sun with an accuracy of $\sim 0.0003°$ (Reda and Andreas, 2008*a*). It is valuable to note that typical solar trackers operate at an accuracy of around $0.1°$ to $1.5°$. Thus being able to calculate the position of the sun with an accuracy of $\sim 0.0003°$ is pretty valuable in any man's terms.

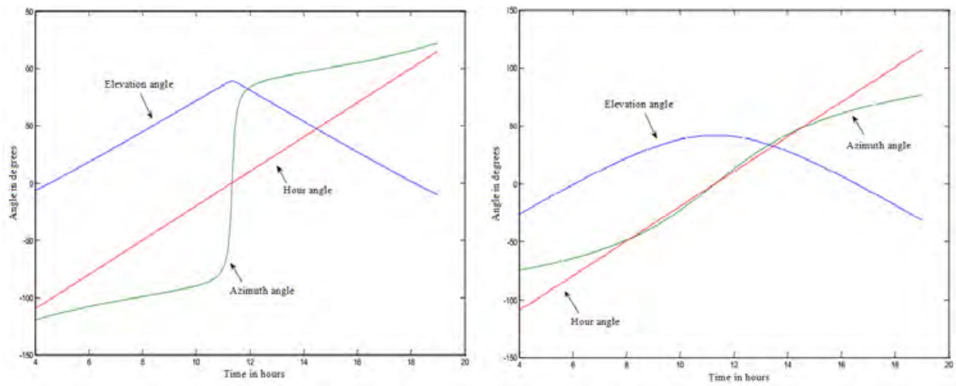


Figure 1.11 Solar azimuth and elevation angles of the daytime sun path for the summer solstice (left) and winter solstice (right) for the same geographical location (Ray, 2012).

This set of sun paths or sequences of discrete solar vectors can then be used by the controller of solar tracking platform system (Figure 1.12) for that site to follow the sun. Typically a sun following means requires mechanical actuators to drive the solar tracking system to ensure very precise perpendicular focussing of the solar optic harvesting device onto the centroid of the sun from that particular solar installation site and its exact geographical location.

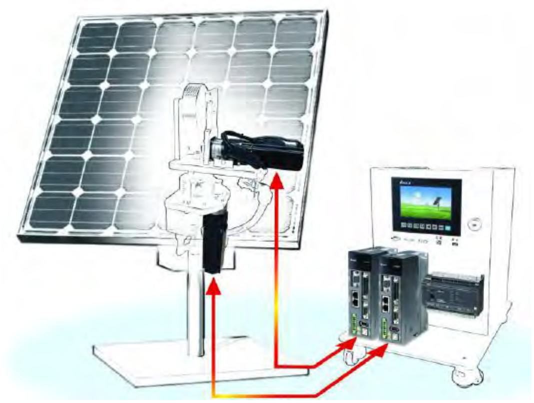


Figure 1.12 Example of solar tracking platform with a dual-axis actuator platform capable of following the azimuth and elevation angles of the sun on its daytime path (Delta Automation, 2014).

Any open-loop automated solar tracking system needs such algorithm to automatically compute the solar vectors around the solar disc circumference and to orientate itself along these lines, either continuously or at discrete time intervals. Anyone can use the SPA algorithm (C++ freeware) provided you have the onboard computing power available to run the algorithm. For certain processor or microcontroller environments, adaptations of the SPA algorithm must be used in order to accommodate a reduced set of calculations under certain sets of simplifying assumptions.

The website `http://wiki.naturalfrequency.com/` provides a host of Ecotect Resources and references educational material on the desktop component of Autodesk Ecotect Analysis. The solar tool is on this link `http://wiki.naturalfrequency.com/wiki/SolarTool`. Furthermore, a video on `http://www.sixtysymbols.com/videos/solstice.htm`.

The goal of the chapter on *S*olar Position Algorithms (Section 3.2) in this book is to guide the interested reader in selecting an algorithms suitable for your computing environment. In this chapter, the objective is more to explain the terminology used in later chapters.

1.4 Sun Path Diagram or Sun Path Chart

Sunpath diagrams map the path of the sun across the sky. They show the position of the sun relative to the solar tracker location site, both by time of day and time of year. Such three dimensional sunpath diagram (also sun path chart or sun path map) thus describes aspects of the solar position in terms of the location, time of day, direction of movement, sun path movement lines, altitude angles as well as azimuth angles of the sun.

Such diagram further show the dynamics of change throughout the various solar seasons and monthly solar cycle changes. Together with irradiation data tables, sun path diagrams provide the daily irradiation levels available at a specific location for a concentrated solar power system. A plan of the objects that will shade the site (currently and in the future) can also be drawn onto the sunpath diagram.

Sun-Path Diagrams are important visualisation tools with which to model and display the path of the sun as it moves through the sky, as observed from a specific geographic location on the earth's surface. These diagrams uses an astronomical framework to provide a two-or three dimensional representation of the trajectory of the sun's movement through the sky as observed from a specific location on the surface of the earth. Sun-Path Diagrams further shows the dynamics of change throughout the various solar seasons and monthly solar cycle changes.

This stereographic or three dimensional (3D) sun-path diagram for an arbitrary location close to the equator shown in Figure 1.13 is for a day in the month of February. This diagram shows the winter and summer solstices for the apparent disc trajectories of the sun's movement as well as the location of the sun in the sky at a particular date and point in time. Such 3D sun path diagram helps to visualise the solar disc trajectories (shown earlier in Figure 1.8), and it helps to put the sunpath into perspective as it shows the daily trajectory of the sun as well as the seasonal solar disk movement along the polar axis.

To help the reader to visualise the course of the sun from GPS locations on various latitudes, the illustration in Figure 1.14 shows the different sun path diagrams for different locations on the ground. This display is helpful in visualising the solar path or course of the sun at a particular tracker location placed at different latitudes.

The illustration in Figure 1.14 emphasizes the variation in the sun's movement in relation to latitude (Autodesk, 2014*c*). It includes Azimuth Lines (azimuth angles run around the edge of the diagram), Altitude Lines (altitude angles are represented as concentric circular dotted lines that run from the center of the diagram out), Date Lines (date lines start on the eastern side of the graph and run to the western side and represent the path of the sun on one particular day of the year) (first day of January to June are shown as solid lines, while July to December are shown as dotted lines) (Autodesk, 2014*c*).

In architecture, sun path diagrams are used to inform how the sun will impact the building. Solar path diagrams are thus regularly used in architectural designs where the solar seasonal movement geometry is generated with the Autodesk Ecotect tools package (Wood, 2010). This is because the sun's movement is an important consideration in prop-

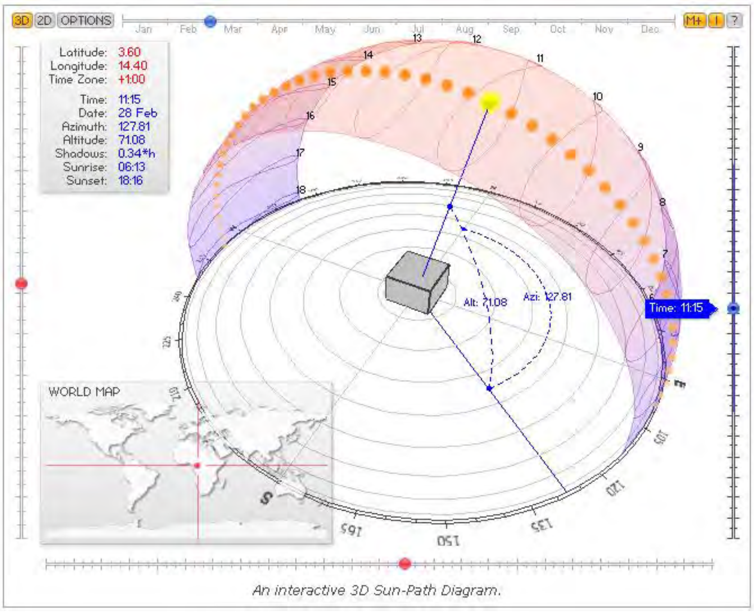


Figure 1.13 Sun-Path diagram showing the movement of the sun at a specific geographic location in 3D (Marsh, 2014).

erty and landscape models where the sun is rendering sunlight on designs and the designer needs to analyse aspects such as solar thermal impact and sun shadowing (i.e. from other buildings or trees). In a sun tracking context, the same stereographic sun path diagram tools can be used to read the solar azimuth and altitude throughout the year for a given solar tracker location site (Autodesk, 2014*c*).

The Autodesk studio companion Ecotect includes a visualization tool that allows enables designers to model interactive displays of sun and shadows, solar rays, sun path diagrams in terms of the sun contour. Analysis surfaces are defines to calculate and visualize solar issues that are relative to the sun angle as shown in Figure 1.15 and Figure 1.16(Godsell and Franklin, 2013).

In Figure 1.15 and Figure 1.16, we see the solar flux intensity sun-Path diagram, showing the movement of the sun at a specific geographic location in 3D, with the solar radiation or solar superimposed on the sun position chart (Godsell and Franklin, 2013). This helps to understand the relationship between the sun path and the analysis grid and is very helpful for solar resource surveying and solar orientation studies (`http://mod.crida.net/thesis/S1-2013/uncategorized/tun/`). This Ecotect sun exposure analysis feature data can also be transferred back to the solar tracking system from where the numerical values from the data can also be used to determine the solar power impact that any sun shades may have on a solar tracking system.

We can now look at the solar vector and the variations in solar vector properties for different days of the year. In Figure 1.17 there is shown a Sun-Path Diagram for the city of London for a day in the month of March (Marsh, 2014). This diagram shows the winter and summer solstices for the apparent disc trajectories of the sun's movement during a full year cycle as well as the location of the sun in the sky at a particular date and point in time (10.00am). The "S" or "8" like figures on the diagram depicts the hour lines of the sun

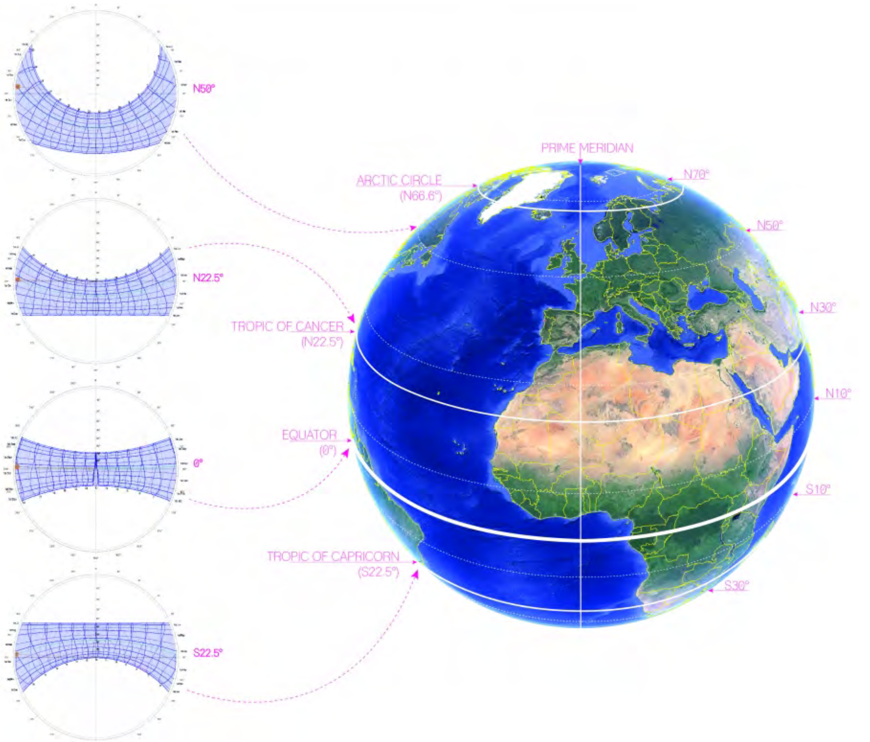


Figure 1.14 Sun path digram illustrates the variation in the sun's movement in relation to latitude (Autodesk, 2014*c*).

(Analemma position of the sun at particular time of the day over a period of 12 months will be discussed later in this section).

Figure 1.18 shows the fundamental components that make up a Sun-Path Diagram within the context of various reference lines (Ecotect, 2014*a*). The displays show the sun chart in terms of Azimuth Lines (azimuth angle lines run around the edge of the diagram), Altitude Lines (angle lines represented as concentric circular dotted lines that run from the centre of the diagram out), Date Lines (lines that represent the path of the sun through the sky on one particular day of the year), and Hour Lines (lines that represent the position of the sun at a specific hour of the day, throughout the year (Ecotect, 2014*a*).

The hour lines in Figure 1.18(bottom right), show a set of "figure-8" style lines that intersect the date lines. In this display, the position of the sun is represented by the intersection points between date and hour lines. Half of each hour line is shown as dotted, to indicate that this is during the latter six months of the year. "This characteristic figure-8 shape results from what is termed the Analemma, an effect resulting from the elliptical orbit of the Earth around the Sun and the slight tilt of the Earth's axis of rotation relative to its orbital plane. This simply means that there is some seasonal variation in the difference between local and solar time" (Ecotect, 2014*a*).

From a solar tracking perspective, we want to explain the consequences of the Analemma or Analemic Curve in a little more detail. Photographic techniques (pinhole Sonography) are often used in studying the course of the sun and will in this case be used to explain the impact of the Analemma on automatic solar tracking. It will be shown that solar tracking

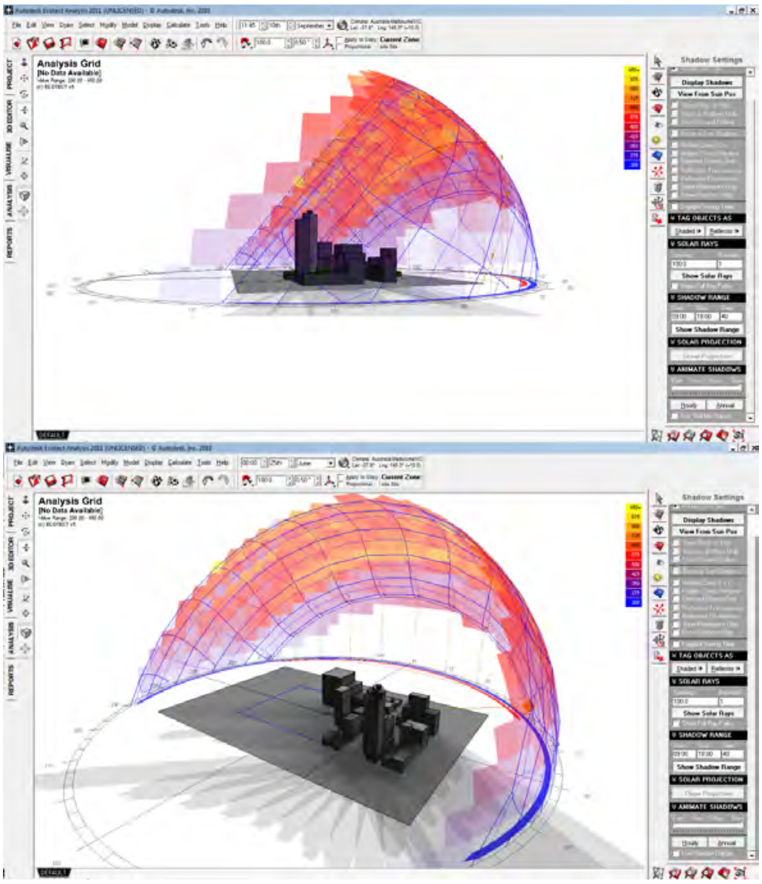


Figure 1.15 Sun-Path diagram showing the movement of the sun at a specific geographic location in 3D, with the solar radiation or solar superimposed on the sun position chart (Godsell and Franklin, 2013).

is not as simple as switching the solar tracker azimuth speed at a fixed setting and simply following a set elevation pattern movement throughout the year. This is because the speed of the sun appears to change throughout the year (when the sun is viewed from any GPS location on the earth).

Consider Figure 1.19, photographic illustrations of (bottom) hourly snapshots of sun position for a particular day of the year (to show the sequence of solar vectors and course of the sun for one full day) as well as (top) daily snapshots of the sun position taken at noon every day for 265 days of the year (to show the variations in sun position or solar vector at noon every day of the year). Figure 1.19(bottom) confirms our understanding that the sun always traces out an arc through the sky as in the series of pictures (taken during winter solstice from the UK).

On the other hand, when the sun is photographed at exactly noon every day for a full year as in Figure 1.19(top), it is seen that as winter transitions into summer, the sun arc gets higher and higher in the sky, peaking at its highest point during the summer solstice and then declining back down to its low point as summer transitions back into the winter (Siegel, 2014). More importantly, it also illustrates that the position of the sun at noon every

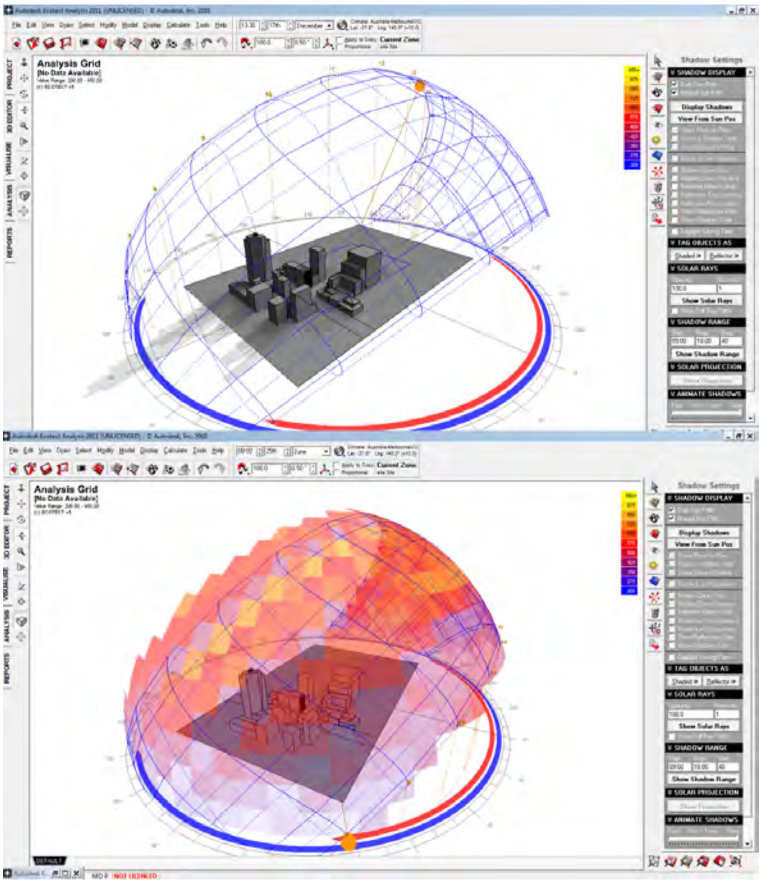


Figure 1.16 Sun-Path diagram showing the movement of the sun at a specific geographic location in 3D, with the solar radiation or solar superimposed on the sun position chart (Godsell and Franklin, 2013).

day is not vertically in line throughout the year, but forms the type of figure-8 Analemma cure in the sky (Siegel, 2014).

Giesen presents a whole range of valuable applets and programs on this website `http://www.jgiesen.de/GeoAstro/sundials.html` to study sun charts, the sun position as well as the Analemma. In particular the Analemma Sundial Applet `http://www.jgiesen.de/analemma/` will help readers to study this phenomenon in more detail for a particular solar tracker location (Giesen, 2014).

In summary, the analemma and the Equation-of-Time are a result of the sum of the effects of the earth's elliptical orbit around the sun and the tilt of the earth's axis in relation to the plane of its orbit around the sun. The chart in Figure 1.20 shows the effect of this summation and presents a galley of images to demonstrate the Analemma in sun charts and photographic snapshots.

From a solar tracking perspective, designers simply have to note that the shape of the Analemma is as a result of the apparent changes in the speed of movement of the sun during its transition from summer-to-winter and winter-to-summer throughout the year (Analemma.com, 2014). However, the Analemma is not a phenomenon that the solar

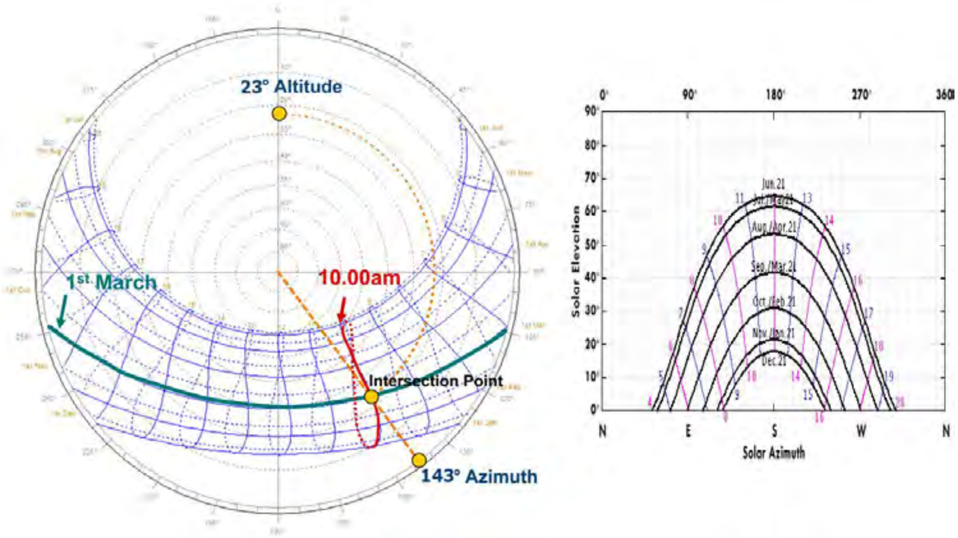


Figure 1.17 Stereographic sun path diagrams showing the movement of the sun in spherical coordinates (left) and orthographic coordinates (right) (Marsh, 2014).

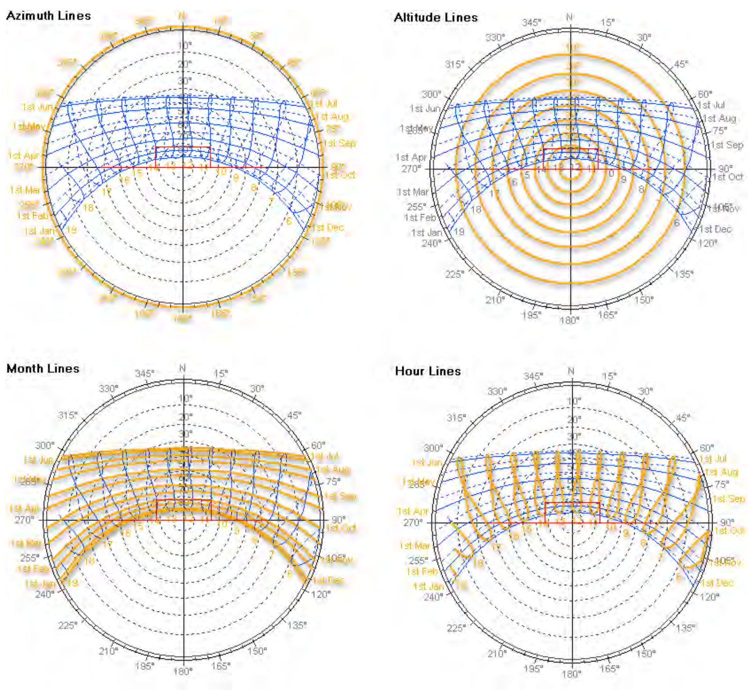


Figure 1.18 Fundamental components of a Sun-Path Diagram, including Azimuth Lines (top left), Altitude Lines (top right), Date Line (bottom left) and Hour Lines (bottom right) (Ecotect, 2014*a*).

tracker designer have to compensate for in addition. All solar position algorithms inherently incorporate this phenomenon and the tracker will automatically adjust to the varia-

Figure 1.19 Photographic illustrations of the sun path for a single day (bottom), as well as daily photographic snapshots of the sun position taken at noon every day for a full year (top) to show the Analemma curve (Siegel, 2014).

tions in the apparent speed of movement of the sun when an accurate solar position algorithm is used in the computer, PLC or microcontroller.

To close off this section, and for those readers who are interested in how stereographic sun path diagrams are used to read the solar azimuth and altitude throughout the day and year for a given position on the earth, we recommend reading Sun Path Diagrams `http://sustainabilityworkshop.autodesk.com/buildings/reading-sun-path-diagrams` as well as the animations Sun-Path and Sun Positions on this link`http://wiki.naturalfrequency.com/wiki/Sun-Path/Reading_Sun_Positions` (Autodesk, 2014*c*).

1.5 Drawing the Sun Path Diagram for Your Tracker Location

In the previous section, it was shown how a sun chart or sun path diagram illustrates the variation in the solar vectors or course of movement of the sun in relation to latitude. In this section, the reader is urged to participate in studying the sun path diagram for the GPS geographical location for your sun tracker, so as to visualise the solar vectors that make up

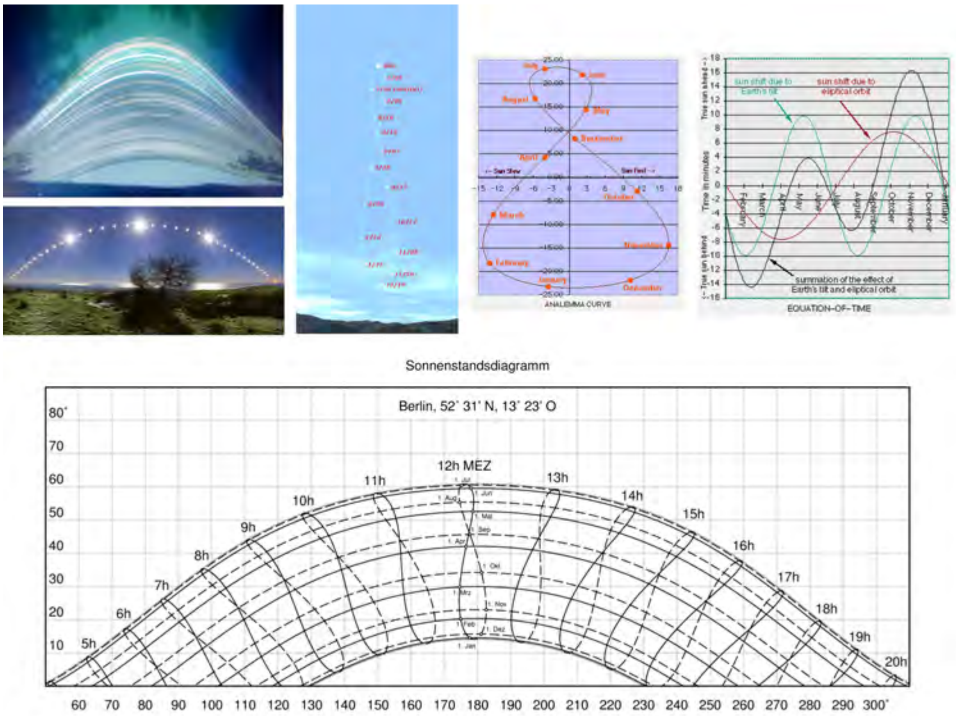


Figure 1.20 Example of a sun path diagram for a certain solar tracker location to show the Analemma curve for different times of the day (bottom), as well as a series of photographic images and plots to show relative variations in sun movement throughout the year (top) (Analemma.com, 2014)(Manske, 2014)(Kevin, 2014)(Siegel, 2014).

the course of the sun at your location from where the solar tracking system must follow the sun.

In general, algorithms such as the NREL SPA can be used as the basis for computing the sun-path diagram. Because of its accuracy, many computer programs and online websites use the NREL SPA to calculate the sun-path for any selected variety of past, present or future seasons and time-of-day cycles. With these tools (personal computer based visual representations used by architects and property developers), a sun path diagram can be displayed in either Cartesian/Orthographic coordinates or in Polar/Spherical coordinates. It can also be used to analyse aspects of the sun path such as shading analysis and to detect any objects (trees, buildings, mountains, etc.) that may be obstructing the view of the sun from any potential solar tracking installation site.

To start off with, there are excellent interactive websites by Vladimir Agafonkin (Agafonkin, 2014) and Andrew Marsh (Marsh, 2014) respectively, to learn and play with interactive sun path diagrams `http://suncalc.net/#/51.508,-0.125,2/2014.09.28/19:39` and `http://andrewmarsh.com/scripts/educational/solar-position-and-sun-path`. In particular, the 3D implementation of SunCalc (Agafonkin, 2014) on this link serves as an interesting tool to play with the sun path at your location `http://10k.aneventapart.com/2/Uploads/660/`.

SolarBeam is also an application (see Figure 1.21) for drawing solar path diagrams (Matusiak, 2014). In this free software, the user specifies the geographical location, while the code draws the sun path diagram for the trajectory of the sun over that GPS location, for various times of the year (`http://solarbeam.sourceforge.net/`). It also shows the times of sunrise and sunset (`http://www.gaisma.com/en/`).

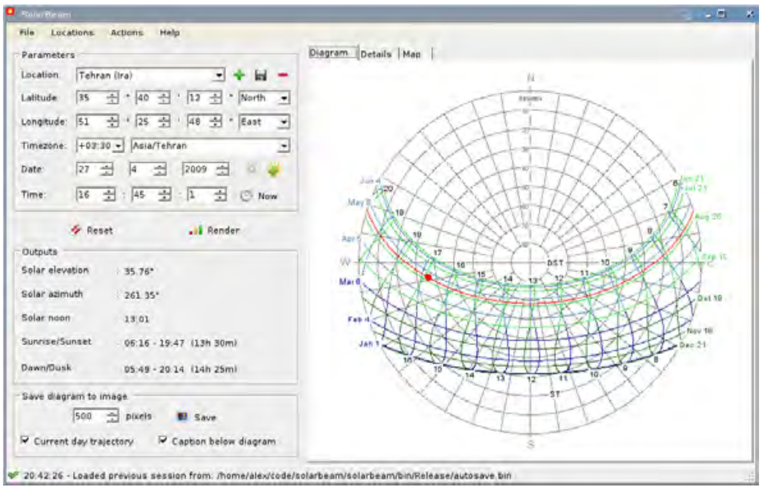


Figure 1.21 SolarBeam application for drawing solar path diagrams (Matusiak, 2014).

Figure 1.22 shows the graphic display of the analemma curves in terms of the accumulation of direct solar radiation throughout the year with daily solar positions (Ngai, 2014). This software, a rewritten version of a sun position algorithm is written in VB.net and can be downloaded form this link `http://www.tedngai.net/files/sun_system-Irradiation-Year.zip` (Ngai, 2014). Note that the solar thermal values in the code do not consider the scattering and absorption effects (i.e. water vapor, ozone, aerosol).

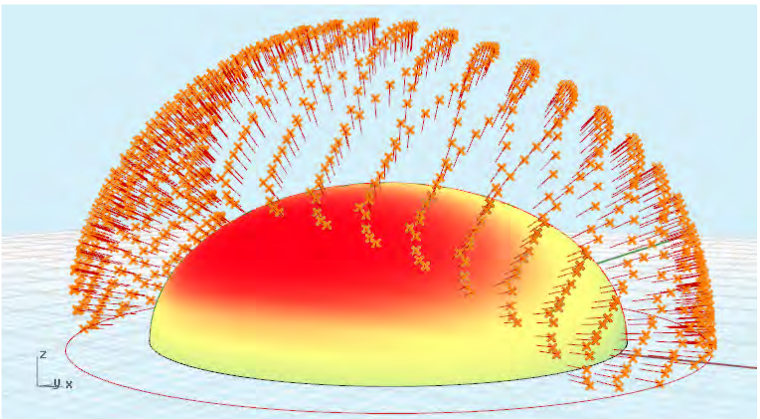


Figure 1.22 Graphic display of the accumulation of direct solar radiation throughout the year with daily solar positions are also displaying the analemma (Ngai, 2014).

Another handy software package available for download is called Sunpath (freeware) (Hennings, 2014). It enables the solar tracker designer to calculate sun position charts through a sun chart calculator. The latest DynVis Light beta version of the software also displays visualization of daylight characteristics of an area and visualizing daylight properties of a room (see `http://www.eclim.de/index5.htm`).

SunEarthTools provides a valuable set of online interactive tools that includes modules with which solar sun path charts can be plotted either in Cartesian (rectangular) or Polar coordinates `http://www.sunearthtools.com/dp/tools/pos_sun.php` (Sunearthtools, 2014).

Furthermore, the Sunpath Diagram and sun trajectory for every latitude and longitude location (GPS Coordinates) on the surface of the earth is available on the Jaloxa website (`http://www.jaloxa.eu/resources/daylighting/sunpath.shtml`). The sun path tools on this website is also very handy to conduct a *Site Analysis* for every site where a solar power system will be installed (Jaloxa, 2014). The Sun Path Analysis Tools on the Jaloxa site also includes *Shadow-Masking* with which shades cased by buildings or trees can be modelled to determine the available sunlight energy at any site.

1.6 Sun Path in Augmented Reality for Smartphone Tablet Devices

Certain mobile telephone application software, such as Solmetric and Sunseeker, include *A*ugmented Reality Sun Viewer features that provides the user with an augmented reality view of the sun path for a specific location. With these solar path viewer apps (compiled with Android SDK or iOS SDK), the user simply looks at the surrounding scenery through his/her mobile phone camera view and sees the present sun location as well as the sun path trajectory superimposed onto the camera view, as shown in Figure 1.23. This augmented reality sun path diagram viewer enables user assessment of the sun path at a proposed site of installation and provides an understanding of the impact of shading on the sun path potentially caused by buildings or other obstructions at any date of the year at an anticipated site of installation.

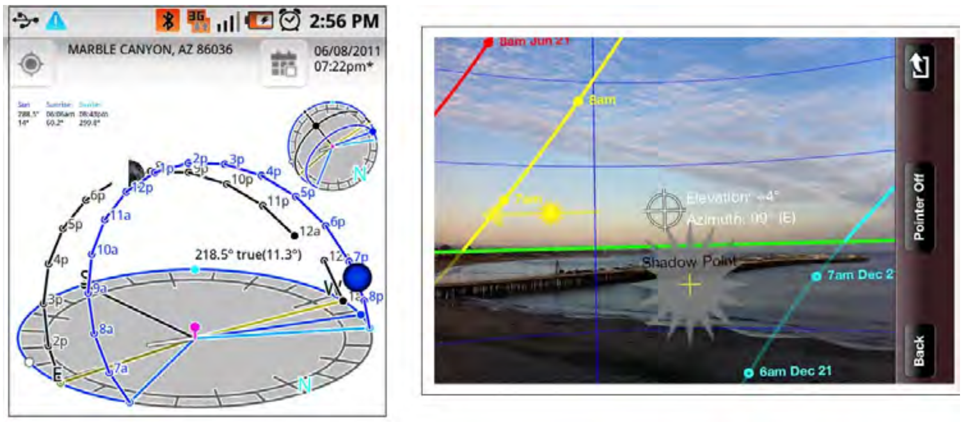


Figure 1.23 Screenshots of mobile application SunSurveryor (left) SunSeeker (right) 3D augmented reality sun trajectory viewers (Sunsurveyor, 2014).

An augmented reality solar viewer app provides the user with precise information about the position of the sun at the current location, while the camera view screen allows the user see if/when the sun will be masked (solar tracker device shadowed) behind another building, neighbour's house or trees (effecting solar power generation) as for example illustrated in Figure 1.24 (Xayin, 2014).

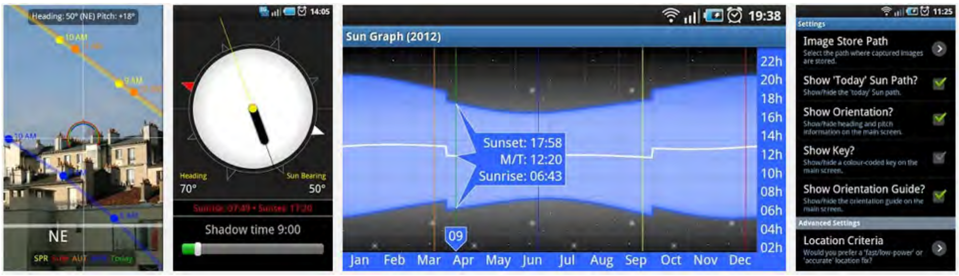


Figure 1.24 Screenshots of the SunPlan mobile solar position application to show sun trajectory viewer, augmented reality sun path diagram viewer and shading analysis viewer features in mobile apps (Xayin, 2014).

Thus, in Figure 1.24 there is shown screenshots of an example mobile solar position application with sun trajectory viewer and augmented reality sun path diagram viewer (Xayin, 2014). This type of app overlays sun paths for the Spring Equinox, Summer Solstice, Autumn/Fall Equinox, Winter Solstice and present day data onto a live stream from the smartphone camera, following the sun path when panning the camera. It also allows for photos to be taken with complete with overlay and location information, can be captured for later reference.

For the BB10 and other Blackberry users, one example is the SunCalc Premium app, for which two screenshots are shown in Figure 1.25 (Crackberry, 2014). This app allows the user an interactive augmented reality display to track the sun position and its path through the local sky for that GPS location/date, get exact times of sunrise, sunset, dawn, dusk, twilight (civil, nautical, amateur, astronomical) levels, time of transit, day/night length (also compared to other days and solstice) and shows day/night length graphs for the entire year for any location and real-time astronomical data of the sun.

The Windows app "World Astro Clock" includes an educational world-clock, solar sunlight map (Figure 1.26), global weather chart, calendar, timer, alarm and astronomical almanac on a tablet or smart phone (AstroTempus, 2014). The sunlight map on this display shows the current position of the sun with the current time analemma curve) and graphically highlights the parts of the earth are in daylight and those parts in the night. The display is overlaid with the time of sunrise, moonrise and transit in any location on earth as well as the sun's local and celestial coordinates, time and date of equinox and solstice, phase of the Moon, equation of time and the analemma (AstroTempus, 2014).

Various other mobile phone and tablet type applications (for iPhone, Windows Phone, Samsung, Blackberry, etc.) are also available to analyse sun path trajectories from the location of the observer (see Section 23.9 for more links), for example Solar Sunseeker, Sungraph (also shows effect of the analemma on rise and set times almost anywhere on Earth), SunGraphHD, SkySafari for Android and iOS, Sun Surveyor, Helios Sun Position, Sonnenbahn Indikator Pro, Pilkington Sun Angle Calculator, Safersun (meteocontrol), SolarTrack, Solmetric iSV, Planetary Path, Sun Position, Sol Et Umbra, LunaSolCal, World Astro Clock Light, Wolfram Alpha (sun position) etc. Some of these applications uses the GPS positioning coordinates of the mobile device to access data on the average energy available at a particular geographic site.

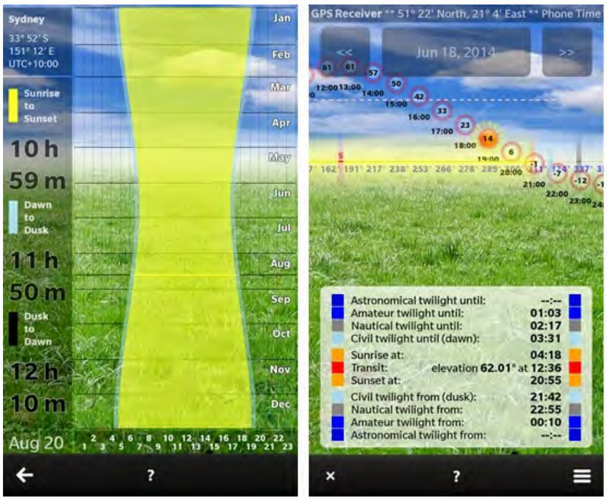


Figure 1.25 Track the sun position (elevation and azimuth) for any location and date using Blackberry (Crackberry, 2014).

Figure 1.26 Windows World Astro Clock App display of analemma on the sunlight map (map that shows parts of the earth that are in daylight and parts in night) (AstroTempus, 2014).

1.7 Solar Energy Capture vs Tracking Orientation

In this book the emphasis is on solar tracking. This brings us to the importance of directionality and the importance of locking onto the solar resource, capturing solar energy from the sun by following its movement across the sky by day.

Nature developed the sunflower principle that can be applied perfectly to optimizing efficiency in solar energy systems. It is well known that the sunflower orient itself towards the sun during the course of a day. It is a simple, but brilliant principle that can be applied perfectly to optimizing efficiency in solar energy systems. The reason: Photovoltaic modules that follow the suns path capture a higher amount of energy and therefore produce decidedly more power than modules in a fixed installation.

Solar power systems produce the highest levels of energy only when the sun is at the optimum angle to the solar collector or harvesting means. Thus, fixed solar tracking systems only operate at its optimum levels. Active solar tracking systems on the other hand, improve performance and energy production. Such systems require motion dynamics and drive technology such as slewing drives for mobility. Motorized frames provide supporting movement in both single and dual-axis solar trackers by including kinematic platforms to make solar systems more efficient.

In Figure 1.27 the is shown an example graph that compare the solar energy capture rates for example through non-tracking (fixed tracking) and (active) tracking solar harvesting means (LCPV tracking system (Hebrink, 2012)). It illustrates the energy yield for fixed and two-axis tracking systems and how the energy yield is maximized in the output of for example a photovoltaic system that tracks the sun throughout the day. This means that accurately following the sun is of great importance since it effectively enable one to harvest more energy from the sun.

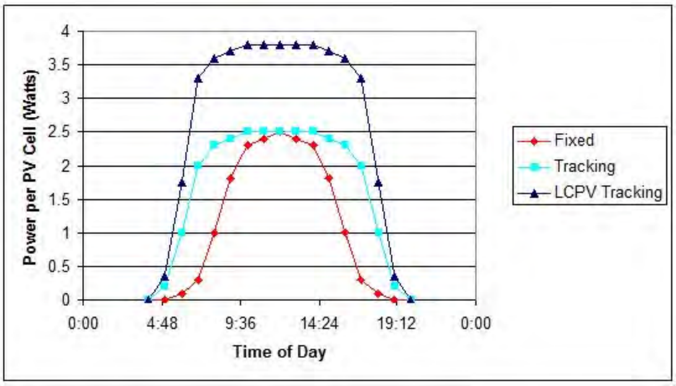


Figure 1.27 Tracking improves the total energy output of a photovoltaic system (Hebrink, 2012).

In solar power systems, such as parabolic dish concentrated solar power systems, tracking is even more important since the red window in Figure 1.27 in a concentrated beam is much narrower if no tracking takes place. For concentrated solar systems, the ideal situation is when the sun is hitting the panels at a perfectly perpendicular angle (90°). This maximizes the amount of energy striking the receiver means. In solar tracking, the two factors that such an angle is controlled by are the orientation (azimuth) and the angle of the receiver from the surface of the Earth (elevation).

A study by Catarius in the UK carried investigated the performance of dual-axis solar tracking systems on solar PV systems (Catarius, 2010). The aim was to investigate increasing the energy output of a solar collector by using a dual-axis tacking system. According to their report, the dual-axis tracking system increases the annual energy by around 48%, compared to a fixed model and by around 36% than a single-axis system. The use of solar tracking systems can thus be very attractive since the tracking advantage improves the economic scale of the system.

Figure 1.28 shows how the effectiveness of a solar array or collector diminishes as its orientation and tilt move away from the optimum position. The example in Figure 1.28 shows that to capture maximum solar energy with an array located at a latitude of 35° North, the optimum array orientation is pointing due South and the optimum tilt is the same as the latitude, in this case 35°. If the array system has to be mounted on a roof with a pitch of 45° on a building pointing South West it will only receive a maximum of about 90% of the available solar energy.

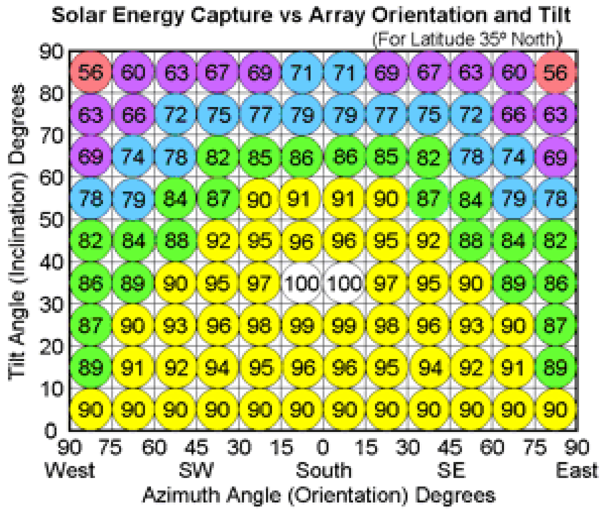


Figure 1.28 Effectiveness of a solar array or collector diminishes as its orientation and tilt move away from the optimum position (Woodbank, 2014).

Thus, the amount of solar energy received at any location on the earth is directly proportional to the angle at which the sun rays incident on the solar receiver means, as depicted in Figure 1.29 SolarChoice2014.

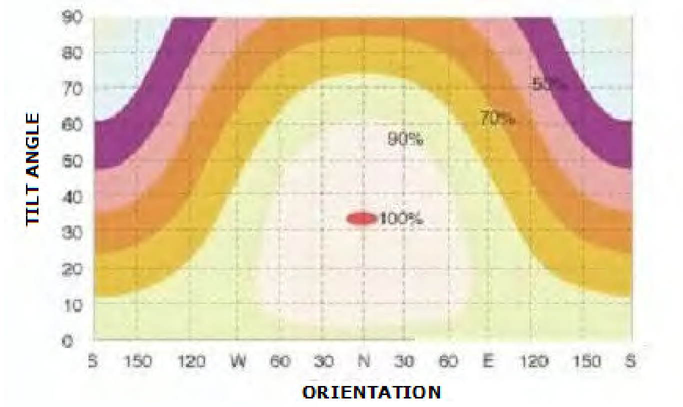


Figure 1.29 Example of the efficiency of a non-tracking solar PV system at different angles and orientations to show the harvesting capacity in terms of sun movement (SolarChoice, 2014).

The angle of the sun changes as a result of the sun progressing throughout the sky. Furthermore, the angle at which sunlight strikes the Earth varies by location, time of day, and season due to the earth's orbit around the Sun and the earth's rotation around its tilted axis (as discussed in the previous chapter). All of these factor needs to be compensated for by using a solar tracking means in order to capture the maximum amount of solar energy (Figure 1.28).

It is shown in the architectural representation of Figure 1.30 that various shades of red and blue reflect the amount of solar thermal energy for the different months of the year (the darker the red, the hotter) (Lechner, 2014). Although this architectural representation of solar thermal energy in actual fact represent the solar energy for a particular faade of a building, the intention is more to show the wealth of information that can be represented graphically.

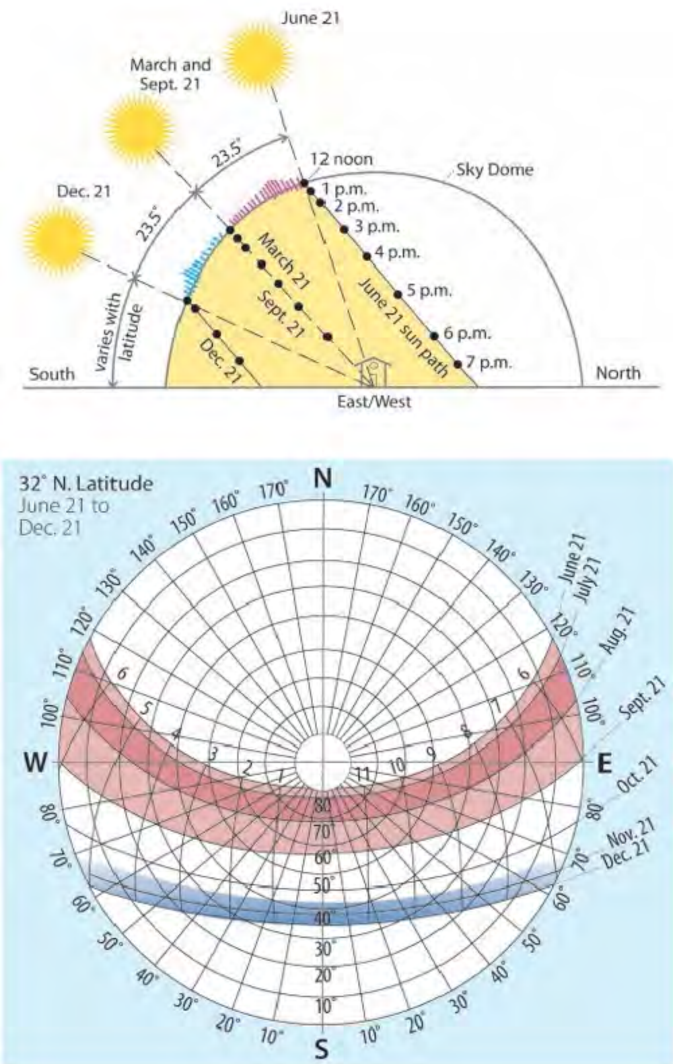


Figure 1.30 Graphical presentation of solar thermal energy in which various shades of red and blue reflects the amount of thermal energy for the different months of the year (the darker the red, the hotter) (Lechner, 2014).

The representations in Figure 1.30 is described in more detail on this link `http://greenpassivesolar.com/2014/06/playing-the-angles-for-solar-responsive-design/`. To quite Lechner: ”the lower part of the solar window is called the *w*inter solar window, which extends up from the winter solstice to the part of the dome corresponding with the month when winter ends in that climate. The shades of blue reflects the typical temperatures in each month (the darker the blue, the colder). Although the location of the solar window is a function of latitude, the size of both the summer and winter solar windows is a function of the severity of the climate at the building site (i.e., how hot it is in the summer and how cold in the winter). One major goal of solar-responsive design is to collect the sun shining through the winter solar window while rejecting the sun when it shines through the summer solar window" (Lechner, 2014).

In Figure 1.31 we see another type of graphic representation of the annual sun paths as well as the available solar thermal energy for a particular solar tracker location, where a sun shading analysis is included in the solar thermal analysis display (Pzarch, 2012). This type of illustration helps to express and quantify the amount of solar energy available for capture versus the orientation of the solar collector for that particular site.

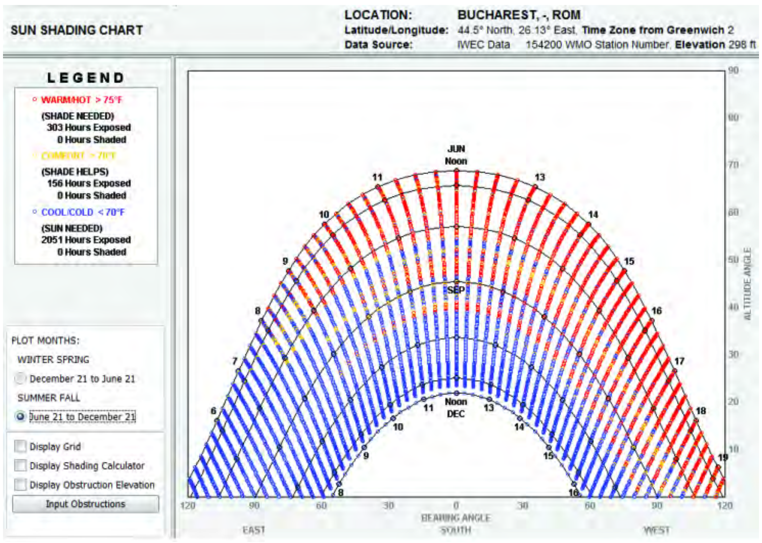


Figure 1.31 Graphic representation of the sun paths and available solar thermal energy for 12 months of the year at a particular tracker location, with a sun shading analysis included (Pzarch, 2012).

Figure 1.32 shows another type of graphic visual representation by Krymsky in which Ecotect produced tabular representations of the solar radiation data for a particular geographical GPS location and building faade (e.g. tiled with solar panels) is plotted in terms of solar heat gain and orientation in a single graphic (Krymsky, 2013). Although this display is more to represent the solar thermal or heat energy radiated on a particular face of a building, the type of display could also be used to represent the power budget for a particular solar tracking system at a particular location.

To end off this chapter, we refer readers to the software analysis tools on the website of SunEarthTools for further reading and understanding of the solar resource potential as well as the sun path at any particular location on the earth (Sunearthtools, 2014). This site (`http://www.sunearthtools.com/dp/tools/pos_sun.php`) offers a collection of tools to analyse the potential and how to work with solar energy at any potential site of installa-

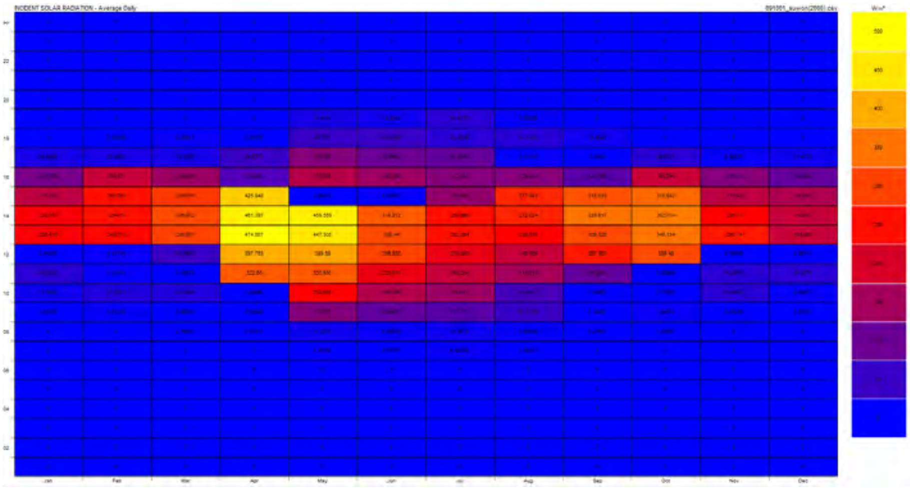


Figure 1.32 Graphic illustration of cumulative incident solar radiation and normal radiation data in a type of orientation bar graph (Krymsky, 2013).

tion. It further includes platforms for the calculation of sun position, latitude longitude coordinates, photovoltaic systems, emissions CO_2.

The site also includes graphical tools for the calculation of suns position in the sky for each location on the earth at any time of day, illustrating the azimuth, sunrise sunset noon, daylight and graphs of the solar path at a particular location. It further offers valuable conversions of latitude/longitude geographic coordinates, in a variety of formats, such as decimal, sexagesimal, GPS DD DM DMS degrees minutes seconds, or finding the coordinates by clicking on a map (Sunearthtools, 2014).

The effect of cloud cover on the solar spectrum is an important consideration for which the effects will be discussed in mode detail in Section 13.2. The spectrum of solar radiation received on top of a mountain in a remote region can differ markedly from the spectrum received in an industrial or urban area near sea level. Furthermore, the amount and type of radiation on the parabolic dish or photovoltaic panel for a solar tracking system on the earth also depends upon the changing characteristics of the atmosphere.

For example, Figure 1.33 presents a graphic illustration of spectral shift in solar irradiance on the earth as a function of sky conditions (Lee, 2014*a*). This illustration emphasises the spectral effects on the solar spectrum of sunrays that pass through the atmosphere, showing that extra-terrestrial solar radiation is reduced by cloud scattering and absorption caused by air molecules, aerosol particles, water droplets and ice crystals. It shows that a spectral shift is taking place, that may be an important consideration in the type of material used in solar power systems, and to ensure that the technology bandpass spectrum match the solar spectrum for those systems that operate in cloudy conditions.

1.8 Summary

In summary, the principle of solar harvesting revolves around accurate solar tracking and this chapter detailed aspects of the apparent movement of the sun through the sky during the day on a conceptual level. It presented graphical illustrations and demonstrations to

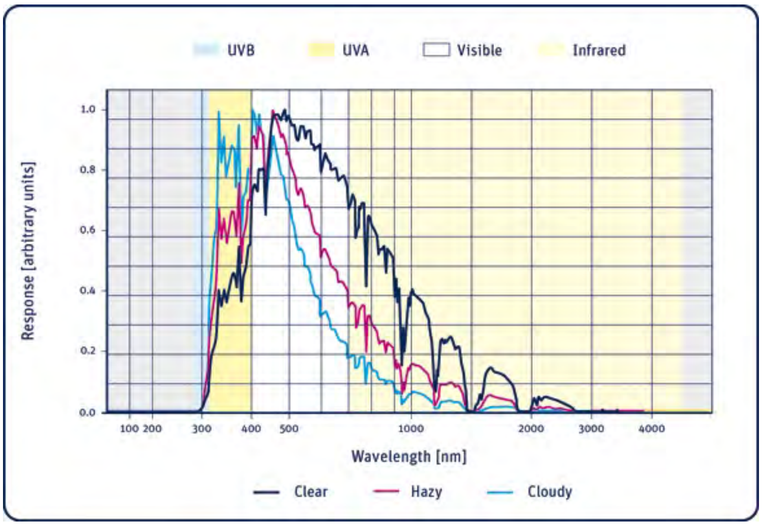


Figure 1.33 Graphic illustration of spectral shift in solar irradiance on the earth as a function of sky conditions (Lee, 2014*a*).

show how the sun moves across the sky in a sun path, that can in turn be calculated from an astronomical based solar position algorithm. It also illustrated that this motion can be viewed as if the sun is apparently moving along the circumference of a disc which is displaced from the observer at various angles, depending on the season of year. The centre axis of the so-called solar discs was shown to be the polar axis and constitutes an imaginary line that connects the location of the solar tracker system (or observer on the earth) and the Northern Star (Polaris).

This lays the foundation for any solar tracking systems that needs to ensure very precise perpendicular focussing of the solar optic harvesting device onto the centroid of the sun. With the exact solar coordinates and the trajectory path of the apparent movement of the sun known through the SPA or Sun-Path Diagram at any given geographic location of the surface of the earth, this information can serve as input to the pointing controller for the appropriate manoeuvring of a solar energy harvesting system to face the sun directly.

CHAPTER 2

SOLAR TRACKING MECHANISMS AND PLATFORMS

Solar Tracking, First Edition.
By Prinsloo, Dobson

2.1 Introduction

In the previous chapter, it was shown that the amount of solar energy captured is a function of the solar collector orientation. Efficient solar energy harvesting can thus only occur with the aid of a solar tracking system. This chapter deals with the mobility platform that ensures the movement of the solar collector system to follow the sun in order to harvest solar energy during the day.

Assume for the moment that the exact solar coordinates and the trajectory path of the apparent movement of the sun at your GPS location is known (i.e. the SPA or sun path diagram at any given geographic location of the surface of the earth as described in the second part of this book). This solar vector information can now serve as input to the positioning system controller.

The solar tracking mobility platform plays a crucial role in the development of solar energy applications, especially in high temperature solar concentration systems that directly convert the solar energy into thermal or electrical energy. In these systems, high precision tracking is required to ensure that the solar collector is capable of harnessing the maximum amount of solar energy throughout the day. In order to maintain high levels of power output, a high-precision sun-tracking system or solar tracking mobility platform is necessary to follow the sun on its trajectory as it moves across the sky.

2.2 Solar Tracking Platform Components

In this chapter we are particularly interested in controlling the movement of a solar harvesting means in an energy efficient manner. The concept of a solar tracking platform describes that part of the system that ensures solar collector mobility and tracking control, for example a dual axis cross-coupled (mechatronic) steering platform.

In general, an electrically driven solar tracking mobility platform includes a solar tracking control system for driving the motion of a concentrating solar collector. It may be used to track the sun in two dimensions and to focus the sunlight onto a solar receiver means. The complete integrated system typically includes the following elements and components:

1. Transmission/actuator mechanical drive subsystem: Linear actuators, worm gears, linear drives, slew drives, and planetary gear drives form part of the positioning system to move the reflector to face the sun;

2. Electric motors: DC or AC electric motors to drive the mechanical drives, through current, frequency or speed control;

3. Battery storage: Backup battery system for power storage and start-up power requirements;

4. Motion sensing subsystem devices: Linear or rotational shaft encoders, tilt sensors, inclinometers, photodiodes, photosensitive resistors to monitor the present position of the dish while it moves to the desired position;

5. Solar position algorithm: Algorithm to continuously calculate the sun vector $S_Q(\gamma_s, \theta_s)$, as solar azimuth and elevation angles;

6. Control unit subsystem: Programmable device to coordinate the modes of operation, as well as the control strategy to position the system according to the solar position algorithm or sensor coordinates;

7. Limit switches: Devices to prevent mechanical movement beyond pre-defined limits in order to prevent tracker or cable damage;

8. Environmental or atmospheric ambient sensing devices: Light intensity sensing, solarimeter, pyranometer, anemometer/wind sensor, ambient temperature sensor, humidity sensor and atmospheric pressure sensors to detect any emergency or threatening environmental risks.

9. Payload: The solar collector subsystem, typically an optical element, lens, collector, reflector or dish system with associated solar harvesting means (i.e. Stirling engine/device or concentrated photovoltaic module mechanically mounted at the focal point of a parabolic type dish);

The development phases of your project will thus include the design and implementation of a mechanical platform with a mechanical transmission or actuator system as well as electronic or digital electronic control in order to realise smooth power input solar trajectory contour following. The detailed designs of the power conversion unit and grid interface/power electronics aspects of the system is described in a follow on book prepared by the authors.

2.3 Types of Solar Tracking Platforms

Figure 2.1 illustrates the full spectrum of types of solar tracking platforms designs under consideration. In a simple one-axis sun tracker design, the tracking system drives the collector about an axis of rotation until the sun central ray and the aperture normal are coplanar.

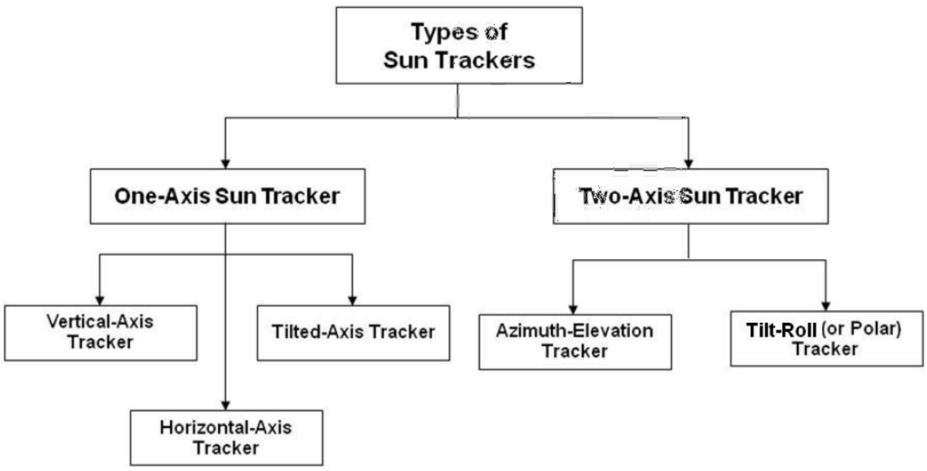


Figure 2.1 Type of existing solar tracking platforms (Chong *et al.*, 2014).

There are typically three types of one-axis sun tracking designs available. This includes a horizontal-axis tracker (tracking axis is to remain parallel to the surface of the earth and it is always oriented along East-West or North-South direction); tilted-axis tracker (tracking axis is tilted from the horizon by an angle oriented along North-South direction, e.g. Latitude-tilted-axis sun tracker); and vertical-axis tracker (the tracking axis is collinear with the zenith axis) also known as an azimuth sun tracker (Chong *et al.*, 2014).

Two-axis or dual-axis sun trackers, such as the azimuth-elevation and the tilt-roll sun tracking systems, follow the sun in the horizontal and vertical plane. In the azimuth-elevation sun-tracking system, the solar collector must be free to rotate about the azimuth and the elevation axes. In these systems, the tracking angle about the azimuth axis is the solar azimuth angle and the tracking angle about the elevation axis is the solar elevation angle. Such dual-axis tracker systems track the sun on two axes, such that the sun vector is normal to the aperture as to attain near 100% energy collection efficiency.

2.4 Solar Tracking Platform Principles

Any solar tracking platform with electronic control system must be designed for the continuous orientation or positioning of the solar harvesting means with respect to the sun vector. This requires knowledge of the sun vector. The previous chapter of this book introduced the concept of a solar vector and this aspect will be dealt with in more detail in the second part of this book, where the sun vector describes the sun the angle and elevation from the perspective of a specific Global Positioning System (GPS) orientation on the earth. Assuming you have identified and so-called solar position algorithms are intended to track the sun as solar resource and to follow its apparent movement throughout the sky.

The technology behind motion, actuation or transmission drive systems for solar harvesting platforms and solar tracking movement shows some relation to concepts and components used in digital satellite tracking, military radar following, radio astronomy and radio telescopes. Some of the design approaches in solar tracking and control mechanisms differs slightly from solar tracking, while tracking systems such as gun turret designs provide dual-axis movement concepts has a proven track record of robustness in harsh environmental conditions. These designs and mechanisms provides an interesting perspective from a solar tracking platform point of view and will be discussed by way of examples.

To repeat an example showed before, Figure 2.2 illustrates the solar vectors for a solar path (azimuth and elevation angle contours) that needs to be tracked by a solar tracking system. This sequence of sun vectors needs to be tracked by motor drives at a solar installation site for a given geographical location before any solar harvesting can begin.

Figure 2.2 illustrates the sun path contours for an example location site. These sun-paths are typically calculated from the SPA solar position algorithm as a sequence of solar vector and is used by the controller of solar tracking platform system for that site.

Figure 2.2 also shows the estimated available solar energy at that particular location, data that is typically obtained from solar DNI models for that particular location (Manfred, 2012). In this way, the DNI can also be used to predict to amount of solar energy available for that location, or the information can be used to evaluate the viability of installing a solar energy system at the site on an *a-priory* basis.

In this example, the solar concentrator dish needs to dynamically track the movement of the sun throughout the duration of the day on both azimuth and zenith angles. The actuator responsible for correct positioning on the azimuth angle is referred to as the azimuth drive while the actuator responsible for the correct positioning on the elevation angle is known as the altitude drive.

The azimuth/elevation tracking drive mechanism of the solar tracking system shown in Figure 2.3 uses a dual slew drive pan-tilt control mechanism to realise dual axis solar tracking (Greyvenstein, 2011). In this tracking mechanism, the altitude and azimuth drives

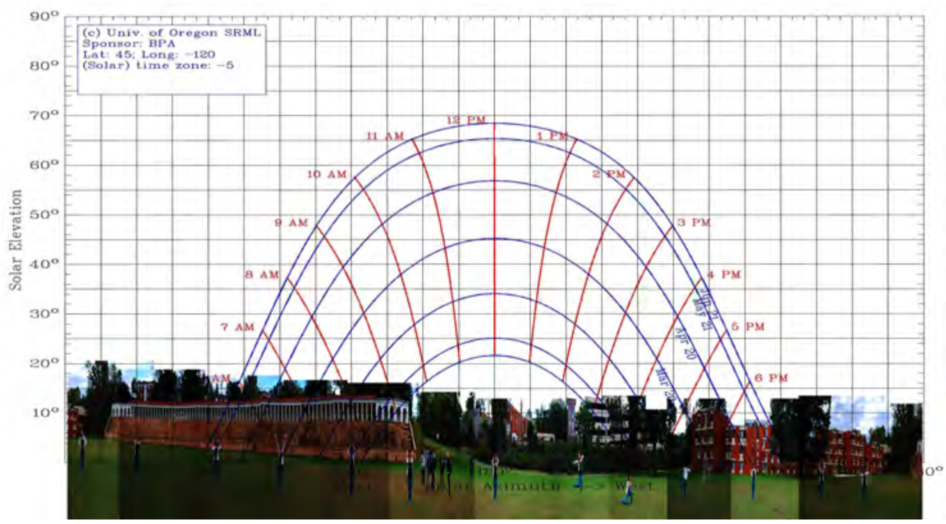


Figure 2.2 Typical sun path diagram in Cartesian coordinates, showing the azimuth/elevation of the sun daytime path at a given location (Manfred, 2012).

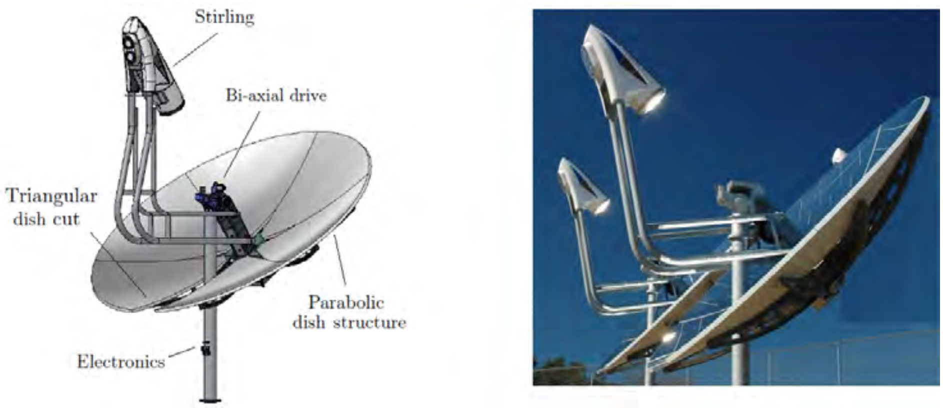


Figure 2.3 Bi-axial drive solar tracking platform implemented by Infinia (Greyvenstein, 2011)

have been combined into one gearbox unit (see Figure 2.3). This balanced cantilever design allows for smaller and less expensive drives to be used. Unfortunately this type of design requires a triangular cut from the bottom half of optical dish to allow for mechanical movement during elevation, which typically results in losses ($\sim$ 10% to 15%) in square meter solar reflecting area.

In general, dual-axis solar tracking devices are designed to improve the performance of solar collectors by following the sun positions. Solar tracking systems track the normal beams of the sun directly and it increases the performance of solar collectors by around 50% in summer and around 30% in winter for a clear sky condition.

In azimuth/elevation solar tracking, the concentrated solar power system harnesses solar energy by rotating in the azimuth plane parallel with the horizon as well as in the elevation plane perpendicular to the horizon. This dual axis movement allows for the parabolic dish to be moved in an upwards or downwards direction as well as from left to right in order to follow the movement of the sun throughout the day.

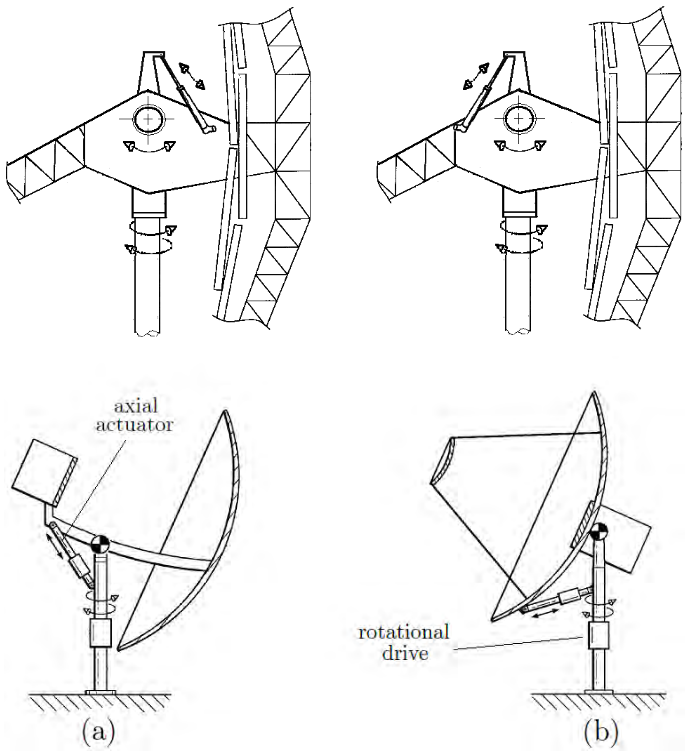


Figure 2.4 Dual axis solar tracking system using independent actuators in various configurations (Dietrich *et al.*, 1986)(Esmond *et al.*, 2011).

In other systems, dual axis solar tracking mechanisms drives the altitude and azimuth movements independent from each other. Examples of such independent solar concentrator drive mechanisms are shown in Figure 2.4 using various actuator location configurations.

In this figure, drawing (a) shows how the dish elevation movement pivots in front of the dish, and in drawing (b), the elevation movement pivot point is located behind the dish.

One problem with solar tracking systems driven from behind the dish is that there is a large load bias on the front of the dish due to the weight leverage of the solar receiver (usually as Stirling power generator). This requires large and overly expensive tracking drives to overcome the hanging load of the power conversion unit on both the azimuth and elevation angle drives. Large counterweights are often employed to reduce the solar receiver load, but this increases the total weight of the system and increases the potential for system instability. Increased additional weight (with no physical benefit) requires larger and more expensive bearings as well as a stronger and more expensive pedestal framework.

McDonnell Douglas proposed a novel point-focusing parabolic dish solar tracking system with full tracking capabilities in on an elevation-over-azimuth axis. The parabolic dish reflector was developed to meet commercial requirements in both power grid connected and remote (off-grid) applications (Dietrich *et al.*, 1986). The McDonnell Douglas parabolic dish solar tracking system is presented in Figure 2.5(a) to illustrate the typical components of a mechatronic solar tracking platform design. The rights to this design was later taken over by SES and some improvements to it was made to it.

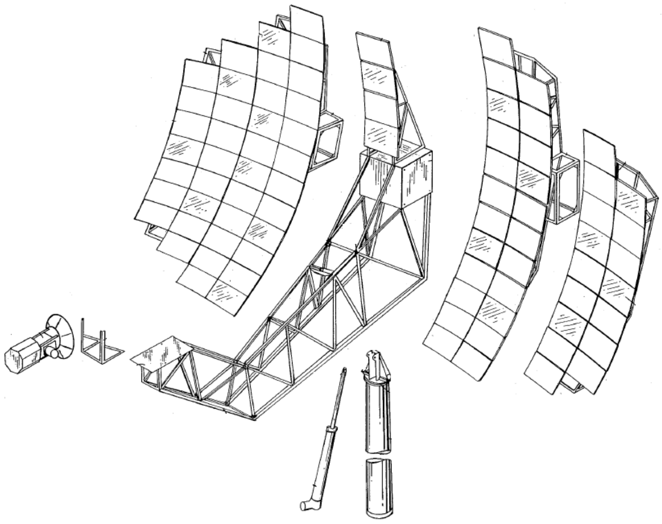


Figure 2.5 McDonnell Douglas counter-balanced tilt-and-swing concentrated solar tracking platform (a) side-view and (b) exploded view (Dietrich *et al.*, 1986).

Figure 2.5(b) shows the exploded view of this concentrated solar power system design configuration, in which five sub-assemblies can be identified, namely: the solar dish surface, the solar tracking structure, the base structure, the azimuth drive and the elevation drive. This design uses a weight balanced cross-beam design, where the weight of the parabolic dish (on one end) and the receiver/generator (on the other end) is balanced on a pivot point over the pedestal stand. This solar tracking design integrates a dual drive system for which the positioning of the altitude and the azimuth drives were placed in separate positions. These positions were chosen so that the drives can perform as close to their ideal efficiency points as possible.

Figure 2.6 illustrates a dual axis counter-balanced tilt-and-swing concentrated solar tracking mechanism and platform (Wilson, 2014). A linear drive adjusts the tilt motion or elevation angle movement of the solar concentrator while a rotational drive adjusts the panning or azimuth motion of the solar tracking concentrator. A solar receiver and power conversion means, in this case typically a linear free piston Stirling engine, is mechanically suspended at the focal point of this dish configuration.

During solar tracking, the solar tracking platform and power conversion means converts thermal energy to electricity by using a mirror array to focus the suns rays on the receiver end of a Stirling engine, which heats and expands a gas. The pressure created by the expanding gas drives a piston, crank shaft, and drive shaft that turns a small electricity generator. The entire energy conversion process takes place within a canister the size of an oil barrel.

For solar tracking systems, the goal is to achieve dish movement through the desired rotational motion and with minimum torque. The sun progresses relatively slowly along a stable track (around 15° per hour), therefore tracking requires azimuth and elevation drives with high gear-ratios. Solar tracking systems typically employ actuator drives with gear-ratios in the region of $30,000 : 1$ (Dietrich *et al.*, 1986). To achieve such high gear ratios,

Figure 2.6 Dual axis counter-balanced tilt-and-swing concentrated solar tracking platform (Wilson, 2014).

the gear-ratio multiplication factor in gear trains are often used in solar tracking actuator systems.

The Stirling Engine Systems (SES) dish uses a linear drive for elevation tilt movement, as shown in Figure 2.7. The linear drive is a self-contained actuator that combines the ball screw jack and worm gear reducer into a single compact package (Wilson, 2014). Sun tracking is accomplished through azimuth and elevation (screw jack, shown in white in Figure 2.7) drives that require a high degree of accuracy and durability. The azimuth drive in both the McDonnell Douglas and the SES designs were planetary gear drives (Winsmith Planocentric drives) with a gear ratio of at least $30,000 : 1$.

The advantage with such a large gear ratio is that very precise positioning can be achieved with relatively small permanent magnet electric motors driving the azimuth and elevation movements. In general for solar tracking solutions, large gear-ratio drives are preferred in sun path tracking, since the movement of the sun is limited to less that 1° minute. Such relatively slow moving requirements through large gear-ratios provide the added advantage that less torque is required for the initial stages of every incremental movement of the dish. With less torque required, less current is drawn by the electric motors during every incremental start-up phase.

The construction of a typical photovoltaic or flatplate solar tracking platform may consist of a pedestal pole, a linear elevation drive, a rotational azimuth drive as well as supporting arms with profile rails for attaching any solar harvesting modules (see Figure 2.8). Such flexible dual-axis tracking of the platform in both the azimuth and elevation angles ensures solar tracking throughout the day.

For both photovoltaic and dish-type concentrated soar harvesting systems, the solar receiver needs to move on azimuth axis in harmony with the earth's rotation at a constant rate of around 15° per hour (elevation axis movement is even slower). To ensure that solar dish orientation remains on target, a gear drive mechanism with high torque and slow speed (large gear ratio) would be preferred as design choice.

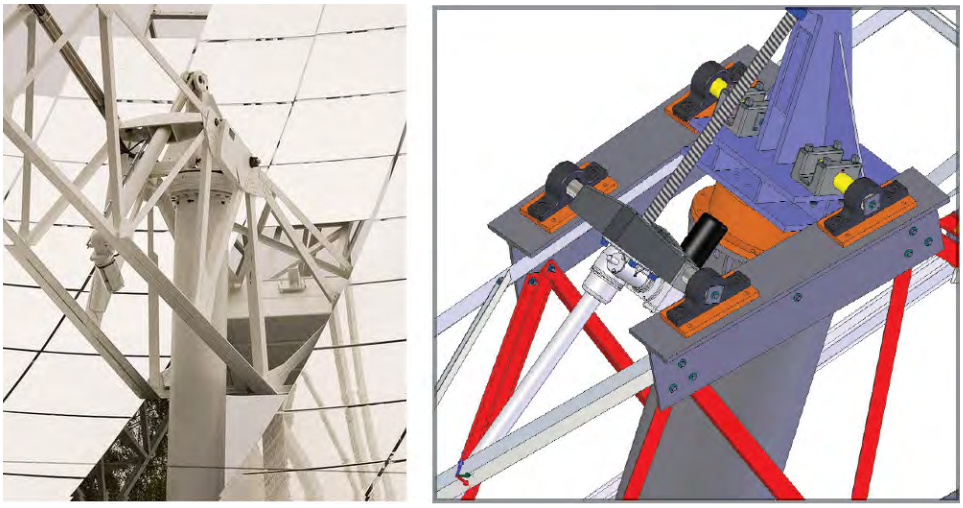


Figure 2.7 Elevation drive mechanism in a counter-balanced tilt-and-swing concentrated solar tracking platform (Wilson, 2014).

Figure 2.8 Sonnen Systeme dual axis solar tracking platform system (SMA, 2014).

For those that are interested in more detail, Lee *et.al* (Lee *et al.*, 2009) providing a high level overview of solar tracking systems and presents details of a variety of closed-loop and open-loop types of sun tracking systems. A review sun tracking systems is also provided on this link `http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3297124/`.

Tilt-and-swing type dual-axis motion mechanisms are widely used in a number of dual-axis motion means, such as in the design of camera cranes, surveillance camera systems, pan-and-tilt type gun/cannon turrets, robotic arms and construction cranes. In digital satellite, radar or radio telescope systems, the payload typically includes a lightweight radio-antenna feed-horn or secondary optical telescope reflector, while in solar Stirling power generation systems, the payload comprises a complicated metal thermal to electrical energy converter of which the weight far exceeds that of any satellite or radar tracking payloads.

2.5 Solar Tracking vs Satellite Tracking

We are often asked the question whether a satellite dish and satellite tracking means can be used for solar tracking and for solar harvesting. Professional applications would probably not consider this as a viable option, but from an experimental and initial proof-of-concept perspective there are certain merits to consider this as an option.

Firstly, the focal point of a solar/satellite dish in Figure 2.10 is of importance as this is the point where concentrated heat is transferred to the solar receiver. It also determines the angle of entry of sunlight, meaning the angle at which the reflected sun rays enters the solar receiver cavity. Compared to radio and satellite dish designs, the parabolic focus plane and payload for a concentrated solar system is normally located further from the dish (higher f/D ratio) to ensure proper thermal impedance matching between the parabolic dish and the solar receiver (aperture and cavity). Section 14.2 later in this book deals with the shapes and ratios of parabolic dishes and parabolic troughs in mode detail.

A satellite dish is thus typically very ”deep” and the focal point of the dish can be closer to the dish than in the case of a solar parabolic dish. In technical terms, a satellite dish is said to have a lower f/D ratio. The f/D ratios normally used in concentrated solar dishes are typically around $f/D = 0.6$, and in satellite dishes this ratio can be as low as $f/D = 0.3$ or lower (Stine and Geyer, 2001). When the focal point of the dish gets closer to the dish, then may be more difficult to accomplish thermal heat transfer to the solar receiver aperture (see Figure 2.9), especially since the incident concentrated sun rays reflected from the outer edges of the dish strikes the receiver aperture entrance at a very low angle.

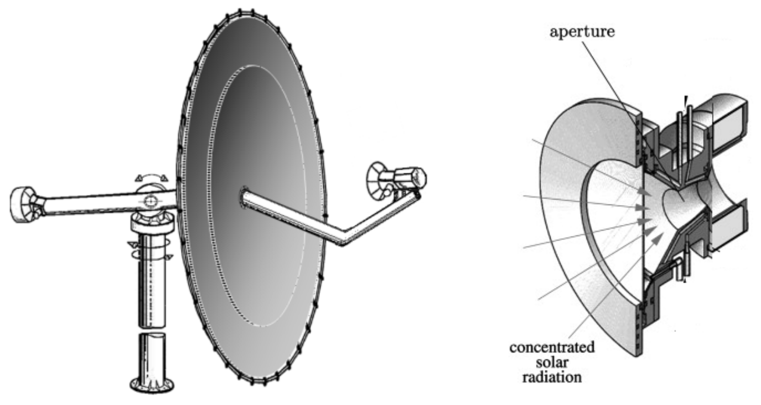


Figure 2.9 Simplified illustration of a typical solar receiver system to illustrate a cone-type solar sunray receiver (Prinsloo, 2014*b*)(Taylan and Berberoglu, 2013).

In solar parabolic systems, a higher f/D ratio (with a value around 0.6) also introduces mechanical control complexities as a higher parabolic ratio increases the effect of the hangover weight on the structure and control system due to the moment of this longer arm. Furthermore, instead of a cool, lightweight, feed-horn transmitting or receiving antenna, the payload for a concentrated solar system operate with considerable energy and thermal heat with secondary added weight in terms of a Stirling type engine and its cryco cooling means. These power conversion and cooling devices not only introduces mechanical vibrations during operation, but the overhanging weight of this payload requires special consideration in terms of system stability in the design.

Illustrations of satellite dish (and antenna system location at the focal point) will further help to understand valuable similarities in terms of the parabolic dish shapes, but also subtle differences in the parabolic f/D ratios when comparing satellite and solar dishes. In Figure 2.10, for example, one can note some difference between satellite and solar tracking systems, especially in the shape and mount of a typical satellite dish and satellite tracking mount system. It also confirms an earlier point on impedance matching, namely that the focal point of satellite dishes (location of the feed-horn antenna) is typically very close to the dish, because a satellite dish typically uses a lower parabolic constant or parabolic f/D ratio (parabolic dish parameters and calculations presented later in the book in Section14.2).

Figure 2.10 Examples of a polar mount satellite tracking system (left) and sectional parabolic satellite dish elements (middle, right).

The typical digital satellite C-Band sectional composite/mesh antennas in Figure 2.10(left) one would also note that satellite tracking is normally accomplished with a so-called ”polar mount”. It would be noted on the left that the dish is steered with a roll-type action (in this case using a linear actuator) while the polar axis is aligned around the rotational axis (in this case the dish swivel point is the Polar axis).

Most commercial satellite tracking systems come with proprietary satellite tracking software. Such software is often pre-programmed with the contours of 100’s of satellites circling the earth (Kelso, 2014). Most satellite tracking systems/software also includes PC software that enables the user to select satellite names (with their associated sky contours) from drop-down lists or to download the satellite sky motion contours (refer Online Satellite Catalog or SATCAT (CelesTrak, 2014)).

The website `http://www.celestrak.com/software/satellite/sat-trak.asp` can be consulted for more details on celestrial tracking. In satellite tracking PC software, celestial bodies (including the sun, moon and planets) are usually treated as ”satellites” and their sky contours computed from astronomical algorithms can similarly be selected and downloaded from the database list `http://www.celestrak.com/satcat/search.asp`.

By using such software in a polar mount configuration, the tracking of any satellite, planet or the sun is as easy as rigging up the satellite dish, and then selecting the required satellite or celestial body (i.e. the sun for solar tracking) from a drop-down list, and sitting back to watch the satellite dish follow the satellite/planet/sun.

Finally, polar mount tracking are commonly used in satellite tracking systems, meaning that satellite tracking systems include a polar mount for polar tracking software configurations. To refresh the readers mind, we refer back to the illustration in Figure 1.4, from which it will be remembered that the centre axis of the seasonal solar discs are always orientated along a fixed axis, namely the polar axis. A polar mount satellite antenna exploits this angle by keeping one angle of orientation fixed on the polar axis.

From a solar tracker location perspective, a polar mount satellite/solar tracker system also exploits the geometry of the sun's apparent path, knowing that the sun can be followed about the disc circumference with a simple rolling action mechanism (at an angular rate of around 15° per hour). Knowing that solar discs in Figure 1.8 shifts in an annual cycle up and down the polar axis, polar solar tracking compensates for the incremental daily sun disc shifts (function of calendar date) by making once-a-day .

Thus, in polar or tilt-roll solar (satellite) tracking the tracker follows the so-called solar disc shown in Figure 2.11(top), while making incremental once-a-day adjustments to compensate for calendar date solar disc shift variations Figure 2.11(bottom). In this way, the solar collector is steered to follow the sun from east to west, simply through a rolling action, while the angle of the daytime rolling collector orientation is slightly tilted every night to compensate for the daily (calender date) change of sun path disc location.

Therefore, in polar/tilt-roll satellite/solar tracking, one axis of rotation is thus aligned parallel with the earths polar axis that is aimed towards the star Polaris. This positions the tracking platform to tilt from the horizon equal to the local latitude angle using a linear actuator mechanism, as illustrated in the tracking mechanism shown before in Figure 2.10(left).

The other axis of rotation is perpendicular to this polar axis. The tracking angle about the polar axis is equal to the suns hour angle and the tracking angle about the perpendicular axis is dependent on the declination angle. The advantage of tilt-roll tracking is that the tracking velocity is almost constant at 15° per hour and therefore the control system design is simpler.

Figure 2.11 (bottom left) presents another simplified illustration of rotational solar tracking around the polar axis, as well as the (daily incremental) angle adjustments to compensate for seasonal solar disc shifts up-and-down the polar axis (see Figure 2.11(bottom right)).

The tilt-roll (or polar) satellite tracking mechanisms are becoming very popular in solar tracking energy applications, since it requires once-a-day adjustments in one angle and rotational movement in the other axis to achieve two or dual axis tracking (see Figure 2.10(left)). This once-per-day seasonal adjustment shift in terms of the angle of the rotational movement with the polar axis is illustrated in Figure 2.11(bottom right).

A polar solar tracker is a mechanical device capable of orienting the solar collector so that it remains perpendicular to the sun. The polar tracker uses a rolling motion to follow the sun from east to west at sunrise to sunset. Figure 2.12 shows a series of examples of polar axis based solar tracking actuator systems (Muerza, 2007)(NREL, 2014*a*)(RedSolLAC, 2014).

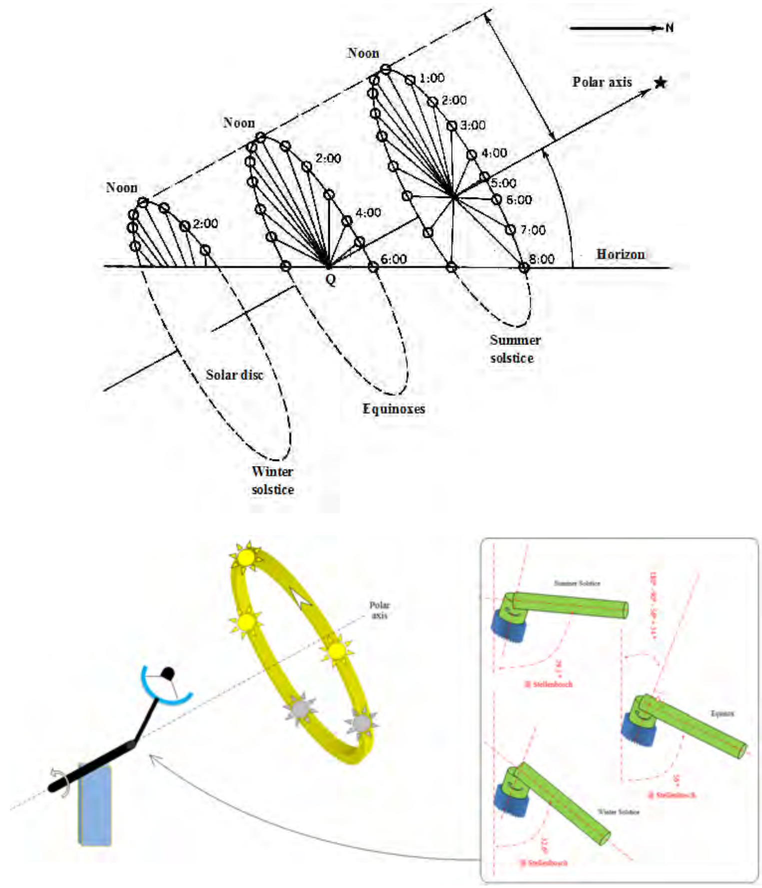


Figure 2.11 Sun path view as seen by a solar tracker at location Q for three seasons (top) (Stine and Geyer, 2001), and (bottom) simplified illustration of the solar disc and polar based rotational solar tracking around the polar axis.

Figure 2.12 Examples of polar axis trackers used in solar tracking technologies (Muerza, 2007)(NREL, 2014*a*)(RedSolLAC, 2014).

In summary, the polar axis points from the location of the observer towards the Northern Star (Stine and Geyer, 2001) and remains fixed for the lifetime of the solar tracking installation. Once configured correctly, a polar tracking axis system or polar solar tracking platform mainly performs rotational movement around this one Polar axis to track the sun on the solar disc circumference (date dependant Diurnal Circle solar tracking).

2.6 Azimuth and Elevation Drive Mechanisms

In this section, aspects of solar tracking functionality and the transmission solution required for a solar tracking platform is discussed. The transmission or actuator solution is detailed in terms of the motion platform concept and the transmission drive components. The picking of this equipment is required as it centres around the integration of the transmission system onto a mechanical platform suitable for accommodating solar tracking.

We therefore describe various lines of modular gearbox systems available for solar tracking design controls. While learning from past solar tracking system experiences, this study also highlights the features, benefits and disadvantages of the various transmission and gearbox systems in solar tracking applications.

Figure 2.13 presents the reader with a gallery of random images of various linear and rotational gear and slew drives. This may help in serving the purpose of assisting readers new to the field of solar tracking to grasp certain of the design concepts described thus far.

Figure 2.13 Image gallery of linear and rotational gear drives, transmission systems, actuators and slewdrives typically used in solar tracking applications (Prinsloo, 2014*b*)(Siemens, 2013*a*)(SKF, 2013).

Available literature discuss various linear and rotational transmission and gear drive mechanisms used and tested in solar tracking applications. This includes practical experiences with both linear and rotational type actuators, such as for example screw drives, worms drives, slew drives, spur gear drives, hypoid drives, helical gear drives, bevel gear drives and cycloidal drives.

2.6.1 Sun Tracking: Drive Speed and Gear Ratios

The sun angle plots for the azimuth angle (and elevation) angle can now be used to determine the solar tracking speed and gear ratio requirements. It was noted before that the partial differential of the solar path movement angle curves (slope at each point) equates to the solar tracking speed (degrees per minute), as illustrated in Figure 2.14. The sun path on the azimuth axis typically moves faster, and the point of maximum sun movement speed can be identified on the graph.

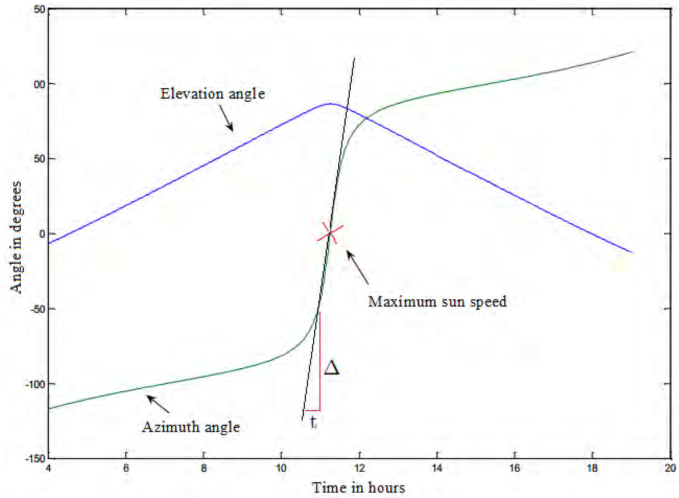


Figure 2.14 Solar azimuth and elevation angles of the daytime sun path for a certain geographical location (Ray, 2012), with the slope of the azimuth curve representing of the maximum sun movement speed superimposed.

With reference to Figure 2.14, one can determine the speed of the sun in degrees per minute by using the parameters obtained from the figure (at the point of maximum slope) in the formula given in Equation 2.1 below.

$$SunSpeed(degree/min) = \frac{\Delta_{SunAngle}(degrees)}{\delta_{time}(minutes)} \tag{2.1}$$

Equation 2.1 computes the speed of the sun in degrees per minute. However, to relate the speed of the sun to motor speed, we need to convert the sun speed to revolutions per minuted (rpm or RPM). Still referring to Figure 2.14, one can therefore determine the speed of the sun in rpm by dividing by $360°$ as in Equation 2.2 below.

$$SunSpeed(rpm) = \frac{SunSpeed(degree/min)}{360°} \tag{2.2}$$

Depending on the location of the observer, Equation 2.2 will show that the sun is moving on average at an angular speed of around $0.25°$ per minute (Stine and Geyer, 2001). Thus, on the fastest moving solar tracking axis, namely the azimuth axis (see Figure 2.14), the solar tracker axis should achieve an angular rate of movement of at least $0.25°/min$ to keep up with the relative sun movement. To achieve an angular movement rate of $0.25°/min$, Equation 2.2 shows that a minimum rotational motion speed of 0.000694 rpm ($0.25°/360° = 0.000694\ rpm$) is required to accomplish successful solar tracking.

Electrical motors typically move at a rate of around 1750-2000 rpm. This means that an electrical motor on its own would thus not achieve such slow rate of movement with adequate torque to drive solar tracking. Therefore a gear drive or transmission system is required to gear-down motor speed while providing sufficient torque at slower solar tracking speeds.

With a gearbox on the fastest moving axis, namely the azimuth axis on Figure 2.14, the motor shaft still needs to turn at a certain minimum required speed in order for the tracker to keep up with the movement of the sun. To determine this minimum required rotational speed for a tracking motor, one can use Equation 2.3 with the sun speed (rpm, determined in Equation 2.2) as follows:

$$MotorShaft_{Min}(rpm) = SunSpeed(rpm) \times Gear_{ratio} \tag{2.3}$$

where the $Gear_{ratio}$ is determined as follows:

$$Gear_{ratio} = \frac{(Motor_{input\ speed})}{(Gearbox_{output\ speed})} \tag{2.4}$$

If the motor and gearbox combination cannot reach the minimum required speed calculated in Equation 2.3, then a different gear ratio (gearbox or transmission system) or higher speed motor needs to be selected.

From Equation 2.3, the maximum allowable gear ratio or reduction gearing allowed to convert a typical rotational speed of a motor of 1750 rpm to the minimum required tracking speed of 0.000694 rpm (solar tracking speed), then the gear ratio of the transmission or gear drive system is computed to be around 2,000,000:1 (1750/0.000694). With such an abnormally high gear ratio, a solar tracker gear drive system and a 1750 rpm motor will just be able to keep up with the sun movement during maximum sun movement.

Typically, a more practical and realistic gear drive system for solar tracking uses a transmission system with a gear ratio between 10,000:1 and 30,000:1. With such gear ratios, solar tracker rotational movement is normally faster than the rotational movement speed of the sun (0.000694 rpm). This is the reason why on/off type solar tracking control systems are used, to synchronise the solar tracker angular rotational movement on the ground with the sun's movement in the sky (solar tracking control described later in Section 8.3.2)

Knowing that one can determine the maximum angular speed of the sun in rpm (Equation 2.2), one can alternatively determine the minimum required rotational motor speed for a given gear ratio that is more realistic or practical. This makes it possible to select a typical solar tracking gearbox or transmission system and then select a motor with sufficient speed to meet the requirement in Equation 2.3.

In this regard, Equation 2.5 can be used to relate the speed of the motor and gear drive axles to the eventual rotational speed of the solar tracking system axis. This formula is valuable to determine the rotational speed of the tracker on either axis from the motor shaft rpm and the gear ratio of the gearbox or transmission system on that axis, and is very handy when the motor speed is fixed or if the motor gear drive can only operate within a certain rpm range.

$$SunTrackerSpeed(rpm) = \frac{MotorShaft(rpm)}{Gear_{ratio}} \tag{2.5}$$

Using Equation 2.5 in a typical practical example, we will show how to compute the rotational speed of the solar tracking axis shaft (rpm) from the motor shaft speed (rpm) and the gear ratio. Assume we have a transmission system with a gear ratio of 15,000:1 and a motor speed around 1750 rpm, then the rotational solar tracking movement calculated from Equation 2.5 will be around 0.175 rpm. This means the rotational solar tracking speed would be roughly 250 times faster than the point of fastest movement of the sun on the azimuth axis (Equation 2.2).

Continuing with this example, we can compute the solar tracking speed by selecting a slower speed motor or by slowing down the speed of the motor with PWM or VFD drives (as discussed later in Sections 9.2.1 and 9.2.2) to operate at a different efficiency point (see Figure 2.15). Say we reduce the motor speed down to around 20 rpm and still use the same gearbox with gear ratio of 15,000:1, then the rotational solar tracking movement speed calculated from Equation 2.5 will be around 0.00133 rpm. This means a rotational solar tracking speed roughly double the maximum speed of the movement of the sun on the azimuth axis (Equation 2.2). This motor gearbox/transmission system combination will therefore be able to keep up with the maximum solar movement as the motor shaft rotational speed will me above the minimum of Equation 2.3.

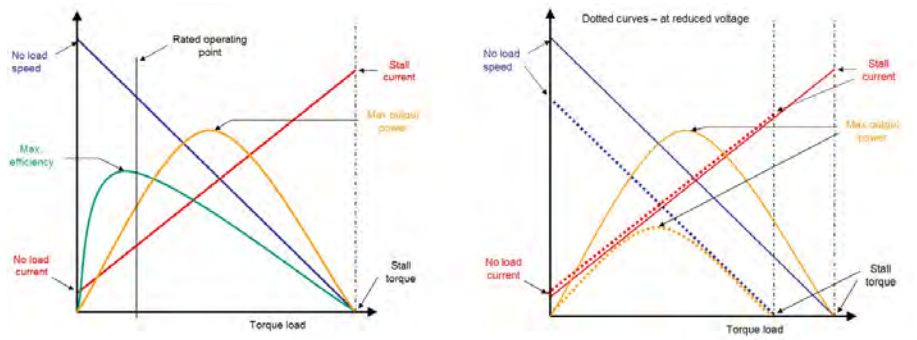


Figure 2.15 Example of motor performance curves and optimal operation points for a typical DC motor (left) and a typical DC motor running at a reduced voltage (right) (Johnson Electric, 2014).

In order to reach an optimum solar tracking motor/gearbox solution, the designer should strive to select a motor/gearbox combination that is able to deliver an acceptable solar tracking and motor speed (Motor Shaft rpm in Equation 2.5), such that the electrical motor operates as close as possible to its point of maximum torque or maximum efficiency as per the motor performance curve (see Figure 2.15). The motor performance curve or test graph is thus a crucial resource during this part of the design phase. The designer should further ensure that the tracking speed or rotational solar tracking angular movement of the solar tracker is at least within the same order or a higher speed than the rate of movement of the sun on the azimuth axis at the point of maximum solar movement (as per Equation 2.1 and Figure 2.14), otherwise the tracker may lag the sun at certain stages.

The remaining discussion will now focus features of gear drives and transmission systems typically used in solar tracking applications.

2.6.2 Sun Tracking: Linear Drives

Linear drives can provide the necessary mechanical movement and torque to enable real-time solar tracking and for the controller to accurately follow the sun as it moves in it's trajectory across the sky.

Some linear actuators integrate a motor drive with a screw, gearbox, control board, position sensor, limit switches, in a lubricant dust sealed housing. This makes these drives a popular choice of drive in photovoltaic solar tracking systems. Linear drives are often of the ball screw jack type. These drives inherently offer large transfer rations with limited backlash. Large transfer ratios in turn ensure movement control at lower levels of current consumption.

An important practical consideration in using linear drives in solar automation or tracking applications is the relevant industry specification (Bisenius, 2012). The Since the linear actuators are used in severe external conditions, and will be exposed to direct sunlight and rain, the industry specification should at least consider IP65 or better.

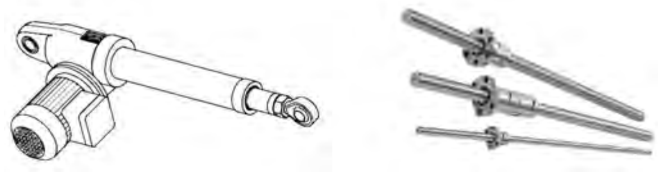


Figure 2.16 Linear drive mechanism used as Elevation drive in some solar tracking applications.

In Figure 2.16, there is shown a typical linear drive (or linear actuator if connected to a drive) used in sun tracking applications. Linear drives are commonly used in PV type systems where optimum energy conversion is achieved during low solar angles with linear sun tracking mechanisms. Push rod type design made to swivel the panels around an axis, such as the polar axis.

In polar tracking systems, a linear drive mechanisms can be used to accomplish rotational tracking about the polar axis, as illustrated in the mechanism of Figure 2.10. In XY dual axis solar tracking systems, the linear drive is typically used in elevation angle control. A rotational drive is preferred for azimuth angle control in XY tracking, although a linear drive can also be used but this limits the angle of movement due to the mechanical limitations around a linear steering mechanism.

2.6.3 Sun Tracking: Rotational Drives

Various lines of modular gearbox systems are available for solar tracking movement control. This includes rotational type actuators, such as screw drives, worms drives, slew drives, spur gear drives, hypoid drives, helical gear drives, bevel gear drives and cycloidal drives.

We can now discuss the features, benefits and disadvantages of the various transmission, actuator or gearbox components used in solar tracking applications. This section describes some of the most prominent drives available for use in real-time solar tracking applications as well as their advantages and disadvantages in consideration of a self tracking solar reflector system.

Compound gear systems ensures multiplicative gear reduction through trains of two or more gears or gear drives connected in series. With multiple gears, the overall gear ratio for gear trains are obtained by multiplying the individual gear reduction ratios. Torque is proportional to the gear ratio and gives a measure of the twisting force which acts on shafts, axles, or gears.

The single worm slew drive (Figure 2.17) is used in many solar tracking applications. This slew drive inherently provides a self-locking solution to solar tracking and is presented by manufacturers as a drive with low backlash.

Dual worm slew gear mechanisms as shown in Figure 2.18 are typically used in renewable energy systems since the dual gear mechanisms allows for interlocking of the main gear through the two side gears. Once the main king gear had been turned to reach the desired position, interlocking of this main king gear is achieved through a slight turn of both the two worm gears in the same direction (forcing the king gear to become locked in the claws of the two secondary worm gears)(IMO (Ingo Müller Oberflächentechnik), 2013).

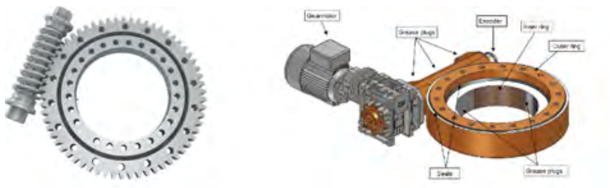


Figure 2.17 Single worm slew gear mechanism used as azimuth or elevation drive in some solar tracking applications (Fang, 2013*a*).

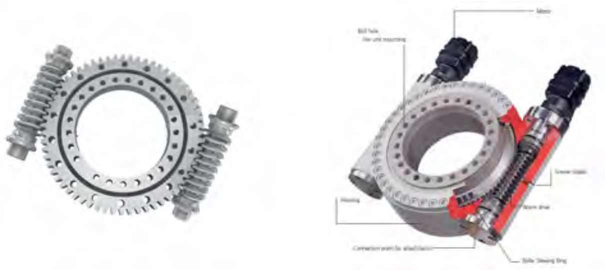


Figure 2.18 Dual worm interlocking slew gear mechanism used for load distribution and angle locking in some solar tracking applications.

Integrated dual axis gear drive mechanisms like those manufactured by Siemens/Nord (2013) (Figure 2.19) are typically used in renewable energy systems. These dual axis drives combine the azimuth and elevation movement in one gearbox, using two slewing drive mechanisms in one housing (Siemens, 2013*a*). For such combined dual axis drive systems to function efficiently, the structure should be balanced and light enough not to cause excessive wear or breakages in the combined drive system. In the McDonnell Douglas design (Figure 2.3) (Dietrich *et al.*, 1986), this problem was overcome by moving the elevation pivot point to the front of the optical reflector (reflector towards the back of the support pole), so that the weight of the dish structure and solar receiver could be balanced over the gearbox on top of the support pedestal.

Figure 2.19 Integrated dual axis drives supplied by Siemens/Nord (Siemens, 2013*a*).

Worm drives (Figure 2.20) have been used in solar tracking applications in an attempt to solve the contact problem experienced by slew drives. However, practical experience again proved that although these worm gears provide acceptable gear-ratios, the gear mechanisms still experience excessive wear when used in gusty wind conditions (Lopez and Stone, 1993*b*). Limited load transfer can result in positional inaccuracies due to external influences such as wind. If the worm or king gear in this assembly is worn, wind gusts cause deviations as a result of the play on the gears, which can have an impact on the real-time solar tracking accuracy.

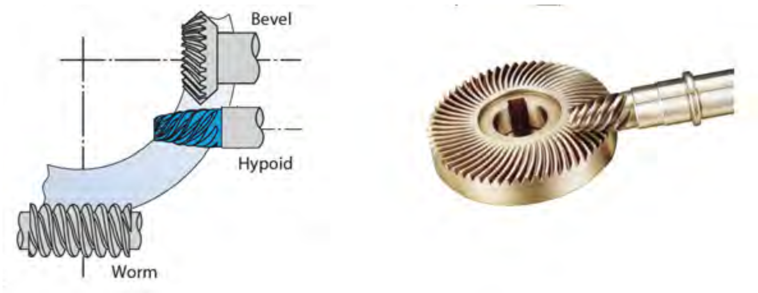


Figure 2.20 Worm hypoid or bevel drives (Lopez and Stone, 1993*b*).

In order to overcome this problem, some solar concentrator manufacturers reverted to planetary gear systems where the contact is shared between three or more planet gears (Lopez and Stone, 1993*b*). A planetary gear system may consist of one or more outer gears, or planet gears, revolving around a central sun gear (Figure 2.21).

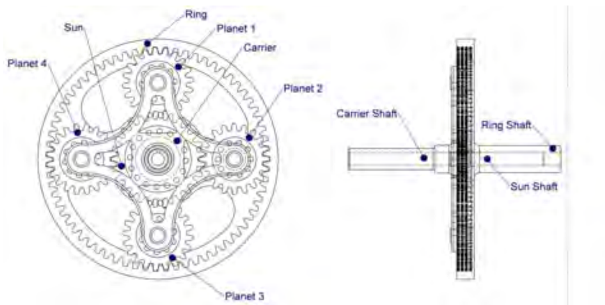


Figure 2.21 Planetary gear consisting of one or more outer gears, revolving around a central sun gear (Lopez and Stone, 1993*b*).

Winsmith Planocentric drives (Figure 2.22) are commonly used in solar tracking applications (Lopez and Stone, 1993*b*). One of the major advantages of the planetary gearbox arrangement in this application is the distribution of the load over a broader section of the ring gear on the circumference. The more evenly distribution of the load and increased rotational stiffness in the planetary gearbox system ensure greater stability than slew drives, and ensure better transmission efficiency within a compact housing space. The transmission load is more evenly shared between multiple gears in the planetary system, which ensures increased torque capability, greater load ability and higher torque density.

Another line of compact speed reducing gear motors with even better load distribution over the main gear section is the Cyclo gear drive (Figure 2.23). The design is fundamentally different from a planetary gear system and provides significantly better shock load absorption features, which makes this type of drive attractive for application in systems where robustness is required in terms of wind loading (Lopez and Stone, 1993*b*).

The cyclo drive design includes only four components, namely a high speed input drive shaft, with an eccentric cam, a multi-lobed shaped cycloid disc, and a stationary ring gear fitted with roller pins on its inner circumference (Lopez and Stone, 1993*b*). This gear drive

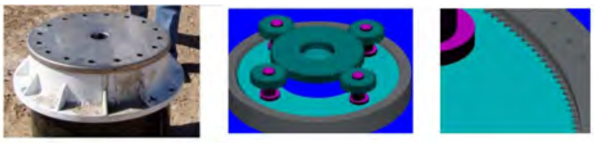


Figure 2.22 Winsmith planocentric drive commonly used in solar tracking applications (Lopez and Stone, 1993*b*).

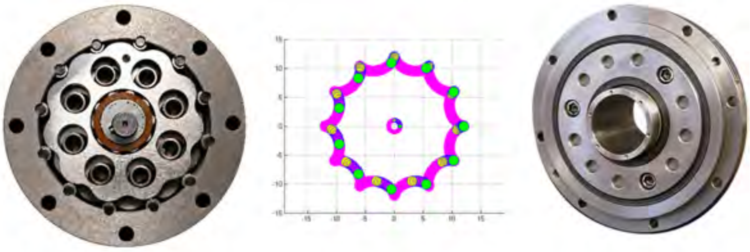


Figure 2.23 Cycloid drive operates by the principle of an eccentric cam driving a multi-lobed disc (Lopez and Stone, 1993*b*).

transfers the rotating motion from the high speed shaft to a slow speed shaft through a multi-lobed cycloid disc. The disc is at the heart of the cycloid design as it is shaped to be smaller in diameter and with fewer lopes/teeth and a smaller diameter than the outer ring gear. An eccentric cam integrated onto the input shaft offsets the cycloid disc with reference to the centre of the rotating axis. The eccentric motion of the cam causes the lobed disc to rotate through the inner circumference of the outer ring gear housing, enabling a reduction of speed of the cycloid disc. During operation, the outer wheel turns slowly on its own axis in the opposite direction to that of the cycloid disc rotation.

In solar tracking applications, one benefit of the cyclo drive would be that is does not shear easily, as the load contact is shared over a larger angle span. In planetary or spur gearboxes, only a small section of gear teeth absorbs the entire shock load when subjected to for example wind gusts, leaving the potential for possible gear teeth breakage. When the cycloid drive is under load compression, more than two-thirds (66%) of the cycloidal disc lobes and ring gear rollers share the contact/shock. It can withstand intermittent shock loads of up to 5 times the torque rating of the drive (Lopez and Stone, 1993*b*).

Section 24.11 in this book lists a number of sources fro solar tracker actuator and gearbox drives such as the products in a few of the links listed below:

http://www.expo21xx.com/renewable_energy/14615_st2_wind_turbine_gear/default. htm

http://www.kinematicsmfg.com/products/le-locking-drive/
http://www.kinematicsmfg.com/products/sde-dual-axis-positioner/
http://hengtai-reducer.en.made-in-china.com/product/fKimNPsrXuce/
China-Cycloial-Robot-Precision-Gearbox-Nabtesco-html

This concludes the discussion on the choice of suitable drives and transmission system components for a solar power generation system. In the next section, the design of the integrated slew drive solar tracking platform concept will be discussed.

2.7 Integrated Slewing Drive Solution

An attractive solar tracking gear drive design is to use a single or dual-axis slewing drive system, shown in the center bottom position in Figure 2.13. In a slewing drive actuator system, azimuth and elevation axis tilt and rotating movements can be accomplished with slew drive actuators fitted on the pinnacle of the pedestal (Figure 2.24).

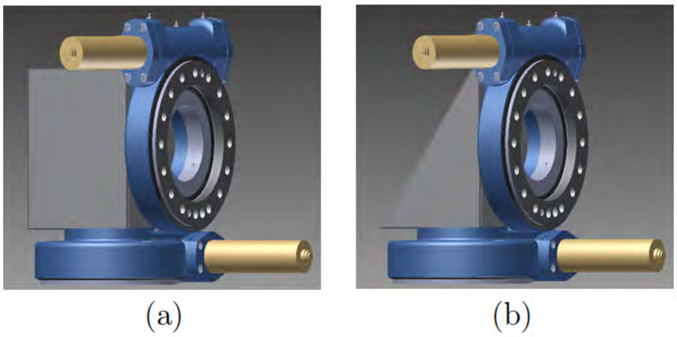


Figure 2.24 CAD drawings of the proposed perpendicular dual-axis slew drive connecting box assembly in (a) rectangular and (b) triangular configuration (Prinsloo, 2014*b*).

A slewing drive consists of a slewing bearing, a worm gear or spur gear, housing and a hydraulic or an electric motor. Such flexible slew drive means integrates a worm gear driven type means into a spur gear driven means, a combination commonly used for vehicle and crane steering systems, lift systems for booms and basket rotation, light crane systems, rotation of attachments such as excavators and fork lifts, handling equipment (automation systems), loading and unloading devices, positioning systems and turntables.

The gear ratio for slew drives (or slewing drive) is typically in the range of (50-60):1, and a variety of torque levels is commercially available. The gear ratio of a slew drive can be increased significantly by connecting a small planetary gear drive in series with the DC drive motor. With such planetary gear drives typically ensuring gear ratios in the range of (250-600):1, the compounded gear ratio of the combination would be able to deliver a gear ratio of at least 12500:1, a ratio desirable for low speed solar tracking. Sealed DC motor driven planetary slew drive actuation systems typically ensure high gear-ratio actuation in integrated self-locking and low backlash features.

When considering potential solutions towards ensuring an integrated design configuration that would accomplish dual-axis solar tracking with two individual slew drive mechanisms, an attractive concept is to integrate individual slew drives for dual axis motion control through metallic brackets or boxing. One such option would be to use the side-mounted connecting box solution. In this solution, the azimuth and elevation axis slew drive mechanisms are perpendicularly linked using a connecting box. The connecting box can be either square or triangular (Figure 2.24). This integration configuration presents an elegant but robust and simple dual-axis solution suitable for rural solar tracking applications and was chosen as solution in the present design.

In order to select a suitable slew drive system, the specifications of various systems can be considered (Prinsloo, 2014*b*). H-Fang New Energy Equipment Company (Fang, 2013*a*) supplies slewing drive mechanisms for a variety of solar tracking specifications. Many of these slew drives include an integrated DC motor, which motors can be selected on the basis of axial/radial load and torque specifications and so forth. The benefit of a permanent magnet brush-less DC motor with planetary gear reducer is that is yields ger radios around 234:1, which is suitable for solar tracking applications (see calculations (Prinsloo, 2014*b*)). DC motor performance curves are typically available and helpful in selecting an appropriate model and gear drive ratio, as well as to ensure that the DC motor is driven at optimum torque and speed efficiencies.

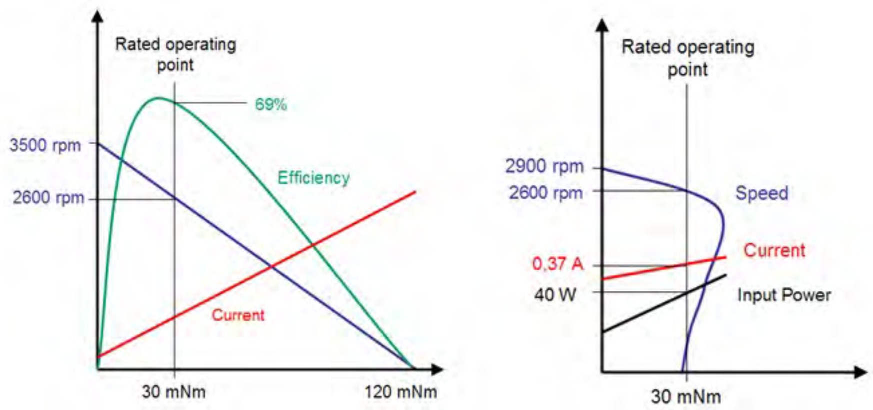


Figure 2.25 Example of motor performance curves and optimal operation points for a brush-less DC motor (Johnson Electric, 2014).

Actuator slew drives provide an attractive solution for solar tracking applications. It has power efficient permanent magnet DC motors and due to its high gear ratios, it can be driven at a very low speed (Yedamale, 2003). In a stand-alone CSP solar power system, solar tracking functionality would often be dependent on battery power. DC motors usually have linear speed current voltage relationships making it easier to predict power requirements when motor speeds must vary. DC motor driven slew drive actuators thus offer a better solution as these motors are typically more power efficient at lower speeds, when they produce higher torque (Yedamale, 2003).

DC motor drives further alleviates the problem of power losses due to DC/AC converter inefficiencies. By further driving the slew drive actuators (offering slew/planetary gear ratios around 12500:1) through power electronics and control techniques, such as pulse width modulation, the proposed slew actuation solution should provide a power efficient solution with the low rotational speeds required for solar tracking. The preferred design choice, in terms of mobility for the mechatronic platform for the solar concentrator system, is therefore on dual slew drive actuators in tandem with DC motor driven planetary gearboxes.

Compared to AC drives, which require expensive frequency speed control and AC inverters for battery operated systems, DC motor driven gear-drive solutions are simple to implement and are thus preferable in smaller (3-12 kWh) solar tracking systems. Compound gear systems ensures multiplicative gear reduction through trains of two or more gears or gear drives connected in series. With multiple gears, the overall gear ratio for gear trains are obtained by multiplying the individual gear reduction ratios. Torque is proportional to the gear ratio and gives a measure of the twisting force which acts on shafts, axles, or gears.

Figure 2.26 illustrates an integrated design that includes conceptual phase of the optical/structural aspects of solar concentrator dish. The parabolic dish serves as load on the solar tracking platform. The first slew drive element to direct the motion of the concentrated solar power system is mounted on the main boom (Figure 2.26). It has a rotary output shaft aligned with the elevation pivotal axis and accordingly controls the solar concentrator up-and-down movement. The second slew drive element is mounted to the pedestal pole and has a rotary output shaft aligned with the azimuth pivotal action, accordingly controlling the solar concentrator left-right movement. Each slew drive element includes a DC electrical motor and a planetary gear unit to drive the main ring gear of the slew units.

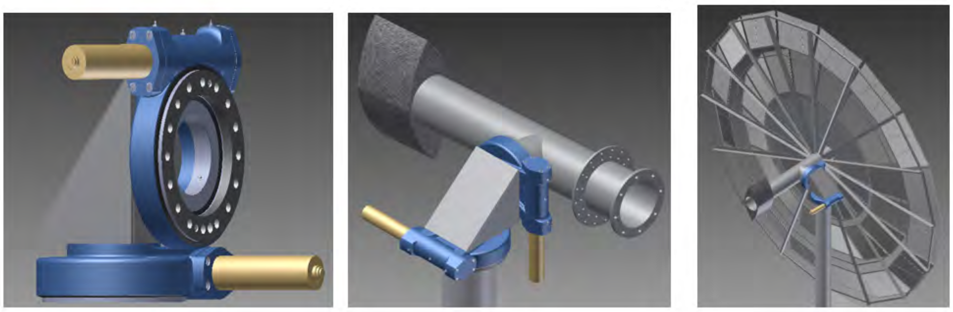


Figure 2.26 CAD drawings showing an example of an integrated solar tracking platform consisting of (a) dual-axis pivoting slewing actuator mechanism with DC motor drive assembly, (b) actuator system fitted to the pedestal, and (c) illustration of a solar concentrator dish with dual-axis actuator and pedestal system assembly (Prinsloo, 2014*b*).

As shown in Figure 2.26, two slew drive elements have been chosen as transmission mechanism for pivotally mounting the solar concentrator frame to the main cylindrical boom. The first slew drive element ensures pivotal motion about an elevation pivotal axis, while a second slew drive element ensures pivotal motion about the azimuth axis. This camera-crane type slew movement offers unique possibilities for solar concentrator movement and control.

The structure for supporting the solar concentrator and solar tracking platform is an essential element of the overall solar power generation system. Any deviation introduced by the support pedestal due to incorrect installation or mechanical moments due to high wind conditions will immediately introduce solar tracking accuracy errors and power generation efficiency degrading. Although wind-load and damage can be minimized by stowing the reflector dish in a horizontal configuration when wind speeds exceed a threshold value, such as $65\ km/h$, the pedestal remains a critical component in the concentrated solar platform design.

The next section described the principle of using information about the solar vector to manoeuvre the solar collector from any arbitrary angle so that it faces the sun directly.

2.8 Sun Tracker Models and Research Prototyping

Upcoming scientists and engineers sometimes experiment with desktop level systems before up-scaling to production scale solar tracking systems. There are many platforms and components available that can be used to play around with desktop type solar tracking platforms and applications.

Many supply stores for example sell a Pan/Tilt Servo Bracket with servo dual axis control motors, as seen in Figure 2.27. These models `https://www.sparkfun.com/products/10335` are light and small enough to purchase on mail order and will go a far way in helping the beginner get going and experimenting with some software on solar tracking.

Figure 2.27 Desktop model Pan/Tilt servo platform with servo dual axis control motors (SparkFun, 2014*b*).

There are also some tutorials with sample sketches for the Arduino processor with which one can experiment `https://www.sparkfun.com/tutorials/304`. Best to start is to connect a joystick to the pan and tilt solar tracking control platform and use the coordinates and pretend the coordinates are elements of a solar vector from a solar position algorithm.

Once this experiment is working, then one can use the Arduino sample sketches for the Helios algorithm to track the sun with the Pan/Tilt servo tracking platform. The source code for Helios are available for free download `http://wiki.happylab.at/w/Solar_Arduino_tracker`. One of the chapters of this book (Section 5.1) also presents details on optical sensors such as light sensitive resistors, photo-transistors or miniature solar cells that can be used to drive a solar tracking platform.

If you want to develop your own control system, then it is possible to link the Arduino to Matlab and use an advanced solar tracking software on Matlab to control solar tracking `http://blog.arduino.cc/2010/09/20/arduino-and-matlab/`. Some source code software for Matlab is also available on this link `http://sts.ustrem.org/sCode.php` and a tutorial and introduction of MATLAB program for Solar Engineering Fundamentals by Fang is also very valuable (Fang, 2014).

A simpler option is to make use of a custom dual-axis antenna positioner system is illustrated in Figure 2.27 (WinRadio, 2014). Positioning and rotator systems are commonly used in antenna steering and is often accompanied by a ready made positioner controller (right in picture) that may be handy in solar tracking applications, as solar steering is related to satellite steering.

Automatic solar positioner tracker using antenna positioning system have the advantage that proprietary positioner devices usually include heavy-duty rotator construction with accurate azimuth and elevation control. These units typically include temperature and electrical limits with weather-proof protection for outdoor applications, while a programmer interface API SDK is often available to ensure software controlled positioning through for

Figure 2.28 Example of a ready made ARP-ELAZ-100 rotator and antennae positioner system (WinRadio, 2014).

example a PC USB or RS232 interface. The complete functional tracking system combined with rotator controller in Figure 2.27 is a versatile and robust system primarily developed for automated satellite tracking, but it may be useful in many other applications such as solar tracking (treating the moving sun as a slow moving star or satellite).

As an alternative to stepper motors, so-called micro spur drives are also quite flexible and includes an integrated planetary gearbox to reduce the motor speed, as shown on this link `http://www.precisionmicrodrives.com/dc-geared-motors`. This project page provides interesting background on components used in solar tracking `http://www.cerebralmeltdown.com/` by way of an Arduino processor `http://forum.arduino.cc/index.php?topic=22670.20;wap2` and `http://quixand.co.uk/?p=6`.

These resources may help to get the experiment going before up-scaling your project to bigger prototype solar tracker systems.

Figure 2.29 Gallery of motor solutions that may be used in desktop scale solar tracking experiments.

If the solar tracking system for your project is not too large, then there is a range of options available for a low budget solution. Figure 2.29 shows examples of a range of electrical motors and gear drive solutions commonly used around the average home or garage. These include motor of sufficient capacity such as a sliding gate/door motor, roll up garage door motor, automotive wiper motor, car electric window motor, electric screwdriver or even a common electric drill can be used to drive a solar tracking platform.

One sample project describes a sun tracker that uses an automatic window opener motor in a desktop solar tracking application `http://www.engedu2.net/v1/ES-E11.pdf`, while this link includes the source code for an Arduino based tracking system for optically tracking the sun or any light source `https://code.google.com/p/arduino-solar-tracking/downloads/list`. The latter system generates sufficient electrical energy to power the tracking system (Luke, 2014).

If the gear ratio of these motor devices is high enough, then the only circuit required is azimuth and elevation angle motor on/off control. This means that solar tracking can be accomplished by incrementally switching the electrical motors on and off for short period of time to follow the sun (sometimes referred to as bang-bang control). Section 8.3.2 of this book shows a solar tracking control concept for such a solar tracking control solution.

A relatively simple and basic solar tracking model is shown in Figure 2.30(left) (Energizar, 2014). The drawing illustrates the mechanical operation of the solar tracker design that allows tilting elevation and rotational azimuth movement for aligning the payload (i.e solar panels) with the sun (the symbols in the drawing are as follows: A.Sensors, B.Solar Panel. C.Gears for tilting movement, D.Tilt motor, E.Corona motion for azimuth, F.Azimuth Motor) (see also (FEiNA, 2014)(Sanchez, 2012)).

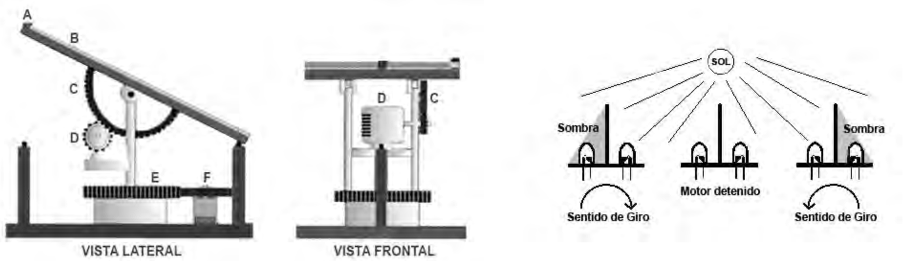


Figure 2.30 Mechanical operation of a solar tracker system driven by optical sensors (Energizar, 2014).

This solar tracker system in Figure 2.30 can operate in closed-loop mode under guidance from four photoreceptor sensors (two for each axis of motion), or alternatively in the open-loop mode using astronomically based sun position calculations. In the open-loop control mode, the microprocessor controls solar tracking using solar vectors computed with a solar position algorithm (more information in Section 3.2). In the closed-loop control mode, the optical sensors in Figure 2.30(right) capture solar radiation to determine the orientation of the sun tracker (more information in Section 5.1). The intensity of solar radiation collected by the sensors is fed to an electronic control system that determines if the tracker is positioned perpendicular to the sun. Any difference in intensity is translated into motor movements that regulate the position of the solar tracker. When the differential solar intensity captured by the solar sensors is zero, then the motors will stop (tracker positioned perpendicular with the sun) (Energizar, 2014).

Commercial solar tracker kits are available on the internet to help the reader get started with basic solar tracking experiments (see do-it-yourself kits in Section 24.6). The company Gears offer a solar tracking kit assembly wherein the Gears-IDS invention can be incorporated into the construction of a stand-alone desktop size solar tracking device (Gears, 2007). This kit, shown in Figure 2.31, provides opportunities for hands on engineering education and real world system integration of solar tracking challenges for engineering experiments and design projects could include medium scale photovoltaic panels, water heaters, or solar ovens.

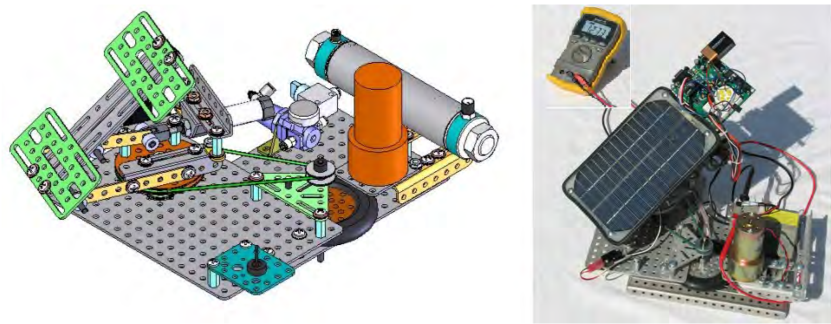


Figure 2.31 Gears solar tracking platform assembly with instructions and C source program based control system (Gears, 2007).

This Gears solar tracking kit assembly (like a lego kit or meccano kit) is available with instructions and source code on this link `http://www.gearseds.com/files/solar_tracker_const_guide_rev4_all3units.pdf` (Gears, 2007). The solar tracker is controlled using a Parallax Basic Stamp and Board of Education, while the structural components are made of aluminium and machined parts to allow the solar tracker to be fitted with a variety of solar energy harvesting devices.

The photovoltaic panel tracker model and kit in Figure 2.32 shows a model as well as mechanical implementation of a tracking concept that includes a large diameter vertical gear to accomplish sun tracking on one axis (FEiNA, 2014)(Sanchez, 2012). The large diameter gear provides a sufficiently large gear ratio to ensure that solar tracking can be performed with a smaller motor. Dual axis tracking can be ensured by including a rotational drive on the horizontal axis to ensure azimuth rotation.

More advanced pre-programmed solar tracker kits are also for sale. Figure 2.33 shows the SunTracking Prototype-Kit, an example of a commercial pre-programmed kit to test sun tracking in a prototype solar tracker application (SunTracking, 2014).

Section 24.3 shows more links to solar tracker kits, like the desktop size solar tracker system in Figure 2.31. The Gears kit incorporates a friction drive coupled to a motor with a belt and pulley to drive to track the azimuth (east to west) motion of the sun. In this way, the tracker offers a dual position pneumatic actuator to optimize the altitude position of the collector surface through a motor speed reduction drive and a pneumatic actuator that is controlled by a microprocessor (with sample solar tracking code included).

2.9 Summary

The dual axis tracking capability is extremely important in solar harvesting applications since the solar concentrator needs to track the sun in a three-dimensional space, using both

Figure 2.32 Solar tracker actuator includes a large diameter vertical gear concept (FEiNA, 2014)(Sanchez, 2012).

Figure 2.33 The SunTracking Prototype-Kit, example of a basic pre-programmed kit to test sun tracking in a prototype solar tracker application (SunTracking, 2014).

an azimuth and elevation drives to dynamically focus the sunlight directly onto the focal point of the reflector where the power conversion unit is mechanically suspended. The primary task of the solar tracking platform solution is to ensure that the thermal/optical focus is maintained. In this chapter, the mechanical aspects of a solar tracking platform design was described. In the next chapter, aspects associated with the calculation of the solar vectors for the manoeuvring of the solar tracking platform will be detailed.

PART II

DETERMINING SUN ANGLE AND TRACKER ORIENTATION

CHAPTER 3

SOLAR POSITION ALGORITHMS AND PROGRAMS

3.1 Introduction

Any reliable solar tracking system must be able to track the sun at the right angle, even during periods of cloud cover. Various types of sun-tracking designs had been proposed to enhance the solar energy harnessing performance of solar harvesting systems.

Closed-loop sun-tracking systems typically produces better tracking accuracy, and will be discussed in the next chapter under optical tracking systems. In this chapter, the discussion will focus on open-loop solar tracking systems where the sun vector is calculated from astronomical algorithms.

3.2 Broad Overview of Sun Position Algorithms

In general, closed-loop sun tracking systems will lose its feedback signal and subsequently its track to the sun position when the sensor is shaded or when the sun is blocked by clouds. Open-loop sun tracking architectures was thus introduced to use open-loop sensors or algorithms that do not require any solar image as feedback. The open-loop sensor such as encoder will ensure that the solar collector is positioned at calculated solar angles, which are obtained from a special formula or algorithm.

Chong *et.al* (Chong *et al.*, 2014) presented an interesting overview of solar tracking systems and sun tracking approaches, showing that the azimuth and elevation angles of the sun vector can be determined by the sun position formula or algorithm at the given date, time and geographical information (Blanco-Muriel *et al.*, 2001), (Grena, 2008), (Meeus, 1991), (Reda and Andreas, 2008*b*) (Sproul, 2007)(Chong *et al.*, 2014)(Shanmugam and Christraj, 2005). Such tracking approaches may achieve tracking accuracies of around 0.2° provided that the mechanical structure is precise and the alignment is perfectly done. Generally, these algorithms are integrated into microprocessor software algorithms due to their computational complexity.

We would recommend the reader to visit the ITACA site (ITACA, 2014), as it provides a very simple background explanation about the formulas for the software code described in this chapter. The site includes a description of Sun As A Source Of Energy and include sections on Solar Astronomy `http://www.itacanet.org/the-sun-as-a-source-of-energy/part-1-solar-astronomy/`, Solar Energy Reaching The Earths Surface, Calculating Solar Angles through the simple formulas detailed on this page `http://www.itacanet.org/the-sun-as-a-source-of-energy/part-4-irradiation-calculations/` and solar Irradiation level calculations through the formulas detailed on this page `http://www.itacanet.org/the-sun-as-a-source-of-energy/part-3-calculating-solar-angles/` (ITACA, 2014). The main aim of this site is to provide technical resources and information on appropriate technology in areas of drinking water supply, sanitation, electrical supply, construction, fuel-efficient cooking stoves and environmental education.

3.3 Determining the Position of the Sun

In this particular book, the focus is solar tracking algorithms an various open source code and solar astronomical algorithms and software dedicated to solar tracking.

Improving the performance of solar collectors to capture of solar radiation and to convert it to useful form of energy depends strongly on the understanding of radiation properties. The required degree of solar tracking accuracy may depend on the specific characteristics of the solar power system concentrating system, but in general a higher tracking accuracy will result in a higher level of output power (Blanco-Muriel *et al.*, 2001). To re-establish our framework of mind, Figure 3.1 shows and example sun path and contour computed with procedures in this chapter for a solar tracker in Aucland. It shows the solar tracking azimuth and elevation/zenith angles with analemma speed variations over 12 month period (CBPR, 2014).

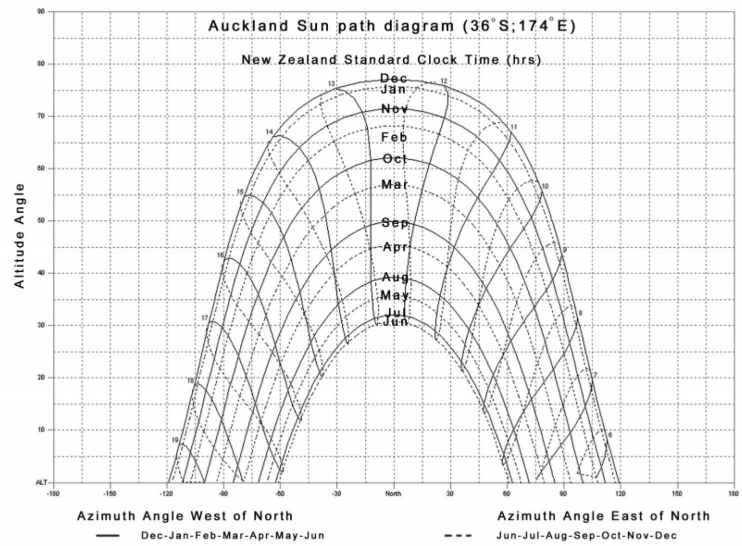


Figure 3.1 Sun path and contour computed for a solar tracker in Aucland, showing solar tracking azimuth and elevation/zenith angles with analemma speed variations over 12 month period (CBPR, 2014).

This section is going to represent the importance of solar phenomena, atmospheric and location effect, calculation of sun positions and components of solar radiation on different tilted surfaces. It will include also some definitions, figures and equations that thought to be essential for solar tracking. It has been noticed that references use different symbols and terms for solar radiation and angles, therefore this section is going to characterize that.

Since accuracy and stability are two of the primary design parameters for a CSP solar tracking system, various control strategy options have been proposed, tested and reported on in the general literature. These include open-loop control systems, closed-loop control systems and in some cases an integrated or hybrid-loop control system where open-loop and closed-loop control configurations are combined.

There are four main categories of control elements that will need to be considered in open-loop and closed-loop controllers in order to meet the design criteria for this study. These include:

1. Position of the sun: To determine the sun vector $S_Q(\gamma_s, \theta_s)$ from the location of the CSP system;

2. Effective drive system: To be able to move the structure efficiently so that it points directly towards the sun;

3. Control inputs: Type of control inputs to use, e.g. sun vector algorithm, photo-diodes or camera;

4. Control system: Control sequence and intelligence (state diagrams) to manage the electric motors and drives that move the payload or Stirling power system.

Since the solar tracker will be used to enable the optical components in the CSP systems, tracking accuracy and mechanical stability will be two of the main elements.

The current trend in modern industrial programmable logic controlled (PLC) solar concentrator and tracking systems is to use open-loop controllers, sometimes also referred to as passive controllers. These controllers use solar positioning algorithms, such as the one provided by NREL, to direct the motion of the solar concentrator system. Closed-loop controllers (or active controllers) reach optimal tracking precision by using light sensitive electronics to enable the controller to observe the movement of the sun and for the concentrator system to be dynamically positioned towards the sun. More complex alternatives involve camera-based solutions, but these are less popular in PLC based controller solutions due to the electronic sensitivity and the processing power requirements for image processing.

3.4 Open Loop Sun Tracking

In a solar reflector system, the Sun needs to be tracked with great accuracy since the energy collected by the optical receiver and transferred to the power conversion unit is proportional to the accuracy of the tracker controller mechanism. This is especially true for concentrated solar thermal systems where two-axis or dual/bi-axis movement control is required in pointing the reflector directly at the centroid of the Solar disk.

Therefore, the Solar-Vector or position of the Sun from a specific geographic location are determined in real-time for the solar tracker to accomplish efficient Sun tracking. The sun vector $S_Q(\gamma_s, \theta_s)$ describes the sun's angle and elevation from the perspective of a specific Global Positioning System (GPS) orientation on the earth (Reda and Andreas, 2008*a*).

This section will discuss the three astronomically based methods or algorithms used in implementing Sun-tracking on a micro-controller system. These three methods will eventually be tested and compared. Artificial Intelligence or Fuzzy Control mechanisms, in which two or even all three of these methods can work together with other controller inputs, may also be considered to achieve a very accurate tracking system with very low parasitic losses.

3.5 Sun Vector Calculation

The Sun-vector or Solar position is described in terms of the Sun's apparent Azimuth and Elevation angles with respect to an observer at a spesific geographic location Q on the surface of the earth, as a function of local hour and season.

It was noted before that NREL developed one of the most accurate algorithms for computing the Sun-vector using an astronomical approach (Reda and Andreas, 2008*b*). This algorithm is known as the NREL Solar Position Algorithm (SPA) and calculates the position of the Sun with an uncertainty of $\pm 0.0003,^\circ$ at vertex, compensating for cosmic changes (including the leap second) from the year 2000 till the year 6000.

Comparative algorithms such as the Grena and PSA algorithms (Grena, 2008) are less accurate or may deviate in terms of accuracy over time, but needs to be discussed due to the processing speed benefits and integration simplicity these algorithms offer.

Various fast solar position algorithms exist with the most accurate algorithms being that of Grena (Grena, 2008) Blanco&Murial from the La Plataforma Solar de Almeria (PSA)(Blanco-Muriel *et al.*, 2001). The algorithm proposed by Meeus in 1988 is accurate by approximately 0.0003 degrees deviation (Meeus, 1991) but requires significant processing power and time.

The Meeus algorithm is therefore not classified as a ”fast algorithm” since it is much more complex and requires longer computational times than that of the fast algorithms. Another well known fast algorithm is the Duffie and Beckman algorithm which, like the Grena and PSA algorithms, can be easily implemented on a PLC (Duffie and Beckman, 2006).

Feedback sensors such as signals from photo-diodes, photo-transistors, light dependant resistors, sun sensors or processed camera images or are some solutions which may be considered to ensure that the instantaneous errors in the azimuth and elevation angles are used to correct the angle values calculated from the SPA algorithm. Such feedback mechanisms and their implementation in various solar tracking solutions will be discussed in the next section.

3.6 Solar Position Algorithm (SPA)

Figure 3.2 shows a typical illustration of a sun-vector and sun-angles to consider when a solar concentrator tracks the sun using any the digital electronic Siemens PLC hardware in conjunction with the SPA algorithm.

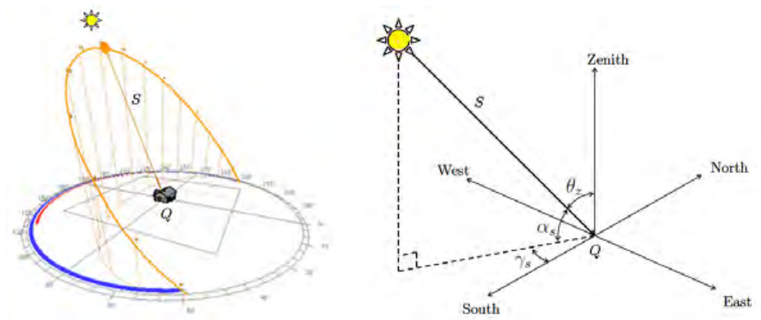


Figure 3.2 Observer at location Q illuminated by sun ray observed along sun vector S_Q, showing solar tracking azimuth and elevation/zenith angles.

A solar position algorithm (SPA) implementation determines the position of the sun at any given time for a specific location. The calculations presented herein are based on the SPA of National Renewable Energy Laboratory (NREL) and is classified as an astronomical algorithm because of the high degree of accuracy. The earth angles described below are the angles required to determine the position of the sun with respect to a plane of any particular orientation (Reda and Andreas, 2008*b*). The following list of parameters relates to the terms used in the calculation of the sun-vector given in Figure 3.2:

- Latitude(ϕ): The angle north or south of the equator of the solar collector (measured in degrees);
- Longitude(ζ): The east-west position of the solar collector relative to the Greenwich (measured in degrees);
- Declination(δ_s): The angular position of the sun at solar noon with respect to the equator (measured in degrees);
- Surface azimuth angle(γ): Deviation of the direction of the slope to the local meridian (degrees);
- Solar azimuth angle(γ_s): Angle of the sun to local meridian or surface azimuth, clockwise from the south (degrees);
- Elevation angle(α_s): Solar-vector elevation from observer (degrees);
- Zenith angle(θ_z): Angle of incidence on a horizontal surface, solar-vector zenith ($90° - \alpha_s$) (degrees);
- Angle of incidence and reflection(θ): Angle between incident solar radiation and surface, solar-vector elevation (degrees);
- Hour angle based on the solar time(ω): Conversion of solar time to an angle where 24 hours = 360° and solar noon is zero.

The sun vector then represents the sun angle and elevation from the perspective of a specific Global Positioning System (GPS) orientation on the earth (Reda and Andreas, 2008*b*). Depending on the longitude (ζ) and latitude (ϕ) position of the solar concentrator installation site on the surface of the earth, the PLC uses Equation 3.1 to Equation 3.6 to calculate the solar vector $S_Q(\gamma_s, \theta_s)$ through astronomical principles (Siemens, 2011*a*).

$$Solartime = Standardtime + 4 \times (\zeta_{st} - \zeta_{loc}) + E \tag{3.1}$$

$$E = 229.2(0.000075 + 0.001868 \times cosB - 0.04089 \times sin2B) \tag{3.2}$$

$$B = \frac{360}{365} \times (n - 1) \tag{3.3}$$

$$\delta = 23.45 \times sin\left(\frac{360}{365} \times (284 + n)\right) \tag{3.4}$$

$$\cos\theta_z = (cos\phi \times cos\delta_s \times cos\omega) + (sin\phi \times sin\delta_s) \tag{3.5}$$

$$\gamma_s = sign(\omega) \times \left|cos^{-1}\left(\frac{cos\theta_z \times sin\phi - sin\delta_s}{sin\theta_z \times cos\phi}\right)\right| \tag{3.6}$$

The solar vector $S_Q(\gamma_s, \theta_s)$ computed through Equation 3.1 to Equation 3.6 describes the azimuth angle (γ_s) for the horizontal alignment and zenith/elevation (θ_s, α_s) for the vertical alignment of the solar concentrator at location Q to pin-point at the sun at any given time of the day.

The detailed NOAA Solar Calculator formulas to determine the Sunrise, Sunset, Solar Noon and Solar Position for any Place on Earth is given on this page `http://www.esrl.noaa.gov/gmd/grad/solcalc/solareqns.PDF` (NOAA, 2014). A less complicated explanation is given on this page `http://www.itacanet.org/the-sun-as-a-source-of-energy/part-3-calculating-solar-angles/` (ITACA, 2014).

3.7 PSA Algorithm Files for SPA

http://www.psa.es/sdg/sunpos.htm

```
// SunPos.h
// This file is available in electronic form at http://www.psa.es/sdg/sunpos.htm

#ifndef __SUNPOS_H
#define __SUNPOS_H

// Declaration of some constants
#define pi    3.14159265358979323846
#define twopi (2*pi)
#define rad   (pi/180)
#define dEarthMeanRadius     6371.01    // In km
#define dAstronomicalUnit    149597890  // In km

struct cTime
{
        int iYear;
        int iMonth;
        int iDay;
        double dHours;
        double dMinutes;
        double dSeconds;
};

struct cLocation
{
        double dLongitude;
        double dLatitude;
};

struct cSunCoordinates
{
        double dZenithAngle;
        double dAzimuth;
};

void sunpos(cTime udtTime, cLocation udtLocation, cSunCoordinates *udtSunCoordinates);

#endif
 // SunPos.cpp
// This file is available in electronic form at http://www.psa.es/sdg/sunpos.htm

#include "sunpos.h"
#include

void sunpos(cTime udtTime,cLocation udtLocation, cSunCoordinates *udtSunCoordinates){

        // Main variables
        double dElapsedJulianDays;
        double dDecimalHours;
        double dEclipticLongitude;
        double dEclipticObliquity;
        double dRightAscension;
        double dDeclination;

        // Auxiliary variables
        double dY;
        double dX;
```

```
    // Calculate difference in days between the current Julian Day
    // and JD 2451545.0, which is noon 1 January 2000 Universal Time
    {
        double dJulianDate;
        long int liAux1;
        long int liAux2;
        // Calculate time of the day in UT decimal hours
        dDecimalHours = udtTime.dHours + (udtTime.dMinutes
                + udtTime.dSeconds / 60.0 ) / 60.0;
        // Calculate current Julian Day
        liAux1 =(udtTime.iMonth-14)/12;
        liAux2=(1461*(udtTime.iYear + 4800 + liAux1))/4 + (367*(udtTime.iMonth
                - 2-12*liAux1))/12- (3*((udtTime.iYear + 4900
        + liAux1)/100))/4+udtTime.iDay-32075;
        dJulianDate=(double)(liAux2)-0.5+dDecimalHours/24.0;
        // Calculate difference between current Julian Day and JD 2451545.0
        dElapsedJulianDays = dJulianDate-2451545.0;
    }

    // Calculate ecliptic coordinates (ecliptic longitude and obliquity of the
    // ecliptic in radians but without limiting the angle to be less than 2*Pi
    // (i.e., the result may be greater than 2*Pi)
    {
        double dMeanLongitude;
        double dMeanAnomaly;
        double dOmega;
        dOmega=2.1429-0.0010394594*dElapsedJulianDays;
        dMeanLongitude = 4.8950630+ 0.017202791698*dElapsedJulianDays; //Radians
        dMeanAnomaly = 6.2400600+ 0.0172019699*dElapsedJulianDays;
        dEclipticLongitude = dMeanLongitude + 0.03341607*sin( dMeanAnomaly )
              + 0.00034894*sin( 2*dMeanAnomaly )-0.0001134

                -0.0000203*sin(dOmega);
        dEclipticObliquity = 0.4090928 - 6.2140e-9*dElapsedJulianDays
              +0.0000396*cos(dOmega);
    }

    // Calculate celestial coordinates right ascension n declination in radians
    // but without limiting the angle to be less than 2*Pi (i.e., the result m
    ay be // greater than 2*Pi)
    {
        double dSin_EclipticLongitude;
        dSin_EclipticLongitude= sin( dEclipticLongitude );
        dY = cos( dEclipticObliquity ) * dSin_EclipticLongitude;
        dX = cos( dEclipticLongitude );
        dRightAscension = atan2( dY,dX );
        if( dRightAscension < 0.0 ) dRightAscension = dRightAscension + twopi;
        dDeclination = asin( sin( dEclipticObliquity )*dSin_EclipticLongitude );
    }

    // Calculate local coordinates ( azimuth and zenith angle ) in degrees {

            double dGreenwichMeanSiderealTime;
            double dLocalMeanSiderealTime;
            double dLatitudeInRadians;
            double dHourAngle;
            double dCos_Latitude;
            double dSin_Latitude;
            double dCos_HourAngle;
            double dParallax;
            dGreenwichMeanSiderealTime = 6.6974243242 +
```

```
                0.0657098283*dElapsedJulianDays
                + dDecimalHours;
        dLocalMeanSiderealTime = (dGreenwichMeanSiderealTime*15
                + udtLocation.dLongitude)*rad;
        dHourAngle = dLocalMeanSiderealTime - dRightAscension;
        dLatitudeInRadians = udtLocation.dLatitude*rad;
        dCos_Latitude = cos( dLatitudeInRadians );
        dSin_Latitude = sin( dLatitudeInRadians );
        dCos_HourAngle= cos( dHourAngle );
        udtSunCoordinates->dZenithAngle =(acos( dCos_Latitude*dCos_HourAngle
                *cos(dDeclination) + sin( dDeclination )*dSin_Latitude));
        dY = -sin( dHourAngle );
        dX = tan( dDeclination )*dCos_Latitude-dSin_Latitude*dCos_HourAngle;
        udtSunCoordinates->dAzimuth = atan2( dY, dX );
        if ( udtSunCoordinates->dAzimuth < 0.0 )

        udtSunCoordinates->dAzimuth = udtSunCoordinates->dAzimuth + twopi;
        udtSunCoordinates->dAzimuth = udtSunCoordinates->dAzimuth/rad;
        // Parallax Correction
        dParallax=(dEarthMeanRadius/dAstronomicalUnit)

                *sin(udtSunCoordinates->dZenithAngle);
        udtSunCoordinates->dZenithAngle=(udtSunCoordinates->dZenithAngle
                + dParallax)/rad;
    }
}

}
```

3.8 Helios Code SPA

```

//sunposSPA.
typedef struct {
  double  El ;                       // variable to store the SPA
  algorithm calculated Elevation position of the sun
  double  Az ;                       // variable to store the SPA
  algorithm calculated Azimuth position of the sun
  boolean night;                     // default night indicator;
} spaType;
spaType sunposSPA ={0,0, false};     // initiate sunpos_SPA values

void sunvector_SPA()                          // simulation for now
{
SPA.calcSunPos(year,month,monthDay,hour,minute,second,longitude,latitude);
sunposSPA.El = SPA.dElevation;
sunposSPA.Az = SPA.dAzimuth;

sunposSPA.night = false;
if (sunposSPA.El<=0) sunposSPA.night = true;
if (sunposSPA.El>89) elevation_180_Swop();
}
      // night sleep indicator
      // detecting date of 180 degree switch
}
```

3.9 C Code SPA

The NREL Solar Position Algorithm (SPA) is very popular amongst solar tracker developers and the C code is available for download from the NREL website `http://rredc.nrel.gov/solar/codesandalgorithms/spa/` (NREL, 2008).

How to use this algorithm and a description of the variables is included in the spa.h header file. Further information on this algorithm is available in the following NREL technical report:

```
Please register to download the SPA C source code.
```

3.10 SunCalc Java/C code by Vladimir Agafonkin

SunCalc is a tiny JavaScript library for calculating the position of the sun as well as the sunlight phases (times for sunrise, sunset, dusk, etc.) for any given time and location. Calculations are based on the formulas on the position of the sun and the planets and was created by Vladimir Agafonkin as a part of the SunCalc.net project (Agafonkin, 2014).

The source code is available on this link: `http://github.com/mourner/suncalc` and the sun path for particular locations can be viewed on these links: `http://iecosolar.co.za/sun-calculator` and this link in 3D view `http://10k.aneventapart.com/2/Uploads/660/`.

3.11 Matlab SPA

Fang presents an introduction of Matlab program for Solar Engineering Fundamentals on this link, which will help the reader with complex calculations of the solar position, a presentation that is very helpful `http://www.ecaa.ntu.edu.tw/weifang/Taisugar/gh-dss/pdf/solar0menu.pdf` (Fang, 2014).

The Solar Tracking Strategies project website of Petrov (Petrov, 2014) deliver a set of tools in the theoretical domain to analyse different solar tracking strategies. The project include advanced hybrid tracking principles using predictions of short-range cloud dynamics. The code for the solar position algorithm calculator for Matlab, PHP and C code can be downloaded from this link `http://sts.ustrem.org/sCode.php` (Solar Position Calculator on this link `http://sts.ustrem.org/spa.php`) (Petrov, 2014). The source includes code for stepper motor library for half and full stepping modes for unipolar stepper motors.

Details of a Matlab function (sun = sunposition(time, location)) that computes the sun position (zenith and azimuth angle at the GPS location of the tracker) as a function of the local time and GPS location `http://www.mathworks.com/matlabcentral/fileexchange/4605-sun-position-m`.

This function computes the sun position (zenith and azimuth angle at the observer location) as a function of the observer local time and position. It is an implementation of the algorithm presented by Reda and Andreas (Reda and Andreas, 2008*a*). The documentation is available at `http://rredc.nrel.gov/solar/codesandalgorithms/spa/` and is included in the .zip file

Input parameters: location time

Output parameters sun: a structure with the calculated sun position sun.zenith = zenith angle in degrees (angle from the vertical) sun.azimuth = azimuth angle in degrees, eastward from the north.

Only the sun zenith and azimuth angles are returned as output, but a lot of other parameters are calculated that could also be extracted as output of this function. See the documentation in the code.

```
  // VARIABLES  sun = sun_position(time, location)
   time: a structure that specify the time when the sun position calculated.
   time.year: year. Valid for [-2000, 6000]
   time.month: month [1-12]
   time.day: calendar day [1-31]
   time.hour: local hour [0-23]
   time.min: minute [0-59]
   time.sec: second [0-59]
   time.UTC: offset hour from UTC. Local time = Greenwich time + time.UTC
   This input can also be passed using the Matlab time format             HH:MM:SS').
   ('dd-mmm-yyyy
   In that case, the time has to be specified as UTC time (time.UTC = 0)
   location: a structure that specify the location of the observer
   location.latitude: latitude (in degrees, north of equator is positive)
   location.longitude: longitude (in degrees, positive for east of Greenwich)
   location.altitude: altitude above mean sea level (in meters)

   pROCEDURE
     sun: a structure with the calculated sun position
   sun.zenith = zenith angle in degrees (angle from the vertical)
   sun.azimuth = azimuth angle in degrees, eastward from the north.

  LOOP{
location.longitude = -105.1786;
location.latitude = 39.742476;
location.altitude = 1830.14;
time.year = 2003;
time.month = 10;
time.day = 17;
time.hour = 12;
time.min = 30;
time.sec = 30;
time.UTC = -7;}

sun = sun_position(time, location);

 sun =

      zenith: 50.1080438859849
      azimuth: 194.341174010338
}
```

This function computes the sun position (zenith and azimuth angle at the observer location) as a function of the observer local time and position.

It is an implementation of the algorithm presented by Reda et Andreas in: Reda, I., Andreas, A. (2003) Solar position algorithm for solar radiation application. National Renewable Energy Laboratory (NREL) Technical report NREL/TP-560-34302, Revised January 2008.

This document is avalaible at `http://rredc.nrel.gov/solar/codesandalgorithms/spa/` and is included in the .zip file

Input parameters:

Output parameters sun: a structure with the calculated sun position sun.zenith = zenith angle in degrees (angle from the vertical) sun.azimuth = azimuth angle in degrees, eastward from the north.

Only the sun zenith and azimuth angles are returned as output, but a lot of other parameters are calculated that could also be extracted as output of this function. See the documentation in the code.

```

  // VARIABLES  sun = sun_position(time, location)
   time: a structure that specify the time when the sun position calculated.
   time.year: year. Valid for [-2000, 6000]
   time.month: month [1-12]
   time.day: calendar day [1-31]
   time.hour: local hour [0-23]
   time.min: minute [0-59]
   time.sec: second [0-59]
   time.UTC: offset hour from UTC. Local time = Greenwich time + time.UTC
   This input can also be passed using the Matlab time format
   ('dd-mmm-yyyy HH:MM:SS'). In that case, the time has to be
   specified as UTC time (time.UTC = 0)

   location: a structure that specify the location of the observer
   location.latitude: latitude (in degrees, north of equator is positive)
   location.longitude: longitude (in degrees, positive for east of Greenwich)
   location.altitude: altitude above mean sea level (in meters)

   pROCEDURE
     sun: a structure with the calculated sun position
   sun.zenith = zenith angle in degrees (angle from the vertical)
   sun.azimuth = azimuth angle in degrees, eastward from the north.

  LOOP{
location.longitude = -105.1786;
location.latitude = 39.742476;
location.altitude = 1830.14;
time.year = 2003;
time.month = 10;
time.day = 17;
time.hour = 12;
time.min = 30;
time.sec = 30;
time.UTC = -7;}

sun = sun_position(time, location);

 sun =

      zenith: 50.1080438859849
      azimuth: 194.341174010338
}
```

3.12 SolPos

Solar Resource Information The Renewable Resource Data Center (RReDC) offers a collection of data and tools to assist with solar resource research. Learn more about RReDC's solar resource: `http://www.nrel.gov/rredc/solar_resource.html` `http://rredc.nrel.gov/solar/codesandalgorithms/solpos/`

3.13 Sun Position in C and C++

Sun Position in C# http://guideving.blogspot.nl/2010/08/sun-position-in-c.html

C# assembly for calculating Sunrise, Sunset, and Maximum Solar Radiation can be downloaded on this link http://www.codeproject.com/Articles/78486/Solar-Calculator-Calculate-Sunrise (Kalkman, 2011). The code is packed in a Visual Studio 2008 solution and contains the assemblies Astronomy and AstronomyTest, with the assembly Astronomy containing the SunCalculator class which performs the actual calculation of the sun position.

3.14 Solar Position in Visual Basic and VB.NET

Tanner developed VSOP87 Functions used to Compute Planetary Positions is listed on this page http://www.freevbcode.com/ShowCode.asp?ID=464 and the download code http://www.freevbcode.com/imagesvr_ce/184390/code/vsop87functions.zip. Tanner (Tanner, 2014) states "These functions are a VB version of the complete VSOP87 planetary theory designed to be used to in a program to compute the heliocentric ecliptic longitude, latitude and distance of the planets Mercury to Neptune over a period of several thousands of years to about 1 arcsecond of precision. They are intended for use by programmers desiring to make their own astronomical computations programs. These heliocentric computations are the first important step in that direction. They are not for the mathematically squeamish. These functions are NOT the amateur formulas seen in many popular astronomical computing books. They are the FULL VSOP87 series, some of which consist of well over 1100 terms. The series of terms may be truncated depending on the precision you require for your own computations.

GeoStars Library http://geostarslib.sourceforge.net (Nelson, 2011) is a geodetic library with functions for dealing with many geodesy-based problems found in positioning, pointing, and surveying situations. It is useful to determine absolute position on the earth, pointing vectors, coordinate transformations, and deg/min/sec conversions and has the following features: ANSI C code Sun position, Accurate Azimuth, Elevation, and Range calculation, Cartesian to Polar conversions, Multiple geocentric to geodetic coordinate conversions, 23 ellipsoid definitions (can be used worldwide), links with the Naval Observatory's Novas library for astronomic calculations and calculates the earth's magnetic declination of any location and time(2010-2015).

Solar Analysis Tool includes a Sun Class routine to compute instances of sun that represent the sun position given the inputs Date, Time, Longitude, Latitude and Altitude (above sea level) http://www.builditsolar.com/References/Source/SunClass/SunClass.htm (BuiltItSolar, 2014). The sun object will provide solar position and clear day solar radiation data when the time inputs to sun class are LOCAL SOLAR TIME. Calculations are based on Lunde's book Solar Thermal Engineering (Lunde, 1980).

To calculate the position of the sun (Elevation and Azimuth) from Latitude, Longitude, Year, Month, Day, Hour, Minutes . The problem is that I wasn't able to find a formula of a step of that in order to get the result! http://www.astronomyforum.net/astronomy-beginners-forum/130242-position-sun.html

Sun Position Calculator gives the Altitude and Azimuth angles of the sun at any time of the year, as well as giving the position in rectangular coordinates for use in positioning the sun in Lightwave. The program also creates a motion file that can be loaded into Lightwave to create animations involving the sun at a given location over a given period of time http://www.planet-source-code.com/vb/scripts/ShowCode.asp?txtCodeId=

10537&lngWId=1 and download code on this page http://www.planet-source-code.com/vb/scripts/ShowZip.asp?lngWId=1&lngCodeId=10537&strZipAccessCode=tp%2FC105377688 or http://www.planet-source-code.com/vb/scripts/ShowCode.asp?txtCodeId=10537&lngWId=1#zip (Mathiason, 2014).

Kalkman (Kalkman, 2011) provides a Solar Calculator to calculate Sunrise, Sunset, and Maximum Solar Radiation http://www.codeproject.com/Articles/78486/Solar-Calculator-Calculate-Sunrise-Sunset-and-Maxi.

Calculate Sun Position in Lat/Lon from Date/time in VB6 http://www.experts-exchange.com/Programming/Languages/CPP/Q_23501542.html?sfQueryTermInfo=1+10+posit+sun. According to this researcher the results are not too accurate http://mobile.experts-exchange.com/Programming/Languages/Visual_Basic/Q_24363977.html.

This sample demonstrates manipulation of the globe light sourceenabling and disabling the light source, moving it as a response to the mouse position, and changing the sun's ambient light and contrast http://resources.esri.com/help/9.3/arcgisengine/dotnet/77a7b41a-4133-4c5d-80bc-b8e3e26f2f95.htm. Open the solution file in Visual Studio and build the solution. Open ArcGlobe or a GlobeControl application (in design mode) and from the Customize dialog box, choose the .NET Samples category. From the command items pane, drag the Sun Position tool onto a toolbar and run the application and choose the tool. Click and drag the mouse to change the sun's position on the globe.

Tool implementation file used to manually set the sun's position on the globe http://help.arcgis.com/en/sdk/10.0/arcobjects_net/conceptualhelp/index.html#//00010000022m000000.

Code in C# on this page http://help.arcgis.com/en/sdk/10.0/arcobjects_net/conceptualhelp/0001/000100000932000000.htm and VB.NET http://help.arcgis.com/en/sdk/10.0/arcobjects_net/conceptualhelp/0001/000100000mtp000000.htm.

3.15 Python SPA

The community-developed, free and open-source solar data analysis environment for Python from where the beta version can be downloaded http://sunpy.org/ and the source code on this page https://github.com/sunpy/sunpy (SunPy, 2014). A video discussion on the code is also available on this link http://www.youtube.com/watch?v=bXPPTCkaVu8 (SunPy Python for Solar Physicists, SciPy 2013 Presentation).

Python code SUNRISET.C computes Sun rise/set times, start/end of twilight, and the length of the day at any date and latitude http://kortis.to/radix/python/code/Sun.py, the general page is on this link http://kortis.to/radix/python/.

Python utility for calculating sun position and pitch angle from Harvard University http://cxc.harvard.edu/mta/ASPECT/tool_doc/pydocs/Ska.Sun.html, which code was modified from http://idlastro.gsfc.nasa.gov/ftp/pro/astro/sunpos.pro.

3.16 Solar Position in Python

Pysolar Pysolar is a collection of Python libraries for simulating the irradiation of any point on earth by the sun. http://pysolar.org/

SunPy Open-source library for solar physics using Python http://sunpy.org/

NumPy Package for scientific computing with Python http://numpy.scipy.org/

Location calculation in Python https://github.com/pingswept/pysolar/wiki/examples

```
The reference frame for Pysolar is shown in the figure below.
```

```
  Altitude is reckoned with zero at the horizon. The altitude is
  positive when the sun is above the horizon. Azimuth is reckoned
  with zero corresponding to south. Positive azimuth estimates
  correspond to estimates east of south; negative estimates are west
  of south. In the northern hemisphere, if we speak in terms of
  (altitude, azimuth), the sun comes up around (0, 90), reaches (70, 0)
  around noon, and sets around (0, -90). Then, use the solar.GetAltitude()
  function to calculate the angle between the sun and a plane tangent to
  the earth where you are. The result is returned in degrees.

host:~/pysolar$ python
Python 2.5.1 (r251:54863, May  2 2007, 16:56:35)
[GCC 4.1.2 (Ubuntu 4.1.2-0ubuntu4)] on linux2
Type "help", "copyright", "credits" or "license" for more information.
>>> import Pysolar
>>> import datetime
>>> d = datetime.datetime.utcnow() # create a datetime object for now
>>> Pysolar.GetAltitude(42.206, -71.382, d)
-20.453156227223857
>>> d = datetime.datetime(2007, 2, 18, 20, 13, 1, 130320) # try another date
>>> Pysolar.GetAltitude(42.206, -71.382, d)
19.551710266768644

>>> Pysolar.GetAzimuth(42.206, -71.382,
datetime.datetime(2007, 2, 18, 20, 18, 0, 0))-51.622484299859529
}
```

https://github.com/pingswept/pysolar/wiki/examples

Estimate of clear-sky radiation in Python https://github.com/pingswept/pysolar/wiki/examples

```

Once you calculate azimuth and altitude of the sun, you can predict the
direct irradiation from the sun using Pysolar.GetRadiationDirect(),
which returns a value in watts per square meter. As of version 0.2,
the function is not smart enough to return zeros at night (thus the
crazy 1814 W/m^2^ output below). It does account for the scattering of
light by the atmosphere, though it uses an atmospheric model based on
data taken in the United States.

>>> latitude_deg = 42.3 # positive in the northern hemisphere
>>> longitude_deg = -71.4 # negative reckoning west from prime
meridian in Greenwich, England
>>> altitude_deg = Pysolar.GetAltitude(latitude_deg, longitude_deg, d)
>>> azimuth_deg = Pysolar.GetAzimuth(latitude_deg, longitude_deg, d)
>>> solar.radiation.GetRadiationDirect(d, altitude_deg)
1814.2039909409739

}
```

https://github.com/pingswept/pysolar/wiki/examples

3.17 Fortran Michalsky

The method described by Michalsky (Michalsky, 1988) requires less processing power and is faster than the method of Meeus. However, this method is limited to the period from 1950 to 2050 with uncertainty acceptable for most engineering tasks in the region of around 0.01° at best. Code in Fortran 90 here https://github.com/jpjustiniano/Subroutines

3.18 Solar Position in Fortran

Where is the Sun ?? Solar position algorithms in Fortran http://jpjustiniano.wordpress.com/2011/07/11/where-is-the-sun-solar-position-algorithms/

Routines to calculate the position of the sun based on geographical data Lat/Lon, local time, local time meridian, from which the program generates values for local solar noon, solar altitude, azimuth, and zenith angle, as well as some other parameters (mass of the atmosphere) http://www.wsl.ch/staff/niklaus.zimmermann/programs/f77.html (Zimmermann, 2014).

3.19 Solar Position in PHP

How do I calculate altitude and azimuth of sun? In his quest to obtain the planetary positions at any date during the 20'th and 21'st century with an error of one or at the most two arc minutes, and to compute the position of an asteroid or a comet from its orbital elements, Schlyter developed the accurate procedures on this page http://www.stjarnhimlen.se/comp/tutorial.html#5 (Schlyter, 2014). An associated routine for calculating the available solar energy and logging it to emoncms is available on this page http://harizanov.com/2012/05/calculating-the-available-solar-energy-and-logging-it-to-emoncms/.

Solar Position Calculator in PHP http://sts.ustrem.org/SourceCode/SPTS%20-%20PHP.pdf (Petrov, 2014).

PHP Procedure to calculate the sun position and path throughout the day http://snipplr.com/view/42266/php-sun-position/

Software routine named date.sun.info returns an array with information about sunset, sunrise and twilight http://php.net/manual/en/function.date-sun-info.php.

3.20 NASA Jet Propulsion Lab HORIZONS Web, Telnet and eMail Interfaces

Engineers from the Solar System Dynamics Group of the NASA Jet Propulsion Lab (JPL) developed the HORIZONS Web-Interface as a tool to provide a web-based limited interface to generate ephemerides or tracking paths for solar-system bodies such as the sun, moon, satellites and other celestial bodies (NASA, 2014). Full access to HORIZONS features is available via the primary telnet interface but an email service and interactive web-interface is also available.

For the web interface, the user interfaces with the software through a very simple top-level form to get a display prompt on the current settings to be used in generating an ephemeris for a particular body, for example for the sun position as shown in the menu below:

- Ephemeris Type [change] : OBSERVER
- Target Body [change] : Sun [Sol] [10]
- Observer Location [change] : Geocentric [500]
- Time Span [change] : Start=2014-10-16, Stop=2014-11-15, Step=1 d
- Table Settings [change] : defaults

- Display/Output [change] : default (formatted HTML)

The NASA HORIZONS Web-Interface tool can be accessed on this link `http://ssd.jpl.nasa.gov/horizons.cgi`, while a tutorial on how to use this online interface is presented on this link `http://ssd.jpl.nasa.gov/?horizons_tutorial` (NASA, 2014).

The HORIZONS system can further be accessed using telnet (instructions on this link `http://ssd.jpl.nasa.gov/?horizons#telnet`) or by email (instructions on this link `http://ssd.jpl.nasa.gov/?horizons#email`) (NASA, 2014).

3.21 Siemens SPA Solar Position Algorithm software library

Siemens developed its solar library around a solution for movable tracking system that precisely follows the course of the sun. The position of the sun as a function of the time of day axis well as the time of year and the location of the tracker installation. The library and control solution is only for the Simatic S7-1200 PLC processor and computes the alignment of the tracker on the basis of its exact location in the world, for any given time and date.

By using this library, a sun tracker platform can run the NREL Solar Position Algorithm SPA to compute the sun angles or solar coordinates of the sun vector as the solar azimuth angle and the solar zenith angle or the solar elevation angle to follow the sun. With the algorithms in this library, sun tracking can be accomplished on a industrial Siemens Simatic S7-1214C PLC TIA platform, wherein the Siemens solar PLC controller directs on-axis sun tracking, following the sun throughout the day on its apparent contour as it moves across the sky. This site provides example code to use the solar library `http://www.bytex.it/Article/eng/Complete-Solar-Tracking-example-code-with-Siemens-S7-1200-Tia-Portal.html`.

The software libraries include both a simple astronomical algorithm and an advanced astronomical algorithm of which more information can be obtained from this brochure `http://www.industry.siemens.com/verticals/global/en/solar-industry/Documents/Solartracker_en.pdf`. The part number such as "E20001-A140-T112-X-7600" is important for ordering of the algorithm for Siemens S7-1200 processors.

The Siemens Simatic Library for Solar Position Algorithm is contained in the control unit (if the license is approved) and is capable of determining the position of the sun to an accuracy of $0.0003°$. Added software allow for DC motors or two/three-phase AC motors to power a typical dual-axis sun tracking system, while in photovoltaic systems, it will align modules such that it prevents neighbouring modules from overshadowing each other during the morning and evening hours, when shadows are especially long. The software bases its astronomical calculations on parameters such as longitude, latitude, and the exact time.

3.22 Beckhoff TwinCAT Solar Position Algorithm software library

The TwinCAT Solar Position Algorithm software library for Beckhoff automation solutions was designed for all year round calculation of the solar vector sun angles and to determine sunrise, solar noon and sunset times. The inputs to this TwinCAT solar library is the date, time and exact longitude and latitude of the geographical location (GPS coordinates) (Beckhoff, 2014). The output is high precision sun angles with additional provision for parameters such as the time zone, slope of the ground or the orientation of the object, the height above mean sea level, air temperature and pressure and atmospheric refraction.

Some links to the Beckhoff TwinCAT that provide more information on the software library and code include http://www.beckhoff.co.za/english.asp?twincat/twincat_solar_position_algorithm.htm and http://www.beckhoff.co.za/english.asp?twincat/twincat_plc.htm. Algorithms for the Twincat PLC Motion Control and robot control system graphical programming can be obtained from this link http://download.beckhoff.com/download/document/catalog/main_catalog/english/Beckhoff_TwinCAT.pdf

The TwinCAT solution is ideal for solar photovoltaic systems, parabolic reflector solar systems or other solutions required to automatically track the sun's position for optimum utilization of the sun's rays. The TwinCAT control algorithm computes the azimuth and elevation/zenith axis angles of the sun with a precision around $0.001°$ and is said to be often used in building automation or with wind turbines for shadow flicker calculations http://www.automation.com/product-showcase/beckhoff-introduces-twincat-solar-position-software.

3.23 Panasonic Solar Tracker Solar Position Algorithm

The Panasonic solar Tracking System includes a tracking algorithm generator, a control positioning monitor for safety devices, it measures wind speed and processes alarms with remote control features https://www.panasonic-electric-works.com/eu/9672.htm (Panasonic, 2014). This system includes a Tracking algorithm, an astronomical calculation of the sun's position enables solar tracking. The algorithm uses a time stamp of a GPS receiver to synchronize the time.

In terms of position control, the actual alignment of the solar panels is checked by an encoder. For safe, reliable operation, Panasonic limit switches are used as safety devices. The actuator dynamic motion is is ensured by a Motor Drive that includes compact PLC-controlled inverters that make various movement patterns for the solar trackers are possible. The control strategy includes fast movement to a safe position in case of danger, or a slow movement for continuous tracking.

Analysis and remote control, alarms is handled by a remote monitoring and maintenance unit that can be operated via a mobile cellular data service network (i.e GPRS, 3G, Edge, etc) or on Ethernet, wireless network or via a Wireless Unit. To cope with inclement weather and to ensure that the solar tracker is not damaged by inclement weather, special control functions are implemented, including snow shedding function and a safety function for strong winds.

3.24 Microcontroller Platforms

Versatile microcontroller platforms such as Arduino and PIC processor makes it relatively easy to take a project from idea to creation. Common problems experienced by developers is the programming or the complicated mathematics described in the previous section.

The Plataforma Solar De Almera SunPos Algorthm in C (also for Arduino and other microporcessors) on this link is a very valuable software routine for computing the sun position http://www.psa.es/sdg/sunpos.htm, while the general link is on this page http://www.psa.es/webesp/index.php (PSA, 2014*a*).

This project uses the Plataforma Solar De Almera SunPos Algorthm in a solar tracking application for which the Arduino Sketch and source code Helios.zip is on this link https://docs.google.com/file/d/0BwJbV7RHxrvnamVtRzFJMU1GZDQ/edit) (Clarke, 2014). The

Arduino code to call the SunPos subroutine can be accessed on this link `http://sam-clarke.blogspot.com/2013/01/chasing-sun-exercise-in-solar-tracking.html` (see listing below):

```
  #include <Helios.h>

/////////// SUN VECTOR/SUN ANGLE VARIABLES /////////////////////
int TheYear  = 2014;
int TheMonth = 6;
int TheDay   = 12;
double TheHour = 05.00;            /*  UTC TIME!  */
double TheMinute = 0.00;
double TheSeconds = 0.00;
double YourLongitude = // my tracker longitude [e.g 151.857964];
double YourLatitude  = // my tracker latitude  [e.g -33.579265];
////// LIVE VARIABLES FROM A GPS HARDWARE MODULE CAN BE USED ///////

Helios SunAngle;

void setup(){}          // microcontroller setup (this example empty)

void loop(){            // main procedure loop
  SunAngle.getPos(TheYear, TheMonth, TheDay, TheHour, TheMinute,
                TheSeconds, YourLongitude, YourLatitude);
  Serial.print("Sun Azimuth Angle:  ");  // Degrees from north
  Serial.println(SunAngle.Azimuth);
  Serial.print("Sun Elevation Angle:  ");// Degrees up from horizontal
  Serial.println(SunAngle.Elevation);
  Serial.print("Sun Zenith Angle:  ");   // Degrees down from vertical
  Serial.println(SunAngle.ZenithAngle);
  delay(500);
}
```

An Arduino sketch to calculate the altitude and azimuth of the sun using latitude, longitude and time zone can also be accessed on this page `http://www.cerebralmeltdown.com/2011/05/30/open-source-arduino-sun-trackingheliostat-program/`. An Arduino heliostat program that calculates the position of the sun is published on this link `http://hackaday.com/2012/01/03/arduino-heliostat-calculates-the-position-of-the-sun/` and the install libraries can be found on this link `http://www.cerebralmeltdown.com/arduino-sun-tracking-heliostat-program-download-page/`. The goal of the Open Sun Harvesting Project is to make advanced DIY sun tracking and heliostat projects more accessible to the general public and the project details are given on here `http://cerebralmeltdown.com/Sun_Tracking_and_Heliostats/` and another on this page `http://www.cerebralmeltdown.com/2013/11/12/heliostat-project-from-students-at-khalifa-university-uae/`.

3.25 Sun Position in Excel

This tool calculates an array of solar angle data that can be copied into spreadsheets and other documents `http://www.susdesign.com/sunposition/`.

The source code for a series of astronomical functions are available as 'user defined functions', meaning it can be pasted into spreadsheets just like the normal functions (example spreadsheets are also available for download). The Excel VBA code and the Visual Basic for Applications source code for the set of user defined functions includes the sun position and is available on this link `http://www.stargazing.net/kepler/astrofnc.html` and a QBasic code on this link `http://www.stargazing.net/kepler/sun.html` and high precision Ephemerides for planatary orbits on this link http://www.stargazing.net/kepler/newlink.html#twig11 (Burnett, 2000).

3.26 Sun Position in Excel, Basic, QBasic and UBasic Code

BASIC program to calculate sunrises and sunposition is indexed on this page http://www.math.niu.edu/~rusin/uses-math/position.sun/ and the source code in UBasic on this link http://www.math.niu.edu/~rusin/uses-math/position.sun/suncalc.ub

Visual Basic source code for the set of user defined functions includes the sun position and is available on this link http://www.stargazing.net/kepler/astrofnc.html and a QBasic code on this link http://www.stargazing.net/kepler/sun.html and high precision Ephemerides for planatary orbits on this link http://www.stargazing.net/kepler/newlink.html#twig11 (Burnett, 2000).

Keith Burnett

```
'*********************************************************
'   This program will calculate the position of the Sun
'   using a low precision method found on page C24 of the
'   1996 Astronomical Almanac.
'
'   The method is good to 0.01 degrees in the sky over the
'   period 1950 to 2050.
'
'   QBASIC program by Keith Burnett  (http://bodmas.org/kepler/sun.html)
'
'   Work in double precision and define some constants
'
DEFDBL A-Z
pr1$ = "\         \#####.##"
pr2$ = "\         \#####.#####"
pr3$ = "\         \#####.###"
pi = 4 * ATN(1)
tpi = 2 * pi
twopi = tpi
degs = 180 / pi
rads = pi / 180
'
'   Get the days to J2000
'   h is UT in decimal hours
'   FNday only works between 1901 to 2099 - see Meeus chapter 7
'
DEF FNday (y,m,d,h) = 367 * y - 7 * (y + (m + 9) \ 12) \ 4 + 275 * m\ 9 + d
'   - 730531.5 + h / 24
'   define some arc cos and arc sin functions and
'   a modified inverse tangent function
'
DEF FNacos (x)
    s = SQR(1 - x * x)
    FNacos = ATN(s / x)
END DEF
DEF FNasin (x)
    c = SQR(1 - x * x)
    FNasin = ATN(x / c)
END DEF
'
'   the atn2 function below returns an angle in the
'   range 0 to two pidepending on the signs of x and y.
'
```

```
DEF FNatn2 (y, x)
    a = ATN(y / x)
    IF x < 0 THEN a = a + pi
    IF (y < 0) AND (x > 0) THEN a = a + tpi
    FNatn2 = a
END DEF
'
'   the function below returns the true integer part,
'   even for negative numbers
'
DEF FNipart (x) = SGN(x) * INT(ABS(x))
'
'   the function below returns an angle in the range
'   0 to two pi
'
DEF FNrange (x)
    b = x / tpi
    a = tpi * (b - FNipart(b))
    IF a < 0 THEN a = tpi + a
    FNrange = a
END DEF
'
'   Find the ecliptic longitude of the Sun
'
DEF FNsun (d)
'
'   mean longitude of the Sun
'
L = FNrange(280.461 * rads + .9856474# * rads * d)
'
'   mean anomaly of the Sun
'
g = FNrange(357.528 * rads + .9856003# * rads * d)
'
'   Ecliptic longitude of the Sun
'
FNsun = FNrange(L + 1.915 * rads * SIN(g) + .02 * rads * SIN(2 * g))
'
'   Ecliptic latitude is assumed to be zero by definition
'
END DEF
'
'
'
CLS
'
'    get the date and time from the user
'
' INPUT "  year  : ", y
' INPUT "  month : ", m
' INPUT "  day   : ", day
' INPUT "hour UT : ", h
' INPUT " minute : ", mins
' INPUT "    lat : ", glat
' INPUT "   long : ", glong

y = 2002
m = 7
day = 9
h = 0
mins = 23
```

```
glat = 45.08096
glong = -93.02377
'
glat = glat * rads
glong = glong * rads
h = h + mins / 60
d = FNday(y, m, day, h)
'
'   Use FNsun to find the ecliptic longitude of the
'   Sun
'
lambda = FNsun(d)
'
'   Obliquity of the ecliptic
'
obliq = 23.439 * rads - .0000004# * rads * d
'
'   Find the RA and DEC of the Sun
'
alpha = FNatn2(COS(obliq) * SIN(lambda), COS(lambda))
delta = FNasin(SIN(obliq) * SIN(lambda))
'
'   Find the Earth - Sun distance
'
r = 1.00014 - .01671 * COS(g) - .00014 * COS(2 * g)
'
'   Find the Equation of Time
'
equation = (L - alpha) * degs * 4
'
'   find the Alt and Az of the Sun for a given position
'   on Earth
'
'   hour angle of Sun
LMST = FNrange((280.46061837# + 360.98564736629# * d) * rads + glong)
hasun = FNrange(LMST - alpha)
'
'   conversion from hour angle and dec to Alt Az
sinalt = SIN(delta) * SIN(glat) + COS(delta) * COS(glat) * COS(hasun)
altsun = FNasin(sinalt)
' y = -COS(delta) * COS(glat) * SIN(hasun)
alt = -COS(delta) * COS(glat) * SIN(hasun)
' x = SIN(delta) - SIN(glat) * sinalt
az  = SIN(delta) - SIN(glat) * sinalt
' azsun = FNatn2(y, x)
azsun = FNatn2(alt, az)
'
'   print results in decimal form
'
PRINT
PRINT "Position of Sun"
PRINT "==============="
PRINT
PRINT USING pr2$; "     year : "; y
PRINT USING pr2$; "    month : "; m
PRINT USING pr2$; "     days : "; day
PRINT USING pr2$; "     hour : "; h - mins / 60
PRINT USING pr2$; "      min : "; mins
PRINT USING pr1$; "longitude : "; lambda * degs
PRINT USING pr3$; "       RA : "; alpha * degs / 15
PRINT USING pr1$; "      DEC : "; delta * degs
```

```
PRINT USING pr2$; " distance : "; r
PRINT USING pr1$; "  eq time : "; equation
PRINT USING pr1$; "      LST : "; FNrange(LMST) * degs
PRINT USING pr1$; "  azimuth : "; azsun * degs
PRINT USING pr1$; " altitude : "; altsun * degs
END
'*********************************************************

' Below is the output from the old program when run for
' 11:00 UT on 1997 August 7.

'   year  : 2002
'   month : 8
'   day   : 7
' hour UT : 11
'  minute : 0

' Position of Sun
' ===============

'      days : -877.04167
' longitude :  134.98
'        RA :    9.163
'       DEC :   16.34
'  distance :    1.01408
' eq time   :   -5.75

' Below is the output from the program including Altitude and Azimuth
' in Chicago, run for 15:00 UT on 2001 March 4th (09:00h Chicago time),
' compared with the altitude and azimuth calculated from
' Chris Marriott's SkyMap Pro 6 demo.

'   year  : 2001
'   month : 3
'   day   : 4
' hour UT : 15
'  minute : 30
'     lat : 41.87
'    long : -87.64

' Position of Sun
' ===============

'      days :  428.14583
' longitude :  344.13
'        RA :   23.025
'       DEC :   -6.24
'  distance :    0.99173
'   eq time :  -11.68
'   azimuth :  134.56
'  altitude :   30.68

' Skymap 6
' --------

' Right ascension: 23h  1m 29.93s = 23.025
' Declination:     -6   14'  58.0" = -6.249
' Altitude:        30   42'    20" = 30.706
' Azimuth:        134   33'    41" = 134.561

' The errors here are about 1.5 arcmin for altitude and much less for
```

```
' Azimuth. Errors are higher than for the RA and Dec and this may be
' due to the failure to allow for the TDT-UT time difference in the
' method given here. To put this all in perspective, the Sun moves
' about 0.25 of a degree in the sky between 0900 and 0901 that morning!
}
```

http://www.redrok.com/sun.zip

3.27 HP Sun Position Algorithm

HP-41CX sun position program

```
Here is a BASIC program which will give the RA and DEC of the Sun to very
high accuracy (a few seconds of arc) given year, date, and time (hours and
minutes) as input. (Note, there are some extra variables printed in this
version - helpful for debugging and generally checking what's happening).
Note that the parallax of the Sun (which can be up to almost 10 arcseconds)
is ignored. The RA, DEC are with respect to the center of the Earth. RA and
DEC are in fractional hours and degrees - not sure what telescope wants.

10 DEFDBL A-H,J-Z
20 PI = 3.14159265#: TWOPI = 2# * PI: CONV = TWOPI / 360#
30 YEAR = 2000: MONTH = 8: DAY = 22: HOUR = 2: MIN = 0

     get the time & date from the calculator instead


40 UTC = (TWOPI * (60# * HOUR + MIN)) / 1440#
50 DIM NDAY(12)
60 DATA 0,31,59,90,120,151,181,212,243,273,304,334
70 FOR I = 1 TO 12
80 READ NDAY(I)
90 NEXT I
100 YEARM = YEAR - 1900#
110 KDAY = INT((YEARM - 1#) / 4#)
120 JULDAY = 2415019.5# + YEARM*365# + KDAY
130 JULDAY = JULDAY + NDAY(MONTH) + DAY
140 IF(YEARM/4# - INT(YEARM/4#)) > .2 THEN GOTO 160
150 IF(MONTH > 2) THEN JULDAY = JULDAY + 1#
160 CENTURY = ( JULDAY - 2451545# ) / 36525#
170 STM = 24110.55# + CENTURY* (8640184.812866# + .093104#*CENTURY)
180 STM = STM/86400# - INT(STM/86400#)
190 STM = 2# * PI * STM: PRINT JULDAY,STM*12/PI
200 DAYS = JULDAY - 2451545# + (UTC/TWOPI)
210 SOLLON = 280.46# + .9856474# * DAYS
220 SOLLON = SOLLON - 360# * SGN(SOLLON)*INT(SOLLON/360#)
230 IF(SOLLON < 0) THEN SOLLON = SOLLON + 360#
240 SOLANOM = 357.528# + .9856003# * DAYS
250 SOLANOM = SOLANOM * CONV
260 SOLANOM = SOLANOM + TWOPI * SGN(SOLANOM)*INT(SOLANOM/TWOPI)
270 IF(SOLANOM < 0) THEN SOLANOM = SOLANOM + TWOPI
280 ECLLON = SOLLON + 1.915# * SIN(SOLANOM) + .02# * SIN(2#*SOLANOM)
290 ECLLON = ECLLON * CONV
300 ECLLON = ECLLON + TWOPI * SGN(ECLLON)*INT(ECLLON/TWOPI)
310 QUADRANT = ECLLON / (PI/2)
320 IQUAD = 1 + INT(QUADRANT)
325 PRINT ECLLON,QUADRANT,IQUAD
330 OBLIQ = 23.439# - .0000004# * DAYS
340 OBLIQ = OBLIQ * CONV
350 RA = ATN( COS(OBLIQ) * TAN(ECLLON) )
```

```
360 IF IQUAD=2 THEN RA = RA + PI
370 IF IQUAD=3 THEN RA = RA + PI
380 IF IQUAD=4 THEN RA = RA + TWOPI
390 ARG = SIN(OBLIQ) * SIN(ECLLON)
400 DEC = ATN(ARG/SQR(1-ARG*ARG)): PRINT RA*12/PI,DEC/CONV

I wrote this as part of the SUNMOON program which was published with
my article on calibrating antennas by observing the Sun or Moon in the
ARRL UHF/VHF Handbook. It uses a formula from the "American Ephemeris
and Nautical Almanac" (published by the US Navy).

If you have questions, you can e-mail me directly.

Dave W8MIF
}
```

http://www.hpmuseum.org/cgi-sys/cgiwrap/hpmuseum/archv015.cgi?read=83378

3.28 Sun Position Applets for Java and Flash

Astronomy Education at the University of NebraskaLincoln provides a rich resource of applets that can be used in solar position calculations and demonstrations http://astro.unl.edu/ (Lee, 2014*b*). Astronomy Flash animations and simulations for the position of the sun, sun seasons, moon phases, coordinate systems, and light can be accessed on this link http://astro.unl.edu/animationsLinks.html#ca_coordsmotion and the general tutorial page http://astro.unl.edu/classaction/.

Range of interactive applets, including an interactive applet to display the position of the sun on the horizon for any date, time and location, and on a world map with day and night regions is accessible on this link http://www.jgiesen.de/GeoAstro/english2.html (Giesen, 2014). The author Giesen published a summary of Java Applets for detailed solar and lunar data and observe the daily and annual path of the sun and moon for any location on this site http://www.jgiesen.de/GeoAstro/GeoAstro.htm.

Ecotect tutorials are available for sun position calculation and solar radiation analysis to Calculate Solar Availability Using Points perform Cumulative Insolation Analysis and Incident Solar Radiation Graphs and determine Solar Availability Using Analysis Grid http://wiki.naturalfrequency.com/wiki/Solar_Radiation_Analysis (Ecotect, 2014*a*).

This applet by Schroeder http://physics.weber.edu/schroeder/sky/SkyMotionApplet.html computes the position for stars, planets, sun, and moon are in the sky and help under-stand the motions of the heavenly bodies. It allows the user to view the sky from anywhere on earth, at any time in the reasonably near future or recent past (Schroeder, 2011). The default view shows half the visible sky, with your horizon at the bottom and zenith (the point straight overhead) at the top. To change the direction you're facing, press and drag on the direction letters just below the horizon. The index link to more resources is as follows: http://physics.weber.edu/schroeder/.

Software library components that operate independently of the DIVA-for-Rhino toolbar include a Sun Position Component on this link http://diva4rhino.com/user-guide/grasshopper/solar. The solar position algorithm used by the component follows the formulas described in "Solar Engineering of Thermal Processed" (Duffie and Beckman, 2006).

Using the equations on the previous page, the position of the sun in the sky can be determined from the observer's location and the time of day. In the top blue squares, enter the observer's location and time of day http://www.pveducation.org/pvcdrom/properties-of-sunlight/sun-position-calculator. An alternate calculator for the sun's path is also available at the PV Lighthouse Solar Path Calculator http://www.pvlighthouse.com.au/calculators/solar%20path%20calculator/solar%20path%20calculator.aspx

Online Satellite Calculations can also be used to calculate the path of the sun. The Sun and Moon Position Calculator interface is accessible on this link http://www.satellite-calculations.com/Satellite/suncalc.htm. Another index provides links to information on satellite tracking software for many of today's popular operating systems (Microsoft Windows, Macintosh, iOS, MS-DOS, Android, Palm OS, Unix/Linux), also in solar tracking applications http://www.celestrak.com/software/satellite/sat-trak.asp (Kelso, 2014).

3.29 Algorithms for Real Time Data (DNI, Atmospheric)

Compiled programs to calculate simple daily, monthly, and yearly summaries of hourly radiation and climate parameters as decompressed from the SAMSON solar radiation can be accessed on this link http://www.wsl.ch/staff/niklaus.zimmermann/programs/f77.html. This source also includes very simple routines program to calculate the position of the sun based on geographical data Lat/Lon, local time, local time meridian, from which the program generates values for local solar noon, solar altitude, azimuth, and zenith angle, as well as some other parameters (e.g. "mass of the atmosphere") (Zimmermann, 2014).

The Virtual Terrain Project foster the creation of tools for easily constructing any part of the real world in interactive, 3D digital form and can be accessed on this link http://vterrain.org/Atmosphere/ (VTP, 2014). VTP writes and supports software tools with an interactive runtime environment while the tools and their source code are freely shared on the site. Already modelled areas include the United States (California, Hawaii, Nevada, New York, Washington), Africa, Asia, Australia, Costa Rica, China, Canada, Europe, France, Germany, Greece, Italy, Japan, Middle East, Netherlands, New Zealand, North America, Central America, Romania, South Africa, South America, Spain, Switzerland, UK and beyond earth. The site allows the download the full VTP 3D software or to download the VTBuilder tool for geoprocessing.

A tutorial on the use of software algorithms for climate visualization for Matlab is available on this link http://www.tedngai.net/?p=571 (Ngai, 2014).

See references in Section 26.1 for DNI direct and GPS direct measurements for locations on the surface of the earth.

3.30 Sun Position Algorithms for Applications

Solar radiation data are used to predict the performance of many different systems from heating loads on buildings to electricity produced by concentrating collectors, with sun path chart program plots the path of the sun across the sky, as well as solar position calculator developed to more accurately obtain astromonical parameters such as solar declination, solar zenith angle, equation of time, and hour angle used in calculating the position of the sun http://solardat.uoregon.edu/SoftwareTools.html (Oregon, 2014).

Interesting application that lets the viewer view the solar tracker location from the sun http://www.fourmilab.ch/cgi-bin/Earth. That is looking down from the sun to the earth view, the view directed at a particular GPS location.

NASA have created a page with access to open source code for developers (http://open.nasa.gov/developer/) who are interested in using NASA data and code to build new technology and help re-think how space exploration and aeronautics mission can be used and remixed to improve life on Earth and life in space.

Algorithm to calculate the sunlight radiation on a point on a building throughout a day with a Genetic Algorithm optimization algorithm to find the most suitable location for rooms. Solar calculation and sun position plugin written in C#, as grasshopper plugin http://www.grasshopper3d.com/forum/topics/solar-calculation-plugin (sunpathver03A.3dm and sunpathver03A.gh) (Eirik, 2014).

3.31 Sun Position Algorithms Resources

The sourcecodeonline website lists a host of Sun Position Calculation software resources for Animated 3D Sun, Annuity Calculation, Autoftp For Sun and Sun Bearing Calculations http://www.sourcecodeonline.com/list?q=sun_position_calculation and http://www.sourcecodeonline.com/list?q=solar_position

Software for Positional Astronomy with Complete Sun and Moon Data as well as Sunrise/Sunset, Moonrise/-Moonset, or Twilight Times http://aa.usno.navy.mil/software/index.php and http://aa.usno.navy.mil/data/index.php

Interactive tool for calculating the azimuth and altitude of the Sun at any date and time by selecting the Latitude and Longitude of the desired location. The tool calculates the current Sun position as well as Sunrise and Sunset times, the Declination and Equation of Time as well as the relative shadow length http://wiki.naturalfrequency.com/wiki/Solar_Position_Calculator (more resources on this link http://wiki.naturalfrequency.com/wiki/Teaching_Tools) (Ecotect, 2014*a*).

Based off a Java applet on a NOAA web page (see the source code for the URL), a procedure by Seligman calculates the sunrise, sunset, and solar noon given longitude and latitude coordinates http://www.scottandmichelle.net/scott/code/index2.mv?codenum=031 (Seligman, 2014). Support functions determine the current phase of the moon given a particular date in which there is included a procedure for the calculation of the sun's position and the sun's apparent orbit http://www.scottandmichelle.net/scott/code/index2.mv?codenum=087.

Compute sunrise, sunset, and twilight times for any date and location and timezone can be accessed on this link http://www.spectralcalc.com/solar_calculator/solar_position.php. It also computes the sun's local position (azimuth and altitude) in the sky at any place and time by inputting any latitude/longitude or select the location from the drop down menu.

SunPosition uses an advanced mathematical algorithm to run calculations to know exactly where to expect the sun http://sunposition.info/sunposition/spc/locations.php.

Online tools for Sun position calculation (when is it sunrise where?), Unit of energy calculator (conversion of kJ, kWh, kcal) and US to metric unit converter (Fahrenheit, cups and acres) available on this link http://www.volker-quaschning.de/software/index_e.php and the sun position calculator on this page http://www.volker-quaschning.de/datserv/sunpos/index_e.php.

For those interested in further read, the book Sun Position-High Accuracy Solar Position Algorithms - A Resource for Programmers and Solar Energy Engineers by Craig (Craig, 2011) answers questions on knowing where the sun is at in the sky with high accuracy. He discusses the software perspective on the real time aiming of sophisticated concentrating receivers, photovoltaic tracking systems and photovoltaic systems using easy-to-implement and easy-to-translate Visual Basic algorithms for solar trackers. This book on VB.Net Programming is also available in digital form (Craig, 2013).

3.32 Summary

This chapter detailed various solar tracking algorithms, software and source code commonly available on the internet to perform solar tracking. With the exact solar coordinates and the trajectory path of the apparent movement of the sun known (i.e. the SPA or sun path diagram at any given geographic location of the surface of the earth), this information can serve as input to the positioning system controller.

CHAPTER 4

SOLAR POSITION ALGORITHM SUPPORTING DEVICES AND SOFTWARE

Solar Tracking, First Edition.

4.1 Introduction

This chapter provides details on typical code used for support devices such as GPS location as real-time clocks. The devices support the solar position algorithm and is crucial in solar tracking application on microprocessor and PLC platforms for solar tracking systems.

4.2 Solar Tracker GPS Location/Coordinates

TinyGPS is designed to provide most of the GPS in terms of functionality for those applications that need position, date, time, altitude, speed and course without the large size that seems to accompany similar bodies of code. To keep resource consumption low, the library can be found on this link `http://arduiniana.org/libraries/tinygps/>` and avoids any mandatory floating point dependency and ignores all but a few key GPS fields.

Sparkfun listed an example code for the NewSoftSerial library for serial communication between a microprocessor and the GPS device. In this way, the GPS TX and RX pin can for example be connected to any board, such as any digital pin on the Arduino, after which the programmer must define the selected pins on the Arduino in the code to communicate with the GPS module. The source code can be found on this link: `https://cdn.sparkfun.com/datasheets/Dev/Arduino/Boards/gps_arduino_1_0.ino` (Aaron Weiss, 2010).

```
#include <TinyGPS.h>                   // initialisation code for GPS
TinyGPS gps;                           // Create an instance of the TinyGPS object
#include <SoftwareSerial.h>
#define GPSBAUD          4800          // Set this baud value equal to the baud
                                       rate of GPS
#define RXPIN            0             // Define which pins for Arduino to
#define TXPIN            1             communicate with GPS
SoftwareSerial uart_gps(RXPIN,TXPIN); // Arduino's TXPIN pin 3 and RXPIN pin 2
                                       (or pin 0 and 1 for uart).
                                       // Initialize the NewSoftSerial library to
void setup()                           the pins defined above
{
  uart_gps.begin(GPSBAUD);             // Sets baud rate of GPS comms pin 2 and 3
  readLocation_GPS();                  // detemine GPS pos n release pin 2 and 3
  delay(2000);
  realtimeClock();                     // read date and time from real time clock
}                                      (GPS or external)

void readLocation_GPS()                // If there is data on the GPS RX pin... //
{                                      load the data into a variable...
  if(uart_gps.available()) {           // if there is a new valid sentence... //
    int c = uart_gps.read();           then grab the data
    if(gps.encode(c))    {             // Read Altitude above sealevel
      gps.f_get_position(&latitude, &longitude);
      laltitude = gps.f_altitude();
      }
  }
  else { }                             // use the default

}
}
```

4.3 Solar Tracker Real Time Clock

The real time clock as an absolutely essential component is any solar tracking systems. This is especially true in open-loop solar tracking where astronomical algorithm calculations receives the real time clock as input to compute the solar vector precisely. Any errors in the real time clock time will directly impact on the solar vector calculations, and consequently on the solar tracker accuracy and energy harvesting efficiency.

The microprocessor type will obviously determine the context of the software code, but just by way of example we can consider the following code for the real time clock module:

```
//RTimeClk.                           // real time clock
byte   hundredths = 1;
byte   second     = 1;
byte   minute     = 1;
byte   hour       = 8;               // 24 hour time
byte   weekDay    = 0;               // 0-6 -> sunday - Saturday
byte   monthDay   = 20;
byte   month      = 7;
int    year       = 2015;


void realtimeClock()
// Read time from GPS satellites
{
  if (!simulation) {
    gps.crack_datetime(&year,&month,&monthDay,&hour,&minute,&second,&hundredths);
    if (debug) Serial.println("reading date and time from GPS");
  }
  else {
    minute = minute+5;
// procedure to accelerate time for simulation
    if (minute>=60) {
      minute=0;
      hour++;
      if (hour>=24) hour=0;
      }
    delay(100);
    }
}
```

This demo code above illustrates that the Real Time Clock RTC is in turn dependent on very exact GPS coordinates for the location of the solar tracking system. If the GPS coordinates are not absolutely 100% correct then the RTC will output the time for a different location (perhaps close by but not exact). This and can consequently lead to large frustrations during the setup phases or debugging stages as the solar tracking errors will only be correct at that time of the day when the solar tracking system was synchronised.

4.4 Summary

This chapter presented details on typical code used for support devices such as GPS location and real-time clocks. The devices are used to support the solar tracking application on microprocessor and PLC platforms for solar tracking systems.

CHAPTER 5

OPTICAL DETECTION AND SUN FOLLOWING

5.1 Optical Sun Tracking

In this section, we would like to briefly review the hardware required for the category of closed-loop solar tracking systems or algorithms.In the closed-loop solar tracking approach, one or more optical sensors may be utilized to sense the position of the solar image on the receiver.

Any discrepancy between the angles calculated through an algorithm and real-time position of the solar concentrator can be detected and corrected in a closed-loop tracking control solution. With this feedback, the pointing control system ensures that any tracking errors due to wind effects, mechanical backlash, installation mismatches, accumulated errors or other disturbances in the positioning of the parabolic dish can be corrected or eliminated.

5.2 Closed-loop Sun Tracking

Solar sensor feedback, camera images or optical encoders typically serve as input to the closed-loop controller in order to activate the drive mechanisms to augment the precise movement the solar dish so that it pin-points towards the exact solar position in the sky.

These sensors generate feedback signals that informs the electronic controller whether the solar tracking means is precisely locked onto the solar receiver. However, any closed-loop solar tracking system that employ only optical sensor devices are easily affected by clouds, weather conditions and environmental factors, it has allowed savings in terms of cost, time and effort by omitting more precise sun tracker alignment work.

Some of these solutions and their operating mechanisms will be discussed in more detail below.

5.2.1 Sun Tracking: Photodiodes and Transistors

Photo sensitive devices and the principles behind their operation are commonly used in closed-loop control for solar tracking systems. In these solutions, light sensitive sensors or infra-red detectors can be employed either to autonomously direct sun tracking or to fine-tune the positioning of the parabolic dish. In general, differential signals from these devices are used in output balancing circuits in order to compensate for differences in component characteristics or changes in light sensitivity levels.

In some solar tracking designs, dual angle tracking is accomplished with optical slot photo-diode sensor arrays which is used to detect whether a solar dish has been oriented towards the solar home position. These photodiode homing sensors are typically mounted on the parabolic dish structure to assist with feedback to the control mechanism for adjusting the dish collector to a position directly facing the sun. Phototransistors have the added benefit in that they can be connected in current circuits to drive the servo motors, thereby physically commanding the drives which directs the parabolic dish mechanism.

Figure 5.1 shows a typical circuit diagram for interfacing a quadrature photo-diode matrix with a solar pointing controller. The quadrature matrix nature of the photo diode is obtained from monolithically integrating four photo-diodes on a common silicon photo sensitive substrate (Cavalier, 2014).

Photo-diodes are commonly used in solar tracking applications and are usually embedded into a sensor housing which may either cause shadow or illumination signal principles

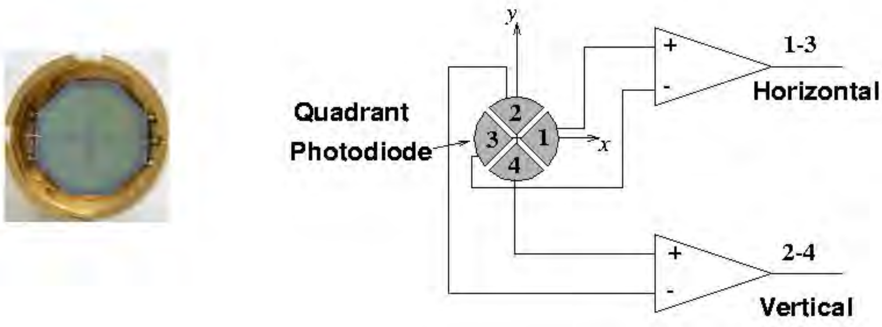


Figure 5.1 Picture and circuit diagram for Quadrant Photo-diode where differential energy levels are used as homing device for fine tuning of solar tracking positioning (Cavalier, 2014).

as input signals to steer the parabolic dish mechanism. In general, this is referred to as solar tracking with homing capabilities.

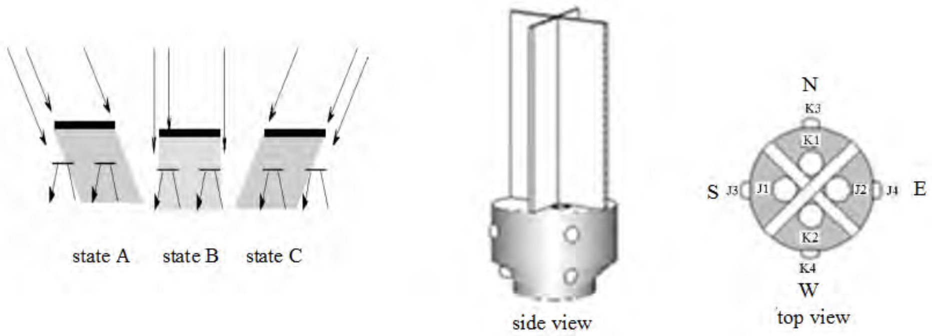


Figure 5.2 Solar tracking control through photo-transistors exposed to light incidence through small aperture or shade screens (Damm, 1990)(Pattanasethanon, 2010).

A Pattanasethanon device (Pattanasethanon, 2010) uses shade screens as a solar angle detector in which a photo transistor configuration is used as input to a logic circuit to detect solar beam radiation through a dual axis feedback signal is obtained.

In an improved design, Shibata and Tambo (Shibata and Toyokazu, 2000) from the University of Toyama in Tokyo proposed a "Dual Axis 5 Photo-Diode" sun sensor to control a solar cell platform. In their design, sun tracking is accomplished with an odd number of photo diodes attached on a frustum of a mechanical pyramid structure as illustrated in Figure 5.3.

The difference signals from the angular diodes due to any angle differences in the incident light are used for solar tracking. This design provides a slight improvement over similar pyramid type photo diode designs in this mechanisms it is able to provide an increased balance of energy output and more accuracy due to the direct sun view of the 5^{th} diode mounter at the pinnacle.

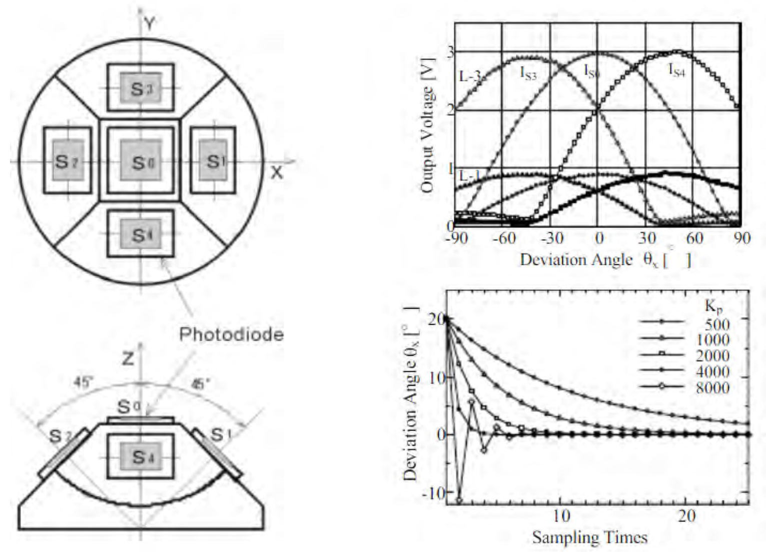


Figure 5.3 Dual axis 5 photo-diode light sensor with associated output voltage and step responses to determine solar angle deviation (Shibata and Toyokazu, 2000).

5.2.2 Sun Tracking: Light Sensitive Resistors or CdS Photo Cells

A light-dependant-resistor (LDR) or photoresistor operates on the principle of photoconductivity in which the resistance of a semiconductor decreases as its exposure to light intensity increases. The semiconductor absorbs the light energy, causing free electrons to move over the silicon band-gap, thereby lowering the resistance of the device (ElectronicsTutorials, 2014).

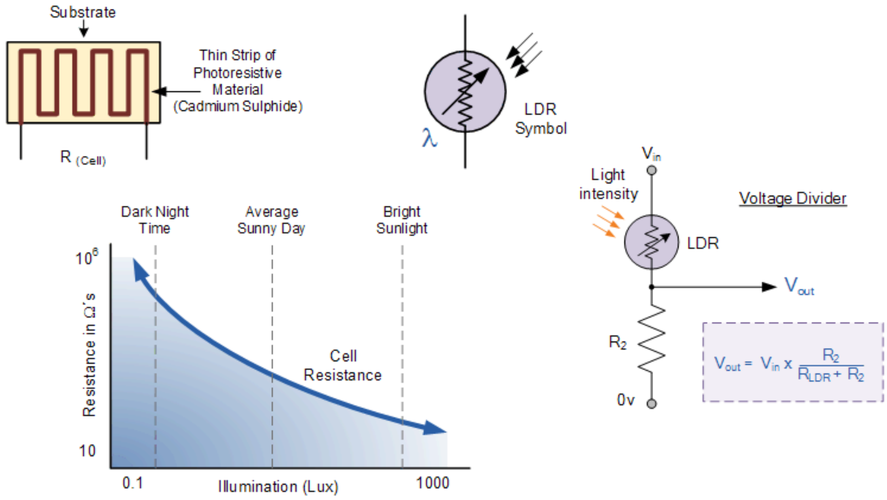


Figure 5.4 Light dependant resistor (ElectronicsTutorials, 2014).

In Figure 5.4 there is shown the substrate with voltage response graph of an LDR. An LDR is also known as a Light Sensor. This is a passive device that converts sunlight energy (visible or infrared) into an electrical signal or resistance output. The LDR can be used in a typical voltage divider configuration, as shown in the illustration (right).

In solar tracking applications, the LDR is typically fixed on the outside or inside edges at the base of a square metallic, ceramic or plastic tube. The variance in resistance of the LDR matrix, as a result of the combined shadowing effect of the square housing tube, is used as feedback signals to determine the solar tracking error angles.

Figure 5.5 presents an illustration of an optical sensor system that incorporates CdS solar cells in an intelligent solar tracking control system implemented on a field programmable gate array FPGA (Xinhong *et al.*, 2007). An FPGA sprouted from programmable read-only memory (PROM) and programmable logic devices (PLDs)that had the option of being programmed in batches in a factory or in the field, thus the name field-programmable. Essentially, programmable logic such as sun following decisions may be hard-wired between logic gates on the FPGA chip.

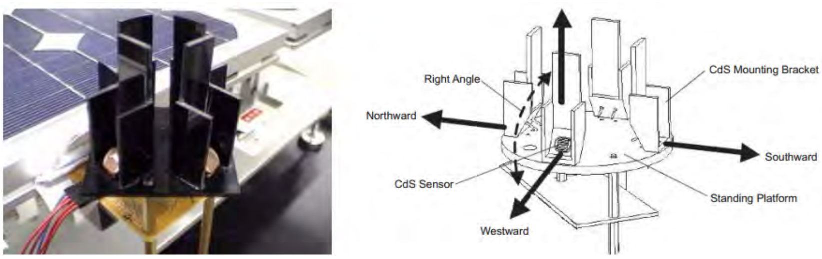


Figure 5.5 Tracking sensor design and stereogram (Xinhong *et al.*, 2007).

In this configuration, the sun tracker sensor includes four similar CdS sensors, which are located at the north, east, west and south sides of the sensor, each detecting sunlight intensity from the four orientations. The CdS sensor (`https://learn.adafruit.com/photocells`) forms a $45°$ angle with special brackets to isolate the light from other orientations. In this way, a wide-angle search prompt on the differential outputs between the sensors can be used determine the position of the sun.

The sensor quadrant output voltage values are interpreted by an A/D converter (ADC) from which the sun following system drive stepper motors towards the orientation of the solar array sensor. If the output values of all sensors are equal, or the differential output voltages are zero, then the solar collector faces the sun directly.

This is a very interesting project of which the full details and component lists can be obtained from the Altera link `http://www.altera.com/literature/dc/2007/t3c.pdf`. In this application, the FPGA logic (acting as a type of microcontroller) outputs a zero motor drive voltage, to stop the tracking operation for a period of time (Xinhong *et al.*, 2007). In a similar type FPGA project (`http://www.mecs-press.org/ijisa/ijisa-v4-n1/IJISA-V4-N1-6.pdf`) a Fuzzy Logic Controller is implemented on an FPGA to accomplish sun tracking in a solar array system (Hamed and El-Moghany, 2012).

An interesting sun position sensor for dual axis solar trackers was invented as far back as 1980 by Rotolo (Rotolo, 1980). This sun position sensor includes a multifaceted solar face with exterior planar surfaces each having a different angular relationship relative to the sun as illustrated in Figure 5.6. The multifaceted solar face includes a plurality of solar sensors each mounted on a different planar surface of the facet to sense solar energy arriving in a respective azimuth and elevation direction, while each sensor is in turn connected to a data encoding means to decode the respective solar azimuth and solar elevation angles through electronic hardware (such and an FPGA in today's terms).

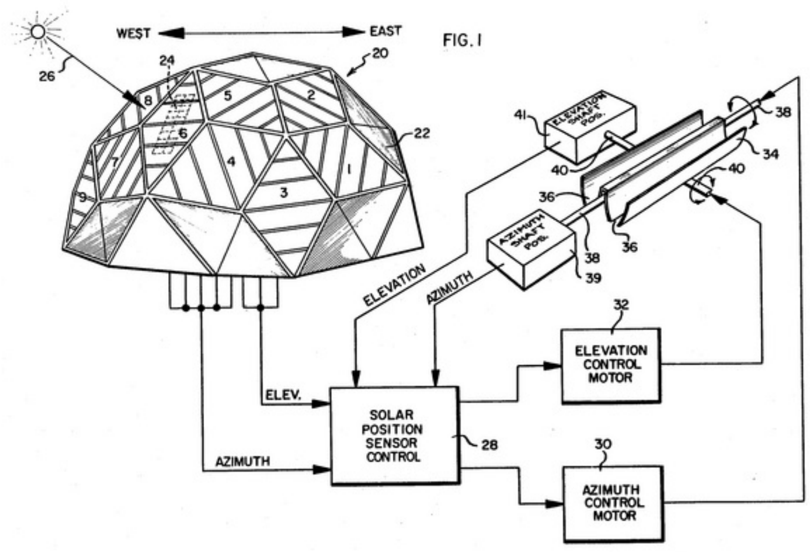


Figure 5.6 Multifaceted Solar Tracking Sensor design shown in a tracking control configuration (Rotolo, 1980).

In the configuration of Figure 5.6, the geodesic dome portion includes several facets each of which contains a respective plurality of solar sensors to provide an electrical output signal representing the amount of solar incidence on a respective sensor/dome facet. Further drawing on this link illustrates how the `http://www.google.com.ar/patents/US4361758`. The solar direction decoding means are then coupled to the solar sensors to derive the solar vector angles from the sensed solar position, while a solar collector for receiving solar energy in that discrete sun direction includes a drive means for positioning the solar collector (Rotolo, 1980).

5.2.3 Sun Tracking: Mini PV Cells

The most common type of photovoltaic light sensor is the solar photovoltaic cell or PV cell. These cells convert light energy directly into DC electrical energy in the form of a voltage or current to a power a resistive load (ElectronicsTutorials, 2014).

Shaping tiny PV cells in a pyramid configuration has the effect of providing differential illumanation on different sides and is able to provide directional information about the position of the sun. In the same way, a tiny flexible solar cell may be shaped in the form of a dome or sphere in order to determine sunlight angles. These concepts can be taken from existing photovoltaic schemes, such as those developed by (Kyosemi, 2012)(RenuSol, 2014) shown in Figure 5.7.

When used as solar direction sensors, the cells will also provide solar power electricity that can be used as small emergency supply for a small solar tracking system. Such mini-watt panels are epoxy encapsulated mono-crystalline polycrystalline silicon solar cells and

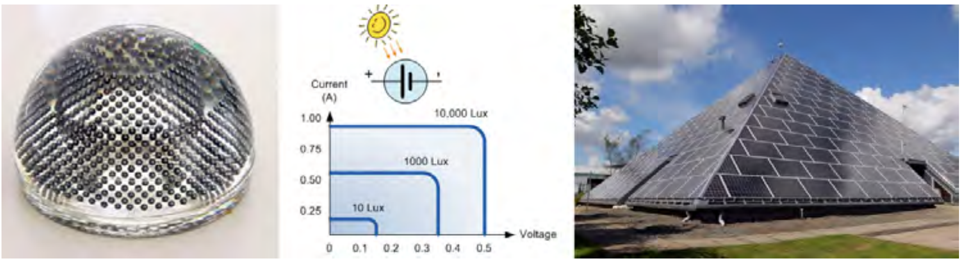


Figure 5.7 Tiny dome- or pyramid- shaped tiny photovoltaic concepts suitable solar tracking directionality (Kyosemi, 2012)(Link Light Solar, 2014)(RenuSol, 2014).

typically provide outputs around 0.1 W and 9 W (Link Light Solar, 2014). Polycrystalline silicon or amorphous silicon photovoltaic cells can generate currents of between 20 to 40 mA/cm^2 (Link Light Solar, 2014). Such mini solar cells are typically used in gardens, electric toys, mobile phone charges or gifts with solar panels. The amount of available current from a solar cell depends upon the light intensity and the size of the individual cell.

In a solar tracking application, the outputs of these mini photovoltaic cells can be input into a microprocessor, while a simple algorithm or hardware decoder circuit can implement an energy balancing approach to accomplish solar tracker steering. In this way, the sun position data computer from the mini voltaic cells and the position data corresponding to the position of the solar collector can be input into a comparator means for comparing the collector position and the solar position and providing a drive signal until the two positions are equal.

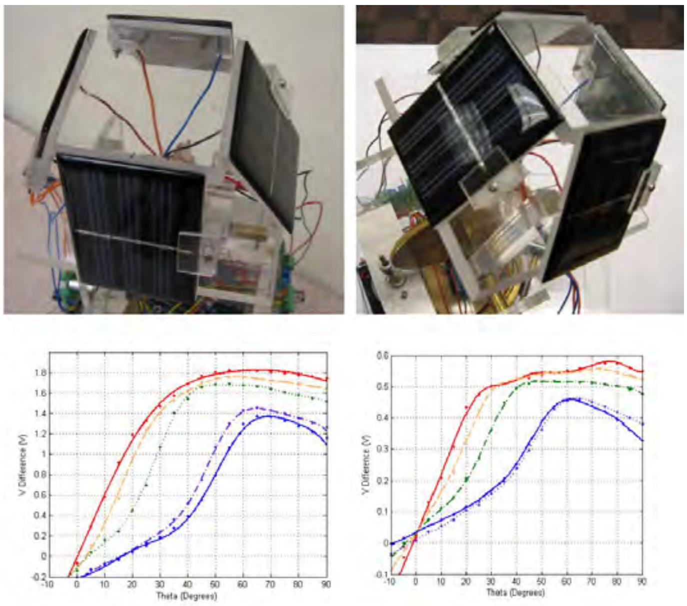


Figure 5.8 Example of a solar PV cell sensor pyramid array (top), with angle sensitivity functions for Thin Film Photovoltaic Cells (bottom left) and Polycrystalline Photovoltaic Cells) (bottom right) (Catarius, 2010).

Figure 5.8 provides an example of such a solar PV cell sensor pyramid array constructed by Catarius (Catarius, 2010). This researcher fashioned the sensor array as an acrylic four sided pyramid in a method to get differential illumination results from this solar sensor configuration, and developed an analogue comparator circuit to drive the sun follower decisions. Figure 5.8 also shows the angle sensitivity functions for Thin Film Photovoltaic Cells (bottom left) and Polycrystalline Photovoltaic Cells) (bottom right) as a comparison between the two types of solar cells in directional applications (Catarius, 2010).

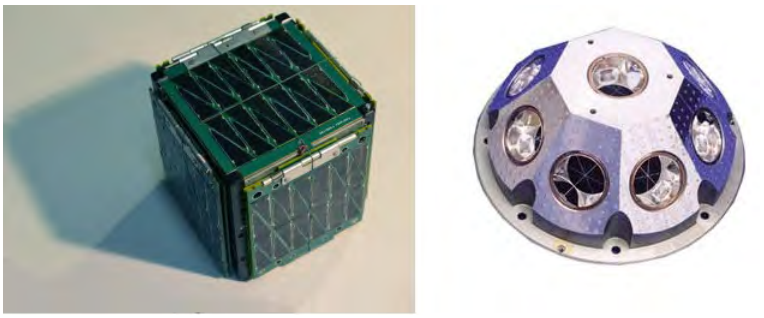


Figure 5.9 Example of a solar PV cell sensor in the shape of a cubesat or satellite (SouthernStars, 2014).

Figure 5.9 presents an illustration of a SkyCube CubeSat, which is a nano-satellite using microelectronics for navigation in the earth's orbit (SouthernStars, 2014). The square cubed shape of these satellites, simply a cube 10 centimetres on a side, are illuminated by sunlight on each side. The differences in illumination will results in differential power generated by each faade of the cube and can be used by microcontroller software to interpret the angular orientation of a solar tracker system if this shape and outer PV structure is used as solar position sensor.

The link `http://www.electronics-tutorials.ws/io/io_4.html` presents a layman's tutorial on operation of photovoltaics, light dependent resistors, light sensitive devices and sensors such photo-diodes and other photo-transistors for those who may be interested in further reading.

5.2.4 Sun Tracking: Sun Sensor

The use of sun sensors stems from the satellite and space industry where the position of the sun, or sun vector, is used in real-time to continuously determine the orientation of the satellite or spacecraft very precisely.

In spacecraft and satellite body orientation, a precise sun sensor (Figure 5.10) is spun at a constant rate to determine the spacecraft orientation with respect to the sun. Designed for use in nano-spacecraft, these sensors are claimed to achieve higher measurement accuracies compared to photodiodes (SolarMEMS, 2013).

In Figure 5.10, incident sunlight enters the sun sensor through a small pin-hole in a mask plate (giving a $\sim$50° field of view, around four hours exposure to the sunpath), where the light is exposed to a silicon substrate which outputs four signals in relation to the horizontal and vertical incidence of light. The sun vector $S_Q(\gamma_s, \theta_s)$ is then calculated through an image detector and a calibration algorithm, providing a solar vector accuracy to $\sim$0.2° (Xie and Theuwissen, 2013).

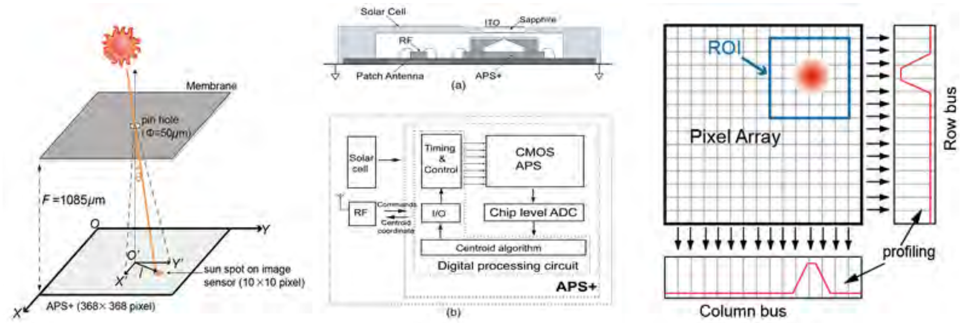


Figure 5.10 Determining the solar concentrator orientation using a CMOS sun sensor to compute the incident ray angle (Xie and Theuwissen, 2013).

In general, the micro-digital sun sensor can detect the angular position of the sun from the angle at which the sun rays illumenate the chip. This system-on-chip sensor is an imaging chip that integrates a CMOS active pixel sensor array of 368 x 368pixels, a 12-bit analog-to-digital converter and a digital signal processing circuit on chip to detect sun angle orientation (Xie and Theuwissen, 2013).

Figure 5.11 shows the more practical side of another micro mechanical sun sensor made by SolarMEMS (SolarMEMS, 2013). It shows the as well as the input and output signals from which data the sun vector is calculated in terms of the true optical azimuth and elevation angle of the sun.

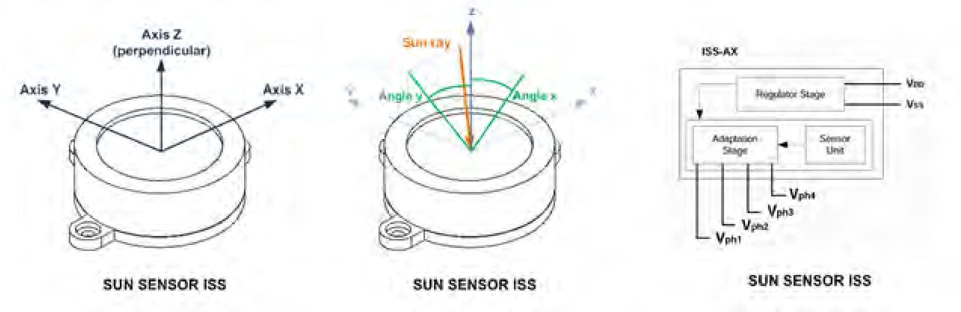


Figure 5.11 The SolarMEMS sun sensor operational and signal parameters (SolarMEMS, 2013).

One practical challenge with sun sensors in general may be weather effects. These sensors have been developed for spacecraft type applications and do pose some problems in solar tracking applications where potential dust and rain causes challenges. These sensors use a very small aperture pinhole configuration to determine the angle of the sun very accurately. This pinhole mechanism may cause the sensor to be prone to dust and rain interferences in the rough rural environmental and agricultural conditions in which a concentrated solar tracking system would typically be required to operate.

5.2.5 Sun Tracking: Camera Image Processing

Camera image processing may also be used to optically control the solar tracking operation or to assist in compensating for errors in azimuth and elevation angle errors experienced in open-loop control mode. With an optical feedback means, the control system can ensure that any tracking errors due to wind effects, mechanical backlash, installation mismatches, accumulated errors or other disturbances in the positioning of the parabolic dish are reduced.

High resolution and accuracy. In general, machine vision algorithms provide the ability to locate objects of known characteristics to within tenths or hundredths of a pixel. The use of a web camera system to augment or fine-tune the positioning of the solar dish during continuous sun tracking was presented by Arturo (Arturo and Alejandro, 2010). Figure 5.12(a) shows a snapshot real-time pre-binarization image of the sun taken by the web camera, while Figure 5.12(b) shows the converted binary image processed to compute the centroid position of the sun on the snapshot image, determining the sun vector $S_Q(\gamma_s, \theta_s)$ according to the principles used by Arturo *et.al.* (Arturo and Alejandro, 2010).

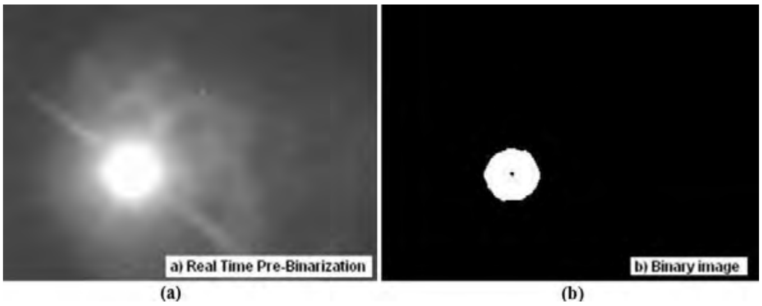


Figure 5.12 Determining the solar concentrator orientation using a web camera with image processing to determine the coordinates of the sun centroid on a binary image (Arturo and Alejandro, 2010).

Web camera mechanisms with image processing can be employed in closed-loop solar tracking control. It uses the image processed sun vector S_Q to align the parabolic concentrator dish towards the sun. In this control strategy, the dish may also be directed through a homing process to guide the dish closer to the true focus point of the parabolic dish.

Rather than use a simple centroid-of-bright-pixels method for determining the center of the sun, a microprocessor first identifies the largest region of connected pixels (referred to as a the sun disc), discarding all outliers (Figure 5.13). Various parameters of this disc are examined and compared against expected values for the sun shape, allowing errors due to haze or cloud cover to be rejected. Additional processing is then performed to determine the center of the sun (Davis *et al.*, 2008).

Figure 5.13 shows the image of the solar disc acquired using pinhole setup, before and after circle-finding. The red circle (center marked with a red dot) illustrates the error that would be associated with a simple centroid calculation of sun position as a result of cloud distortion of sun image.

The Wii Remote also features a PixArt optical sensor, allowing it to determine where the Wii Remote is pointing. The PixArt Imaging IR camera sensor capable of tracking up to four independent IR light sources. Its image processing provides location data at 1024x768 resolution with 100 Hz refresh rate (Lee, 2008). The PixArt Multi-Object Tracking engine (MOT sensor) technology can track multiple objects in an unbelievably quick and responsive way. As a result, it can enable its new gaming controller to interact with people by tracking the movement of the Wii Remote.

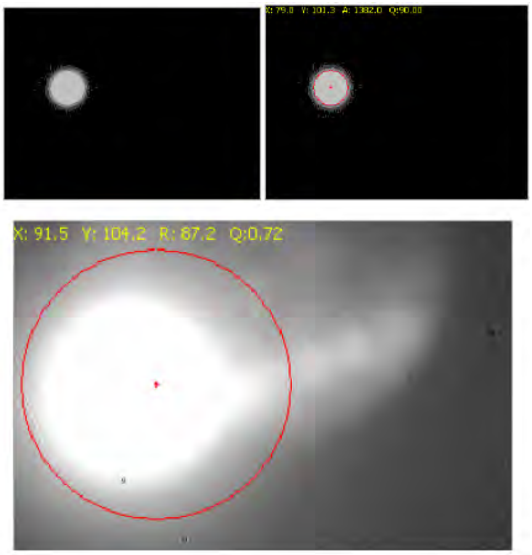


Figure 5.13 Image of the sun acquired using pinhole setup, before and after circle-finding (Davis *et al.*, 2008).

There are also programs available on the internet for using Wii Remote on a Windows PC and to display the coordinates of any infrared sources in the view of the camera as shown in Figure 5.14 (Onakasuita, 2014). The software for the interfacing of microprocessors with the camera is also availableon the the links of Onakasuita2014 here `http://onakasuita.org/wii/index-e.html` and `https://code.google.com/p/darwiinosc/downloads/list`.

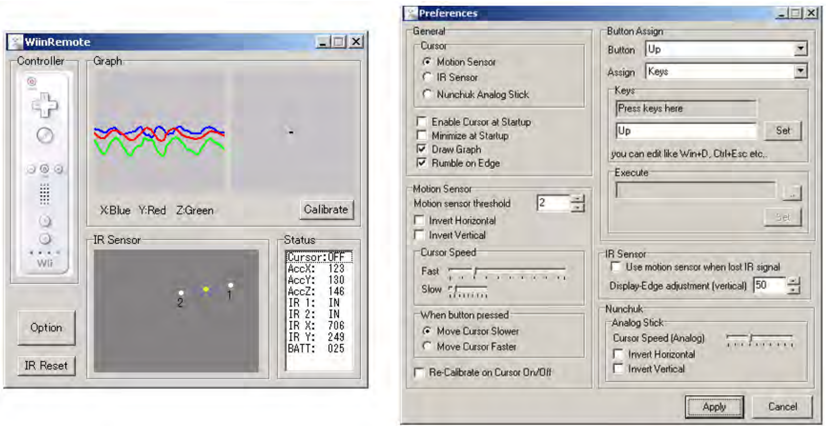


Figure 5.14 Windows PC Wiimote infrared camera coordinate software display for testing Wiimote (Onakasuita, 2014).

The Wii pixart IR camera board includes an integrated processor which outputs the X and Y positions and size of the 4 brightest IR points that is sees (Pixart, 2014). This link explains more `http://www.wiimoteproject.com/`.

The Wii remore infrared camera is a Pixart Infrared Camera with 128 x 96 pixel resolution. This is oversampled onboard to generate a 1024 x 768 resolution view. The camera outputs X/Y coordinates for up to four IR points, as well as approximate intensity/size. There is some interesting information on this link `http://procrastineering.blogspot.com/2008/09/working-with-pixart-camera-directly.html`.

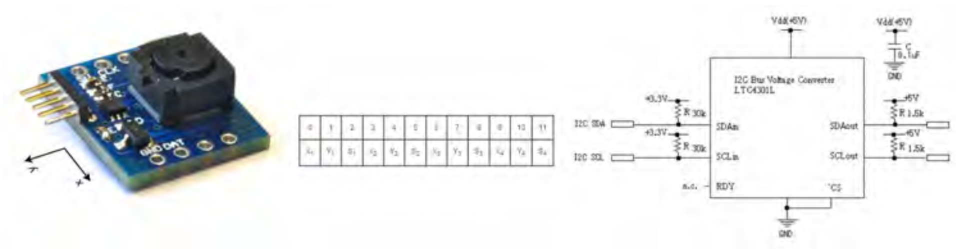


Figure 5.15 Wiimote PixArt camera with built-in multi object infrared tracking (Pixart, 2014).

These infrared and object tracking features of the camera may be very useful for tracking in robotics or human interfaces and perhaps also for solar tracking. We are still experimenting with the potential of using the infrared and multi-object-tracking features of the PixArt Wii remote camera in solar tracking applications, but we are of the view that it may provide an interesting solution towards identifying the coordinates of the sun if a proper lens could be fitted to the Wii remote camera (Prinsloo, 2014*a*). Another option is to conduct template matching by lining up the solar tracking system with the image of the sun, as illustrated in the concept of Figure 5.16 (Prinsloo, 2014*a*).

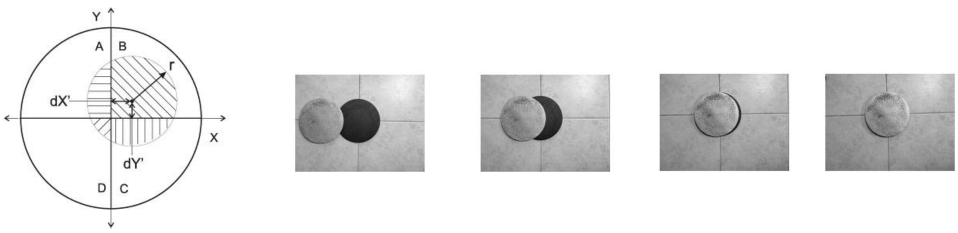


Figure 5.16 Conceptual illustration of solar tracking in terms of lining up the sun with a camera image template (Prinsloo, 2014*a*).

Expert programmer Lee (Lee, 2008) has done significant work on the Wii remote and associated code to. He posted video demonstrations and sample code at his website on how to use the Wii Remote for finger tracking, low-cost multipoint interactive whiteboards as well as head tracking for desktop VR displays. The videos and program code is given on this link `http://johnnylee.net/projects/wii/`.

```
#include <Wire.h>
#define DS1307_ADDRESS 0x68
#define camera_I2C 0xB0;             // real time clock library
                                     // real time clock I2C interface address
                                     // infrared camera I2C interface master address

void setup()
{
  cameraIR_Addr = camera_I2C;

                       // IR camera multiple object tracking (MOT) sensor initialize
```

```
  cameraIR_Addr = cameraIR_Addr >> 1;
  Write_2bytes(0x30,0x01); delay(10);
  Write_2bytes(0x30,0x08); delay(10);
  Write_2bytes(0x06,0x90); delay(10);
  Write_2bytes(0x08,0xC0); delay(10);
  Write_2bytes(0x1A,0x40); delay(10);
  Write_2bytes(0x33,0x33); delay(10);
}
              // 0x21 as the "slave" address to pass to I2C wire Wii camera
//WiiMote Camera INFRARED OBJECT TRACKING

void Write_2bytes(byte d1, byte d2)
{
    Wire.beginTransmission(cameraIR_Addr);
    Wire.write(d1); Wire.write(d2);
    Wire.endTransmission();
}

void trackIRsources()               // buffer to read IR sensor/camera data
{   byte data_buf[16]; int s,i;     //IR sensor read
    Wire.beginTransmission(cameraIR_Addr);
    Wire.write(0x36);
    Wire.endTransmission();

    Wire.requestFrom(cameraIR_Addr, 16);
    for (i=0;i<16;i++) { data_buf[i]=0; }
    i=0;                            // Request the 2 byte heading (MSB comes first)
    while(Wire.available() && i < 16) {
        data_buf[i] = Wire.read();
        i++;
    }

    heatsource_Az[0] = data_buf[1];
    heatsource_El[0] = data_buf[2];
    s   = data_buf[3];
    heatsource_Az[0] += (s & 0x30) <<4;
    heatsource_El[0] += (s & 0xC0) <<2;

    heatsource_Az[1] = data_buf[4];
    heatsource_El[1] = data_buf[5];
    s   = data_buf[6];
    heatsource_Az[1] += (s & 0x30) <<4;
    heatsource_El[1] += (s & 0xC0) <<2;

    heatsource_Az[2] = data_buf[7];
    heatsource_El[2] = data_buf[8];
    s   = data_buf[9];
    heatsource_Az[2] += (s & 0x30) <<4;
    heatsource_El[2] += (s & 0xC0) <<2;

    heatsource_Az[3] = data_buf[10];
    heatsource_El[3] = data_buf[11];
    s   = data_buf[12];
    heatsource_Az[3] += (s & 0x30) <<4;
    heatsource_El[3] += (s & 0xC0) <<2;

    for(int i=0; i<4; i++)
    {
      if (heatsource_Az[i] < 1000)
        Serial.print(" ");
      if (heatsource_Az[i] < 100)
```

```
        Serial.print(" ");
      if (heatsource_Az[i] < 10)
        Serial.print(" ");
      Serial.print( int(heatsource_Az[i]) );
      Serial.print(",");
      if (heatsource_El[i] < 1000)
        Serial.print(" ");
      if (heatsource_El[i] < 100)
        Serial.print(" ");
      if (heatsource_El[i] < 10)
        Serial.print(" ");
     Serial.print( int(heatsource_El[i]) );
      if (i<3)
        Serial.print(",");
    }
    Serial.println("");
    delay(3);
}
```

There is some projects that have started tracking applications that incorporates servo or stepper motors on an Arduino processor in tracker applications. Although not a solar tracking application, but a face tracking application, Hobley (Hobley, 2009) published a Wii camera library and example code that is very useful. The camera connections are described here `http://www.instructables.com/id/Wii-Remote-IR-Camera-Hack/?ALLSTEPS` and on this link `http://www.stephenhobley.com/blog/2009/02/22/pixart-sensor-and-arduino/` while the link to the code `http://www.stephenhobley.com/arduino/PVision.zip`.

By incorporating aspects such as the above in solar tracking applications, means we are working towards robotic solar tracking and using intelligent user interfaces in solar tracking. One of the chapters in this books deals with intelligent solar tracking from an artificial intelligent perspective.

5.3 More on the MEMS Sun Sensor

Optical accuracy during continuous solar tracking is a key performance criteria for the proposed solar concentrator system. A diagnostic optical instrument is required for measuring the solar tracking accuracy and to evaluate system performance on the azimuth and elevation axes. The SolarMEMS ISS-AX sun sensor provides extremely accurate optical measurements of sun ray incident vectors and are fabricated for high-precision satellite applications. It uses a high-precision substrate type integrated circuit sensing structure to measure sun-ray incident angles (SolarMEMS, 2013). This guarantees that the SolarMEMS ISS-AX device ensures reliable optical measurements at low power consumption levels. Such characteristics make the device suitable for high-precision sun-tracking and positioning systems, for example in aircraft altitude control, solar tracking/pointing systems, heliostat control, altitude control using light sources as well as for measuring solar radiation levels.

The operational principles of the SolarMEMS sun sensor is illustrated in Figure 5.3. Interfacing between the sensor and the data acquisition system is accomplished through a four-core cable carrying analogue signals. The sun sensor datasheet is presented in Figure 5.3 and explains how the zero degree position of the sensor is calibrated through a simple alignment process during installation. Continuous output signals allows for the measurement of the sun ray incident vector $S_Q(\gamma_s,\, \theta_s)$, and provides sun ray projection angles in two orthogonal reference axes suitable for solar tracking applications (SolarMEMS, 2013). The SolarMEMS ISS-AX sun sensor can also be integrated into a data acquisition system to operate as solar tracking error datalogger. Moreover, procedures to employ the SolarMEMS ISS-AX sun sensor in a hybrid open-loop closed loop Siemens PLC control philosophy is discussed by Prinsloo (Prinsloo, 2014*b*). This solar reflector tracking system use a solar positioning algorithm to direct the reflector system by computing the direction of the solar vector at any specific location at a particular time using astronomical coordinates as basis of computation. The sun sensor assists with a homing sequence to focus any sun-tracking error remaining through the sun sensor.

Figure 5.3 shows the technical specifications of the MEMS ISS-AX sun sensor device, which allows for the measurement of the incident angle of a sun ray by providing four analog outputs. By means of a simple computation (see formulas Figure 5.3) the solar vector $S_Q(\gamma_s, \theta_s)$ can be computed.

It needs to be stressed that an optical sun sensor can easily be soiled in dusty operating conditions. Sun sensor soiling would significantly affect the sun sensor output and tracking ability of the PLC controller and care should be taken while conducting the experiment as to the condition of the sensor and its ability to return reliable results. Moreover, the presence of clouds could impact on the accuracy of this optical device and therefore, for reasons of comparison, the experiment is conducted on a clear day in order to reduce environmental influences on the experiment. As part of the procedure to compare open-loop and closed-loop solar tracking, the PLC will remain in the last visible sun position, should cloud cover interferences be experienced in the experiment.

5.4 More on Image Processing System

Image processing techniques are used to determine the position of the sun from web camera images for closed-loop camera based solar tracking evaluation. Figure 5.17 illustrates how camera images of the sun is sequentially captured with a CMOS LY208C web camera, while the position of the sun is determined from an image processing algorithm running on a Nootropic experimental development board. The captured image frames with the sun localization coordinates are relayed to the PC USB port and displayed on the PC screen through an ION video-2-pc video conversion system. In the computer display, the processed localization coordinates are continually overlaid onto the snapshot images of the sun as it moves across the sky.

An Arduino microcontroller (Figure 5.17) reads the sun position coordinates from the Nootropic processor `http://nootropicdesign.com/ve/`, converts it into solar vectors $S_Q(\gamma_s, \theta_s)$, and output this as digital control signals to the Siemens Simatic S7-1214 PLC processor `www.siemens.com/s7-1200`. The PLC processor in turn controls the solar tracking process in accordance with the sun vectors received from this image processing system.

Prinsloo compared the solar tracking error sequences obtained with a web camera to that of the sun sensor and reported that the web camera error sequences appear to vary to a greater extent. At the same time calibration bias errors causes the azimuth and elevation error sequences to swing around different averages (Prinsloo, 2014*b*). He determined that web-camera variations are due to the fact that camera-based solar position technology is inherently more complex than sun sensor-based solar position technology.

The camera system used more expensive digitization equipment and a digital signal processing camera technique to compute the sun centroid coordinates from frame-to-frame sun-blob images. On the other hand, a more cost effective satellite quality sun-sensor technique detects the coordinates of the sun from individual sun-rays directed onto micro-substrates. It was determined that the camera's contrast setting would sometimes be re-

Technical Specifications.pdf

3.3. Measurements

The A*ngle X* and *Angle Y* specify the angular position of the incident sun ray inside the field of view of the ISS-AX sensor.

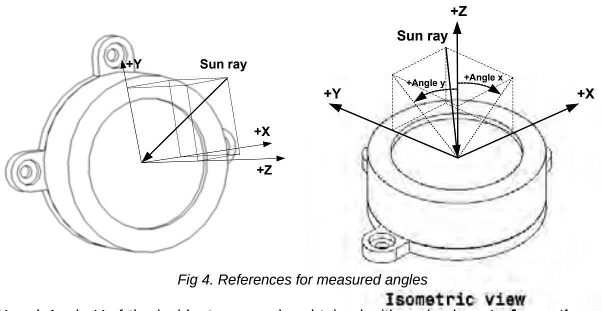


Fig 4. References for measured angles

Angle X and *Angle Y* of the incident ray can be obtained with a simple **set of equations** involving the four photodiode voltages generated by the sensor (V_{PH1}, V_{PH2}, V_{PH3}, *and* V_{PH4}):

$$X_1 = V_{PH3} + V_{PH4} \qquad Y_1 = V_{PH1} + V_{PH4}$$
$$X_2 = V_{PH1} + V_{PH2} \qquad Y_2 = V_{PH2} + V_{PH3}$$
$$F_X = \frac{X_2 - X_1}{X_2 + X_1} \qquad F_Y = \frac{Y_2 - Y_1}{Y_2 + Y_1}$$
$$Angle\ X = arctg\left(C \cdot F_X\right) \qquad Angle\ Y = arctg\left(C \cdot F_Y\right)$$

Type	Value
ISS-A60	1,889
ISS-A25	0,477
ISS-A15	0,273

Table 3. Values of the parameter C according to the type of sensor ISS-AX (Geometric Correction)

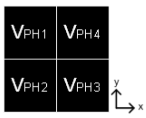


Fig 5. References for the photodiodes

The accuracy of the sensor increases when receiving a radiation perpendicular to the sensor, close to zero degrees in X and Y. This is an outstanding feature that makes it suitable for tracking applications. The **accuracy** can be **increased** in more than one order of magnitude by compensating the offset error after the installation of the sensor by means of **Calibration**.

The use of a **filtering stage is recommended** (for example: 50 Hz sampling frequency and 0,4 Hz bandwidth).

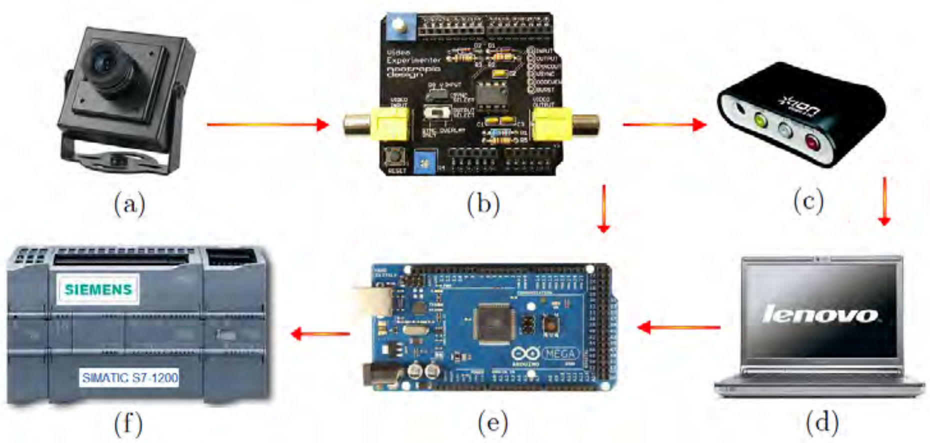


Figure 5.17 Image processing system for determining sun position coordinates from camera images, includes (a) CMOS LY208C web camera, (b) Nootropic image processor, (c) ION video-2-pc USB interface, (d) personal computer, and (e) Arduino μcontroller relaying sun vectors to (f) PLC processor to control solar tracking (Prinsloo, 2014*b*).

sponsible for introducing very small average/offset deviation errors in camera-based closed-loop tracking in the early morning and late afternoon. This was due to sunlight brightness variations between noon and afternoon/morning interferes with the image processing accuracies. It was observed that the solar tracking error rate is sensitive to the contrast sensitivity setting on the web camera.

Prinsloo (Prinsloo, 2014*b*) also found that higher frequency noise and offset error fluctuations in the solar tracking error patterns emanate from the camera-based solar vector computations. This was explained in the context of the technical details and steps used in the camera-based image processing technique.

In camera based solar tracking, an industrial PLC is unable to provide sufficient computing power to support the mathematical complexities of image processing. As a result, separate image processing hardware and a sequence of steps are required to determine the solar vectors through a web camera device, as shown in Figure 5.17. The steps followed in determining the sun position is as follows:

- The web camera faces the sun while external digital hardware captures individual pictures of the sun.

- Image processing software then performs complex processing to box the outline of the most apparent solar disc/blob within the captured image frame, though a process termed ”sun-localization”, typically using edge detection or object tracking techniques (Arturo and Alejandro, 2010). With a fixed web camera contrast setting, variations in the brightness of the sun over the course of the day (morning, noon, afternoons, clouds, etc.) does influence the sun-localization process, introducing potential sun localization errors.

- Continuing along with the (apparent) solar disc boxed/localized within the image, further processing in the next step determines the pixel coordinates of the centroid in the localized sun disc on each picture frame (see Figure 5.10(b, c)).

- This is followed by a step to determine and convert the sun vector pixel coordinates (x,y) into sun vector angles (°) using calibration parameters.

- In the final step, solar tracking azimuth/elevation axes errors are computed from the solar centroid image pixel displacement values.

It was determined that the sun-localization step is normally responsible for inconsistent/fluctuating daytime and frame-to-frame (noisy/biased) sun centroid pixel coordinates, especially since a camera image can be distorted when pictures of the sun are captured in varying sunlight levels and interferences from haze, clouds, wind or dust.

To help overcome distortions and contrast sensitivity problems experienced with the camera solar vector processing system, it is anticipated that a more expensive infra-red camera would help to improve sun-localization that will result in more accurate sun centroid calculations (especially in cloudy or dusty conditions). Furthermore, inter-frame sun centroid coordinate fluctuations/noise could be smoothed by progressively passing the determined output coordinates through a digital low-pass filter (i.e. Kalman moving average filter).

Even with such interventions, it is believed that the camera imaging system would still suffer from inaccuracies and would still not be able to achieve the same levels of sun vector pinpoint accuracies guaranteed by a simple and less expensive sun sensor device.

5.5 Cloud Cover Optical Tracking Survival Angles

One disadvantage with sun sensor based closed-loop solar tracking control is that the system is dependent on solar visibility. Optical solar tracking systems thus have a serious disadvantage in that dust and cloud cover could influence any optical sensor, for example a sun sensor or web camera.

These effects can cause the solar tracking system to lose sight of the sun, especially if the cloud cover continues for longer periods of time. Optical based solar tracking accuracy experiments should thus normally be conducted on a clear day in order to reduce environmental influences such as cloud transients on the optical measurements.

However, when practical closed-loop optic solar tracking experiments are performed and clouds do interrupt solar visibility, then the typical procedure is to program the PLC to remain in the last visible sun position while the system waits for the sun to re-appear. This is because solar tracking with optical feedback alone can cause the system to run after random bright spots in the sky if not guided for example by an astronomical SPA algorithm (Prinsloo, 2014*b*).

Other than with astronomical algorithms, the optical observation means on its own is unable to determine the solar vector if the sun is eclipsed by cloud cover (even moderate cloud cover) or if the sun position moves out of the viewing angle of the sun sensor. This introduces the concept of solar tracking survival time in closed-loop optical solar tracking systems (i.e. what is the time period of cloud cover an optical solar tracking system survive).

For example, the SolarMEMS sun sensor (ISS-A25) has a $\sim 50°$ viewing angle, which allows for maximum $\sim$1.5 hours of continuous cloud cover or loss of view of the sun ($25°$ forward view, $\sim$12 hours over horizon, $\sim$4 minutes/degree), before the sun sensor tracking and control system would lose its synchronization with the sun and would be unable to recover from lost synchronization on that particular day (Prinsloo, 2014*b*).

The reader can consider the viewing angle of an optical means in terms of solar tracking hours, as illustrated in Figure 5.18, to understand the concept of optical solar tracking survival and associated calculations.

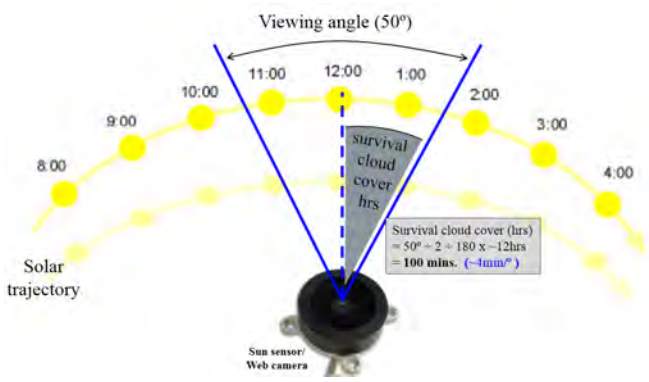


Figure 5.18 Cloud cover survival angle for sun sensor or video camera based solar tracking (Prinsloo, 2014*b*).

From Figure 5.18 it can be seen that the viewing angle of an optical means can be converted into solar hours using a simple calculation given in Equation 5.1.

$$Survival(hrs) = \frac{camera.view.angle(^\circ)}{2(half.view.fwd)} \div 180^\circ \times daylight(hrs) \qquad (5.1)$$

For the SolarMEMS sun sensor (ISS-A25) with a viewing angle of $\sim 50^\circ$ the solar tracking survival in hours/minutes can be calculated as given in Equation 5.2.

$$Survival(hrs) = \frac{50^\circ}{2} \div 180^\circ \times \ 12(hrs) = 100mins.(\pm 4min/^\circ) \qquad (5.2)$$

In the worst-case scenario, given long periods of cloud transients and a low-capacity backup battery, the solar tracking operation demand would drain the backup battery and the control system would eventually end up in a dysfunctional state. In this state, system discontinue tracking and either wait for the tiny solar recharger to recharge the batteries, or remain in such pointing position where the tracker stops at its last solar exposure position to wait for the sun-path to cross in a following day in order to re-establish its sun connection from this last moving position with minimum power and effort (Prinsloo, 2014*b*).

Web camera-based closed-loop solar tracking control also depends on the sun being directly within the view of the camera, meaning that the system would find it difficult to recover from prolonged periods of cloud cover. However, the web camera has an advantage over the sun sensor in still being able to locate the sun's position in moderate cloud cover, while the camera's zoom function could in future be used to dynamically adjust or broaden the camera's field of view. In this respect, a camera with an adjustable viewing/zoom angle between 50° and 90° allows for an adjustment between $\sim$1.5 to 3 hours of continuous cloud cover or loss of view of the sun (45° forward view, $\sim$12 hours over horizon, $\sim$4 minutes/degree), before such a camera based tracking and control system would lose its synchronization with the sun and would be unable to recover from lost synchronization on that particular day.

It needs to be stressed that in closed loop or optical feedback solar tracking control, an optical sun sensor or camera can easily be soiled in dusty operating conditions. Sun sensor soiling would significantly affect the sun sensor output and tracking ability of the PLC controller and care should be taken while conducting experiments as to the condition of the sensor and its ability to return reliable results.

5.6 Summary

A parabolic dish must be tracked in two dimensions in order to allow focussing of the sunlight and to maintain the incident beams of the sun normal to the solar receiver aperture. This chapter detailed various design options in terms of optical feedback sensors and optical solar tracking. In the next chapter, solar position algorithms will be discussed.

Generally, quadrant photo diode configurations or camera image processing are used to optically register deviations between the pointing direction of the reflector system and the calculated sun vector. These quadrant diode signals are typically fed into the control unit of the tracker in order to fine-tune the reflector pointing axis. However, optical illusions caused by atmospheric gasses during low solar elevation as well as other atmospheric interferences from clouds and haze cause these systems not to always achieve the required accuracy (Gisi *et al.*, 2011).

On the other hand, camera images suffer from the same optic deficiencies. However, certain camera devices are able to process the infra-red spectrum of the image separately. In such imaging systems, the above problems with solar tracking control can be are overcome by directing the reflector tracking with a supplementary infra-red based camera homing system.

CHAPTER 6

POSITION AND ANGLE FEEDBACK MEASUREMENTS

Solar Tracking, First Edition.

6.1 Introduction

This chapter provides details on determining the angular orientation of the solar tracking system. It discusses details of devices such as angle sensors, rotary encoder and tilt sensors. The devices are required to support the solar tracking application on microprocessor and PLC platforms for solar tracking systems.

6.2 Solar Tracker Angle Orientation Sensors

In general there are two types of angular sensors, namely the absolute encoder and the incremental or differential encoder. The absolute encoder keeps track of the angular position of a system and will maintain angular information when power is removed from the system. This has the benefit that the last position of the encoder is known exactly and is available immediately after applying power to the sensor.

One method to measure solar tracking orientation (with respect to pointing orientation) is to mount a shaft encoder or angle sensor on the azimuth and elevation shafts of the solar tracking platform. This often creates practical challenges as one do not always have access to the centre shaft of any of these axes. Often the centre axis is located inside a gearbox or drive mechanisms and is difficult to reach or mount external parts.

The general practice is to connect the shaft encoder or angle sensor onto the solar tracker DC or AC motor actuator drives, and to count the revolutions of the azimuth and elevation drive motors during solar tracking operation. Most industrial motors simplify this challenge as motors often include (check this when you purchase a solar tracker motor) an integrated magnetic pulse generator for the output of magnetic pulses to a magnetic pulse encoder.

To convert the motor rotation pulse counts into solar tracking angles, your microprocessor simply have to do a quick computation. At this stage it suffices to say that one simply divides the counted motor revolutions/pulses with the gear ratio of the gear-train (multiply gear ratios if more that one gearbox/actuator) from the motor shaft to the solar tracking axle and divide this by 360°. The exact details will be discussed in more detail in a later chapter in this book, namely the chapter entitled *Manoeuvring the Solar collector*.

The rest of the discussion in this section explains how the magnetic pulses are converted into solar tracker azimuth and elevation information.

6.3 Differential Encoder Angle Sensors

Magnetic pulse encoders are typically incremental or differential encoders. These encoders record differential changes in the shaft position of a system very precisely, typically in terms of magnetic pulses. Figure 6.1 shows the operational principles of a magnetic pulse encoder. This type of encoder do not keep track of the physical position of the system, except if an electronic module is attached to the unit that stored the sensor values continuously.

The main feature that distinguishes an incremental encoder from an absolute encoder (discussed next) is the lack of memory about its previous angle location. An incremental encoder detects only incremental changes in the position of the tracking axis and reports these pulse counts to the microcontroller or counting electronics. With power-up, the in-

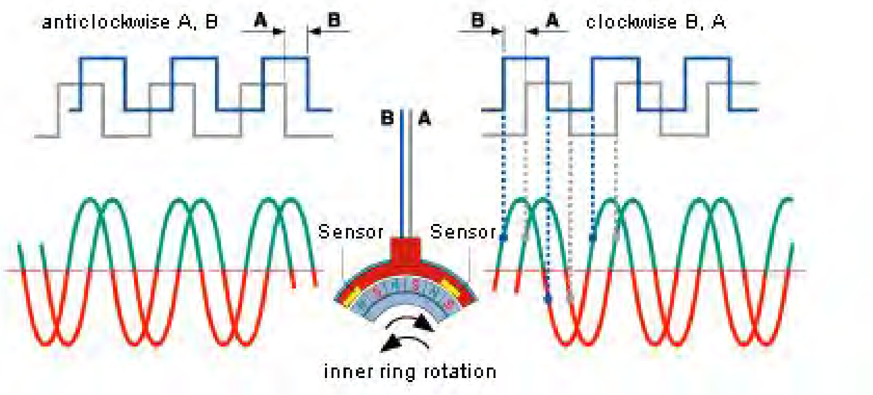


Figure 6.1 Solar tracker azimuth and elevation axis angular positions in terms of magnetic pulse encoders (SKF, 2014).

cremental/differential angle sensor is unable to provide any information about the previous relationship between the physical position of the tracking system and the encoder state.

An incremental encoder needs a microprocessor or associated software to keep track of the physical position of the system by way of counting pulses during movement. To provide useful position information, the encoder position must initially be referenced to the solar tracking orientation upon setup and configuration. It generally requires an index pulse from a reference pulsing unit or trip switch type mechanism.

To count the incremental differential movement, the incremental encoder typically converts two (or more) AC magnetic wave streams into a square wave A and B pulse outputs. More than one magnetic wave or pulse streams are required to differentiate between the direction of motion, either forward or reverse (see Figure 6.1). Thse type of encoders are often also referred to as sin/cos encoders since the A and B magnetic waves are 90° shifted to use the sin and cos relationship to determine the angle.

Pulse counting and angle computations are then performed by external electronics, mostly by the microcontroller that controls the overall solar tracking operation. The microcontroller has to count and continuously store the sensor pulse positions as well as the solar tracking angle orientations, just in case the power trips and the information will be lost. The point where the counting begins depends on the counter setup during configuration.

The relationship between the absolute encoder output value and the physical position of the controlled/tracker system is configured upon setup and calibration, meaning absolute encoders do not need to return home to a reference point for calibration in order to maintain position accuracy.

6.4 Precise Digital Encoder Angle Sensors

Another type of absolute angle encoder is the digital encoder. Modern absolute digital encoders provide a digital output that can be read on the microcontroller bus directly. Digital absolute encoders can be mechanical absolute encoders or optical absolute encoders, either providing a unique digital code for each distinct angle of the shaft. This is the so-called ”on-axis” type angle sensor.

An optical shaft encoder includes a metal or plastic disc with open slots, from which a light source and photo detector senses the optical patterns associated with the angular disc position. The optical encoder principle of operation and output signal codes are illustrated in Figure 6.2.

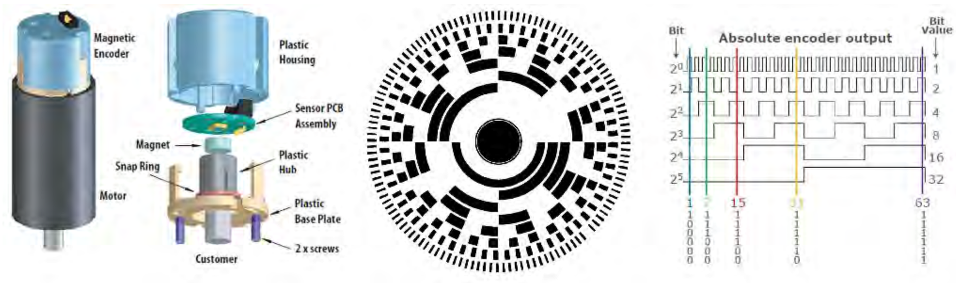


Figure 6.2 Solar tracker azimuth and elevation axis angular positions in terms of optical encoder pulses encoders (Gabay, 2012).

The relationship between the absolute encoder output value and the physical position of the controlled/tracker system is configured upon setup and calibration, meaning absolute encoders do not need to return home to a reference point for calibration in order to maintain position accuracy.

6.5 On-Chip Absolute Angle Sensors

The modern trend in angular displacement measurements is to use on-chip encoders. These encoders include a IC chip that that communicates digitally with the microcontroller over an RS232, RS454, SPI or I2C data bus interface. The function of the chip is to take the burden off the microcontroller by way of keeping track of the angular position of the rotating shaft on a microchip as illustrated in Figure 6.3 (Lin, 2008).

In Figure 6.3(left), there is shown the interpolation process with which the encoder determines the angle. The graphic representation of the phase angle between the two magnetic waves (A and B denoted earlier) $A = sin(\phi)$ versus $B = cos(\phi)$ produces a circle associated with the angular position being measured. The interpolation determines the current discrete angle ϕ_t with predefined angle positions to generate the matching quadrature signals A and B.

The typical absolute Hall angle encoder IC is a magnetic single-chip encoder with 10-18 bit resolutions over 360°, with better than 0.02° angular resolution. It can also be associated with a multi-turn encoder interfaces and can offer up to 46 bit resolution. A absolute shaft position position can be read by a microcontroller over a standard interface such as SPI or I2C digital bus (IC Haus, 2014).

IC type sensors mostly work with magnetic fields, meaning that it alleviates the burden of connecting a the rotating shaft of the encoder onto the axle of the solar tracking axle or motor. One can simply install a gear on the shaft and mount the IC in close proximity to the shaft to count the gear teeth. This is the so-called ”off-axis” type angle sensor (IC encoders can either be off-axis or on-axis, depending on user requirements).

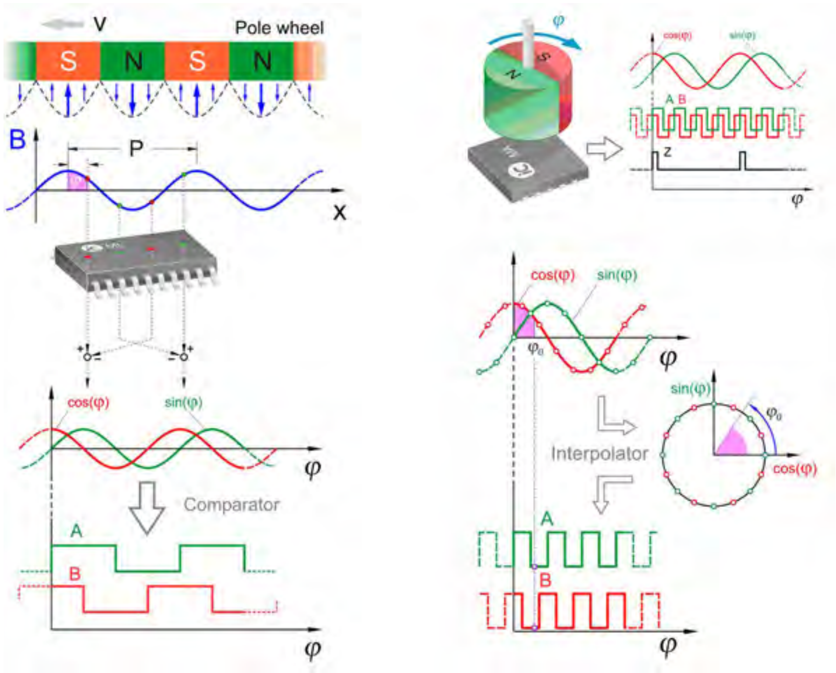


Figure 6.3 Solar tracker azimuth and elevation axis angular positions in terms of digital IC codes (Lin, 2008).

In interesting and practical explanation is given by Lee (Lin, 2008) on these pages `http://staging.edn.com/design/sensors/4324812/Speed-acquisition-made-simple` and another block layout (IC Haus, 2014) on this link `http://www.semiconductorstore.com/cart/pc/viewPrd.asp?idproduct=46655`.

6.6 Analogue Angle Sensors

A more traditional type of angle encoder is the analogue angle encoder that outputs a voltage in relation to the angle. Figure 6.4 illustrates solar tracker azimuth and elevation axis angular position representations in terms of analogue angle encoder outputs.

In this example, analogue encoders provide potentiometer type analogue values as output in accordance with the physical angle of the solar tracking platform orientation. The microcontroller can thus detect the axis angles of the tracker orientation by means of analogue input values on the XY position input potentiometer. The same applies for the azimuth as well as the elevation angle or the zenith angle. In typical industrial grade analogue angle sensors, the output varies in the 0-10 V range (Siemens, 2010*a*).

6.7 Tilt Sensors and Inclinometers

Furthermore there are other angle measuring sensor used in solar tracking applications, such as tilt sensors. These sensors are typically less expensive and use low-power to detect

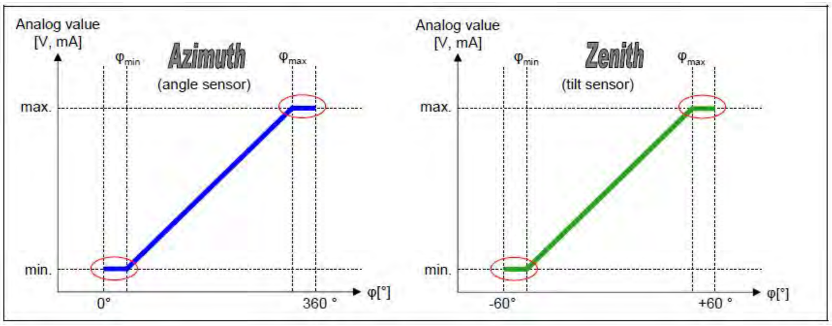


Figure 6.4 Solar tracker azimuth and elevation axis angular positions in terms of angle encoder analogue outputs (Siemens, 2010*a*).

orientation or inclination on the solar tracking elevation axis. These sensors are sealed and do not wear out, as it has limited moving parts.

On the elevation angle of a solar tracking system, this sensor has the advantage that it does not have to be mounted on a rotational axis of the solar tracking axis or driving motor axis. One can simply stick/mount the tilt sensor anywhere onto the titling boom of the elevation boom arm and star with angle measurements. Sometimes these sensors are also referred to as mercury switches, tilt switches or rolling ball sensors. Their simplicity also makes tilt sensors popular for toys, gadgets and appliances.

Industrial grade tilt sensors are mostly sealed sensors that uses solid state 3D-MEMS (Micro-Electro-Mechanical Systems) technology to measure the sensor/tracker inclination relative to the orientation or gravity of the earth. These sensors typically have measurement angles in the range around 0-60 ° and normally provide a 0.5-5Vdc output signal over these angular ranges. Such sealed tilt sensors provide distinct advantages in terms of reliability, stability and compactness over fluid based, electrolytic and pendulum operated sensors for solar tracking operations (Motion, 2013).

A toy sized tilt sensor and its connections with an Aduino microprocessor is shown in Figure 6.5. The tilt sensor can thus detect the tilting of an object on which it is mounted. Data from the sensor can be processed in a simple software program to detect the object’s orientation.

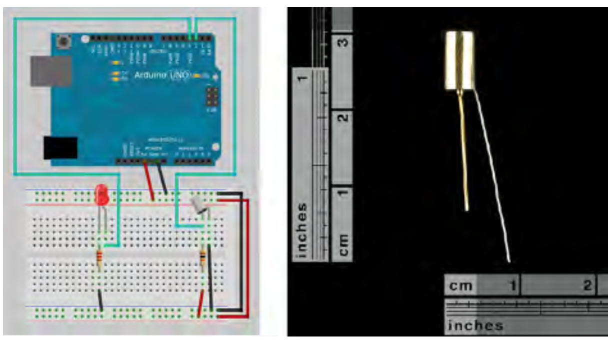


Figure 6.5 Arduino setup for tiltsensor to detect solar tracking elevation angle (Datasheet MS-100906, 2014).

Inside of this tilt sensor are metal balls that make contact with the pins when the case is upright. When the case is tilted over, then the balls do not contact certain pins. The sensor is thus not immune to small vibrations and normally requires de-bouncing code if the sensor is used in unstable applications. The sample code for the tilt sensor is given below. This de-bouncing code example is the same that is used in pushbutton de-bouncing. One can also use a pull-up resistor to use active-low to activate the pins.

`http://garagelab.com/profiles/blogs/tutorial-tilt-sensor-with-arduino`

```
int SensorPin = 2;
int LEDPin = 3;

int LEDstate = HIGH;
int reading;
int previous = LOW;

long time = 0;
long debounce = 50;

void setup()
{
pinMode(SensorPin, INPUT);
digitalWrite(SensorPin, HIGH);
pinMode(LEDPin, OUTPUT);
}

void loop()
{
int switchstate;

reading = digitalRead(SensorPin);


if (reading != previous) {

time = millis();
}

if ((millis() - time) > debounce) {

switchstate = reading;

if (switchstate == HIGH)
LEDstate = LOW;
else
LEDstate = HIGH;
}
digitalWrite(LEDPin, LEDstate);

previous = reading;
}
}
```

`https://github.com/pingswept/pysolar/wiki/examples`

Finally, more complex inclinometers are also used in solar tracking and monitoring of a dynamic structure such as a concentrated solar system. Heckendorn (Heckendorn, 2009) describes an invention for an inclinometer that includes a magnetometer to sense changes in the measured magnetic field of the earth. These changes are indicative of movement of the dynamic or mobile structure. This movement information is interpreted through software to determine a current position or orientation for the moveable structure. In solar tracking applications, magnetic field information can be used to determine the current position of the tracker orientation as part of the process of repositioning the solar concentrator based on the determined angle differences.

6.8 Accelerometer, Magnetometer and Gyroscope Based Angle Sensors

In an inertial solar platform navigation system configuration, a solar tracker may use motion sensors (accelerometers) and rotation sensors (gyroscopes) as feedback devices to continuously calculate the position, orientation, and velocity (direction and speed of movement) of a moving object such as a solar tracking platform without the need for external references. Relative attitude sensors are sensors that generate outputs to reflect the rate of change in attitude. These sensors typically require external information or a known initial attitude to determine the real attitude or absolute attitude and are suitable for applications where the declination angle of the earth's field is difficult to measure with Hall-type sensors (Pasolini, 2011).

Magnetometers are becoming more interesting when combined together with accelerometers for implementing tilt compensated compasses in mobile phones and smart phones and devices. An example of such a device exhibiting six degrees of freedom (6 DOF) is the six-dimensional module LSM303DLH (STMicroelectronics, 2014). This device features a high-performance three-axis accelerometer integrated together with a high resolution three-axis magnetometer into a compact LGA package as shown in Figure 6.6. The magnetic sensing part also includes additional current straps that allow it to electrically set or reset the polarity of the output, and to apply an offset field to compensate for ambient magnetic fields (Pasolini, 2011).

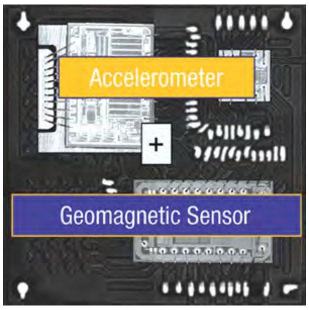


Figure 6.6 Illustration of a LSM303DLH 3x accelerometer and 3x magnetometer in compact package that can be used in solar tracker orientation feedback (Pasolini, 2011).

The MEMS angle type sensor is Figure 6.6 is thus suitable as feedback mechanisms to ensure a type of gyrostabilized tracking platform in solar tracking applications. Such motion reference units are a kind of inertial measurement unit with single-axis or multi-axis motion sensors. They utilize MEMS gyroscopes and accelerometers in multi-axis configurations are capable of measuring roll, pitch, yaw and heave. An example of a Dual Axis Solar Panel Controller and Tracker that uses accelerometer feedback is discussed on this reference (Glazner, 2013).

In general, MEMS gyroscopes and geomagnetic sensors are low-g accelerometers for the implementation of motion-activated user interfaces and protection systems (Pasolini, 2011). MEMS gyroscopes complements MEMS accelerometers as they are capable of measuring angular rates around one or more axes. By using a combination of a gyroscope and an accelerometer it is possible to track and to capture complete movement of a solar tracking system in a three-dimensional space, giving the ability to deliver accurate solar navigation systems using principles of inertial navigation systems. When used in combination, as on the chip, these accelerometer magnetometer sensors are capable of detecting linear accelerations, while gyroscopes, geomagnetic sensors, and other devices are capable of providing feedback in multiple degrees of freedom sensing applications and are very popular for the implementation of navigation functions in mobile telephone devices.

In general in inertial navigation solar tracking techniques, accelerometers and gyroscopes are used to track the position and orientation of the tracking platform relative to a known starting point, orientation and velocity. The inertial measurement unit or chip typically contain three orthogonal rate-gyroscopes and three orthogonal accelerometers, measuring angular velocity and linear acceleration respectively. By processing signals from these devices it is possible to track the position and orientation of the solar tracking platform. Other terms used to describe this technique includes inertial measurement steering, inertial guidance system, inertial reference platform, inertial instrumentation and similar variations.

6.9 Inductive Solar Sensors

It is known by now that sun contour tracking in applications such as photovoltaic and solar thermal systems increases the energy yield of the sunlight by harvesting more energy from the available sunlight. However, with a concentration of direct solar radiation in solar thermal power plants, a large number of parabolic mirror systems must be continuously moved by the solar tracker to direct the sunlight accurately toward the absorber.

In practical systems it is not always possible to get access the rotating shafts of all of these multiple solar trackers that enable the panels to follow the path of the sun. Pepperl n Fuchs supply an inductive position coding system for controlling the azimuth/elevation angle in solar tracker applications. As shown in Figure 6.7, this angular coding system provides the absolute value of the detected angle position of the solar tracker orientation based on non-contact magnetic sensing around the circumference of the rotating tracker platform housing (Pepperl Fuchs, 2014).

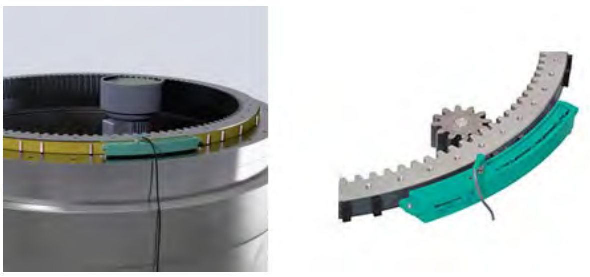


Figure 6.7 Solar tracking with an inductive position coding system wherein the position of the rotating tracker unit is detected by the inductive position coding system (Pepperl Fuchs, 2014).

The inductive sensor in Figure 6.7 ensures non-contact position angle capturing in applications where is may not be possible to access the rotation shaft directly, such as for example in rotary joints, robotic arms and slewing bearings. This induction sensor ensures non-slip absolute position measurements in a large radius and increased accuracy environment that is combined with the benefits of a large read distance between the sensor and code strip.

Induction angle sensors in general are suitable for the inductive position coding systems that is exposed in outdoor mountings. It has the benefit of non wearing and zero maintenance, while being insensitive to the typical solar tracker system challenges such as dust, dirt, oil and grease.

6.10 Summary

This chapter presented details on how to determine the angular orientation of the solar tracking system. It gives details if various angle and tilt sensors devices required to support the solar tracking application on microprocessor and PLC platforms for solar tracking systems.

PART III

SOLAR TRACKING CONTROL AND AUTOMATION

CHAPTER 7

MANOEUVRING THE SOLAR COLLECTOR

Solar Tracking, First *Edition.*

7.1 Introduction

This chapter deals with aspects associated with the manoeuvring of the solar tracking platform. In general, solar harvesting requires accurate solar tracking, which in turn requires precise focusing of the optic reflecting device onto the centroid of the sun. With the exact solar coordinates and the trajectory path of the apparent movement of the sun known (i.e. the SPA or sun path diagram at any given geographic location of the surface of the earth), this information can serve as input to the positioning system controller. The next section describes some of the basic principles of solar mobility platforms and mechanical solar tracking for solar energy harvesting that uses knowledge about the solar trajectory.

7.2 Manoeuvring the Solar Collector

The previous chapter described the calculation of the solar vector and showed the sun path or trajectory on a sun-path diagram. Given the daytime sun-path vectors for the summer solstice, winter solstice and solar equinox for any given location and is helpful in setting up and configuring a solar tracking controller for a particular site of installation. A the same time, the sun-path diagram provides a visual representation of the required solar concentrator movements and is helpful in stipulating the manoeuvring actions, the border regions and angular motion safety margins.

The main task of the solar tracker is it to align the solar collector as close as possible to the solar vector. To discuss the actions associated with the manoeuvring of the solar collector with the use of DC motors, the dual-axis (azimuth angle and zenith angle) PV solar tracker in Figure 7.1 serves as example (Siemens, 2010*b*).

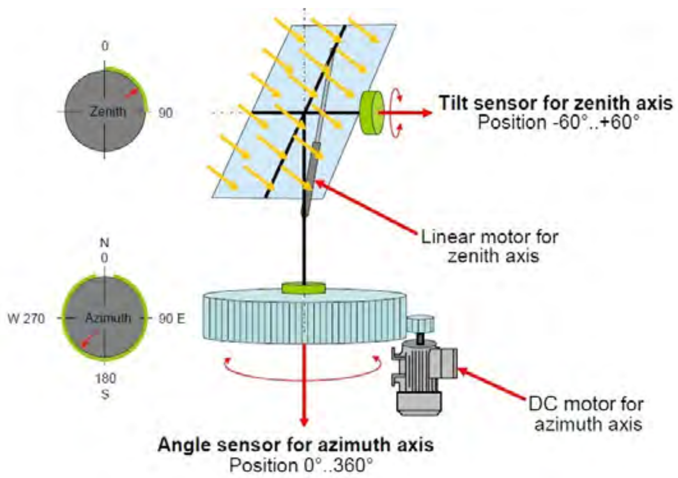


Figure 7.1 DC motor azimuth and elevation axis angular travel distances computed from gear ratio and encoder pulses (Siemens, 2010*b*).

During the process of solar tracking, an angle sensor in Figure 7.1 detects the current azimuth position while the zenith position is detected through the tilt sensor. With the help of the astronomical solar position algorithm the controller computes the azimuth and zenith angle of the solar vector at defined time intervals and compares the current solar tracker orientation with the sun position.

Using the known position of the sun, the PLC or microcontroller keeps record of the solar concentrator angular positions and compare this with the solar vector $S_Q(\gamma_s, \theta_s)$ to determine any required DC motor control signals. Through principles of angular comparisons, the PLC moves the concentrator when the angle difference exceeds the pre-configurable tracking resolution $(\Delta/2^\circ)$.

In order to move the solar collector to point directly into the sun, the PLC or microcontroller needs to compute the required angular movements for the DC linear and rotational drive motors. The relationship between the DC motor angular movement and the solar concentrator angle movement can be computed from the gear ratios of the drive system. These values are then used by the PLC or microcontroller in manoeuvring of the solar collector. The computations are detailed later in this section.

To move the reflector from any arbitrary present position towards an angle where the solar concentrator directly faces the sun, the PLC or microcontroller basically counts the motor pulses and divides this with the gear-ratio of the gear train and the solar concentrator platform movement. In this way, the PLC processor keeps track of the previous and current solar concentrator position in a register.

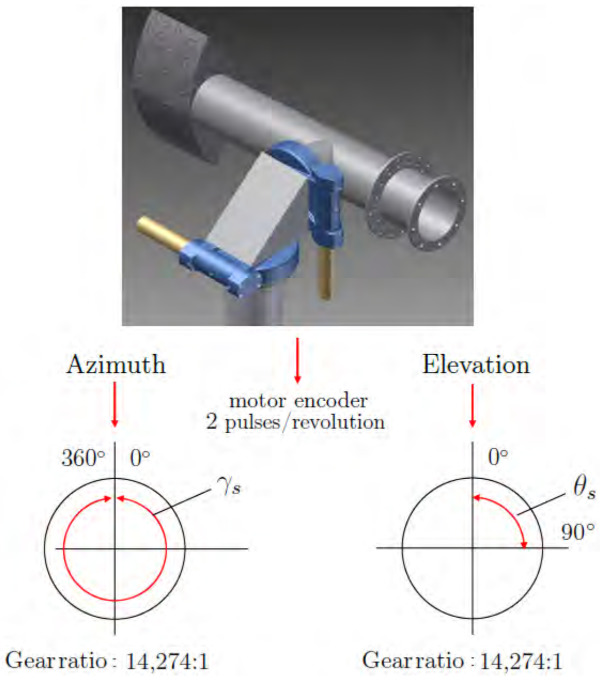


Figure 7.2 DC motor azimuth and elevation axis angular travel distances computed from gear ratio and encoder pulses (Prinsloo, 2014*b*).

Figure 7.2 shows the azimuth and elevation/zenith control ranges for the solar concentrator dual axes movement. Given the gear ratios ($slew_{ratio}$; $planet_{ratio}$) for a selected actuator, a mathematical calculation compares the solar angle to the number of Hall encoder pulses. In this calculation, the angle difference between the sun vector (γ_s, θ_s) and the concentrated solar reflector position is expressed in terms of azimuth/elevation Hall pulses, which in turn is used to command the DC motor travel distances for each of the azimuth/elevation actuators. Since the conversion of the required azimuth angle γ_s and elevation angle θ_z into DC motor travel distance (Hall pulses) is linear, the required DC motor revolutions can be calculated through Equation 7.1 and Equation 7.2 respectively. These formulas relate the relative solar position to the required DC motor movement (Hall encoder pulses) to follow sun to its next position.

$$\gamma_{az} = \frac{\gamma_s}{360°} \times slew_{az} \times planet_{az} \times Hall_{pulse/rev} \tag{7.1}$$

$$\theta_{el} = \frac{\theta_s}{360°} \times slew_{el} \times planet_{el} \times Hall_{pulse/rev} \tag{7.2}$$

With the azimuth/elevation slew gear ratio (61:1), planetary gear ratio (234:1), and Hall pulses (2:1) per rotation known (Figure 7.2), the azimuth/elevation angular travel distances (in pulses) on each of the axes can be computed from Equation 7.3 and Equation 7.4.

$$\gamma_{az} = \frac{\gamma_s}{360°} \times 61 \times 234 \times 2 \tag{7.3}$$

$$\theta_{el} = \frac{\theta_s}{360°} \times 61 \times 234 \times 2 \tag{7.4}$$

The main task of the PLC solar tracking positioning controller is illustrated in Figure 7.3, where it is shown how the PLC control triggers and precisely controls the travel distance of the actuator DC motors in terms of the number of Hall encoder pulses. The PLC monitors and controls the moving dish process according to the solar tracking resolution ($\Delta/2°$), upon inputs from the sun sensor or SPA parameters (Siemens, 2011*a*).

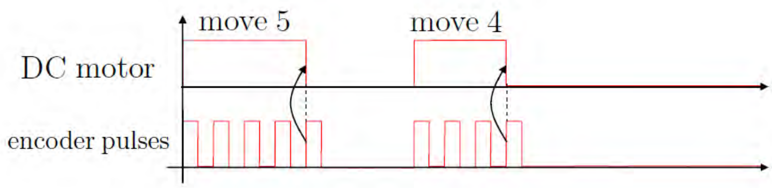


Figure 7.3 Slew azimuth and elevation axis motor travel distances computed by PLC from encoder pulses and actuator gear ratio through Equation 7.1 and Equation 7.2 (Prinsloo, 2014*b*).

The travel distance computations in Equation 7.3 and Equation 7.4 for the azimuth/elevation axes relates to the solar tracking movement. It can be logged/saved to show graphs of the azimuth and elevation axes solar tracking movement patterns as the solar dish follows the sun throughout the day.

Control concepts exist to compensate for variations. These concepts include open-loop control systems, closed loop control systems and in some cases a hybrid control system where open-and -closed loop configurations are combined. Such solar tracking control strategies will be described in follow on chapters.

For solar tracking with stepper motors, the process is very similar. By way of illustration, Figure 7.4 illustrates two stepper motors controlled through an Arduino processor. This implementation uses the EasyDriver Stepper Motor Driver as high current interface between the motor and the delicate electronics of the Arduino processor (SparkFun, 2014*a*) (note that there are many other current drivers available in the market).

A stepper motor based solar tracking system can use the stepper motors directly to drive the azimuth and elevation angles of the motors are song enough to carry the me-

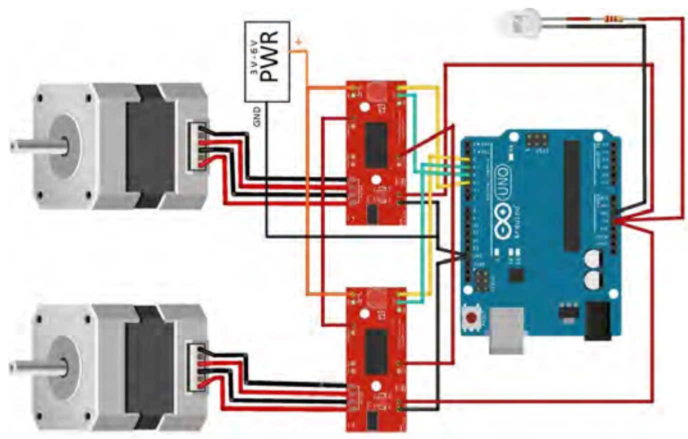


Figure 7.4 Slew azimuth and elevation axis motor travel distances controlled from stepper motor control pulses through Equation 7.1 and Equation 7.2 (SparkFun, 2014*a*).

chanical load. If not, then the stepper motors can be used to drive the solar tracking platform through any type of geardrive, for example slew-drives or planetary gears `http://powerelectronics.com/content/invention-month-drive-lets-solar-panels-track-sun`.

A stepper motor differ from a regular DC motors in that these motors can spin in very precise increments in any direction. A stepper motor can also spin very fast in on direction or another by continuously pulsing the motor. The advantage is that the driver pulses can be counted, meaning the processor can precisely keep track of the position of the stepper motor (Ayyagari *et al.*, 2014) `http://carnot.mech.columbia.edu/~sd/Design2014/Team2/`.

Sparkfun engineers (SparkFun, 2014*a*) have developed sample code and an Arduino sketch to drive the stepper motors through the EasyDriver Stepper Motor Driver. The software code to test the driver is listed below. More information can be obtained on this link: `https://www.sparkfun.com/tutorials/400`.

```
This code controls a stepper motor with the
EasyDriver board. It spins forwards and backwards
***************************/
int dirpin = 2;
int steppin = 3;

void setup()
{
pinMode(dirpin, OUTPUT);
pinMode(steppin, OUTPUT);
}
void loop()
{

  int i;

  digitalWrite(dirpin, LOW);     // Set the direction.
  delay(100);


  for (i = 0; i<4000; i++)       // Iterate for 4000 microsteps.
  {
```

```
    digitalWrite(steppin, LOW);  // This LOW to HIGH change is what creates the
    digitalWrite(steppin, HIGH); // "Rising Edge" easydriver knows when to step.
    delayMicroseconds(500);      // This delay time is close top speed for this
  }                              // particular motor, faster the motor stalls.

  digitalWrite(dirpin, HIGH);    // Change direction.
  delay(100);


  for (i = 0; i<4000; i++)       // Iterate for 4000 microsteps
  {
    digitalWrite(steppin, LOW);  // This LOW to HIGH change is what creates the
    digitalWrite(steppin, HIGH); // "Rising Edge" easydriver knows when to step.
    delayMicroseconds(500);      // This delay time close to top speed for this
  }                              // particular motor. Any faster the motor stalls.

}


}
```

The EasyDriver makes it very easy to use stepper motor driverwith any digital microprocessor output varying in output as digital 0 to 5V pulses (also 0 to 3.3V for the latest Arduino boards if SJ2 is closed on the EasyDriver). To drive a stepper motor on the high current end, the driver requires a 7V to 20V supply. The driver board includes an on board voltage regulator for the digital interfacing with a 4-wire stepper motor to ensure precision motor control.

Other reference sites that can be consulted to learn more about solar tracking motors are `http://powerelectronics.com/content/designing-solar-tracking-motors` and `http://www.dunkermotor.com/start.asp` (Morehead, 2012).

The next section will give the reader an overview into the intelligence behind solar tracking and the principles employed in controlling the mechanical systems described above during the solar tracking process.

7.3 Continuous Solar Tracking Principle

Continuous solar tracking refers to the process of manoeuvring a photovoltaic panel, solar concentrator or optic reflector with an associated power generating payload in such a way that the reflector follows and lock's onto the course trajectory of the sun's movement throughout the full day-time cycle. In this way, the solar harvesting means or solar reflector optimally reflects the solar energy towards the solar power generator or energy converter. The power generating device can be a thermal energy converter or silicon based concentrated photovoltaic (CPV) type system.

Figure 7.5 depicts the control architecture of a typical solar tracking control system in block diagram format (Xinhong *et al.*, 2007). The block diagram illustrates how the solar tracking system uses two motors as mechanical drives that conducts an dual-axis rotation for manoeuvring the solar collector to directly face the sun. This rotation allows the system to track the sun in real time, allowing for the solar collector to optimally harvest solar energy. Typically, the two drive motors are decoupled, meaning that the rotation of one motor does not influence the other, in order to minimize power consumption during operation.

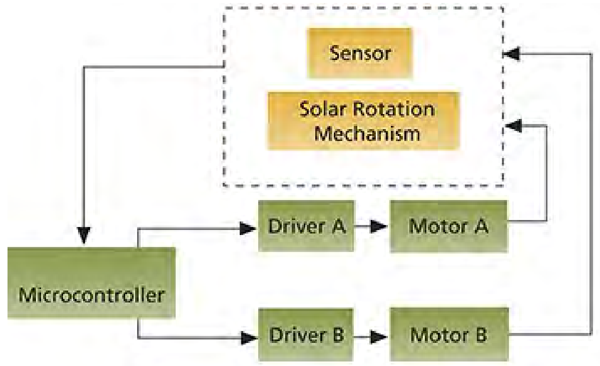


Figure 7.5 Solar tracking control architecture and block diagram (Xinhong *et al.*, 2007).

When the solar tracking system is in operation, it normally executes the following sequence of operations within the context of the flowchart and software procedures:

- Read all angle encoders
- Read tracker positions from microcontroller inputs
- Calculate next sun path trajectory point
- Check for any event triggers
- Perform flowchart event required actions
- Calculate and set the output signals
- Go to next axis and repeat
- Exit from interrupt

Figure 7.6 shows how two cities require different tracking contours throughout the day (i.e. Seattle and Miami). This should give the reader some feeling for the type of movements required by the tracking motors as well as the variations in solar tracking movements from city-to-city. These variations also emphasize the importance in following the sun on a technological basis, using sun vector calculations on a two-axis basis.

The design of the control- and mechanical- drive systems of a solar harvesting system depends on elements such as the mechanical platform, mechanical system behaviour, transmission drives, the control strategy, control system inputs, sensor mechanisms and control system outputs and must be operating within the user defined specification parameters. The design of the control- and mechanical- drive systems of the parabolic dish therefore depends on elements such as the control strategy, control system inputs, sensor mechanisms, mechanical system behaviour, control system outputs and within the user defined specification parameters.

7.4 Summary

This chapter described aspects related to the manouvering of the solar tracking platform. It showed that how the primary task of the solar tracking platform solution is performed to

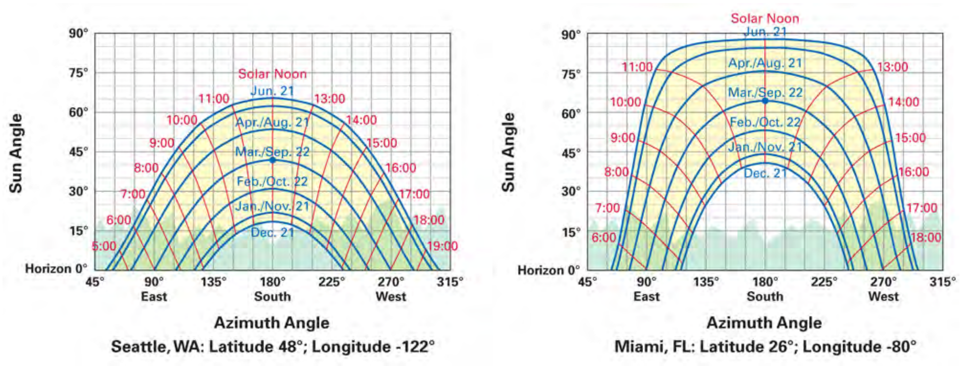


Figure 7.6 Sun part diagrams for Seattle and Miami in the USA showing vastly different solar tracking movement patterns (Homepower, 2014).

ensure that the thermal/optical focus is maintained. In the next part of this book, algorithms and software architectures to achieve high accuracy solar tracking with optimum solar energy concentration and solar power generation, will be discussed.

CHAPTER 8

SOLAR TRACKING AUTOMATED CONTROL

8.1 Solar Tracking Control

The study proposes the development and implementation of a novel power optimized control tracking strategy and algorithm to realize carbon footprint optimization of the solar reflector system.

Concentrated solar applications such as parabolic dish systems require a high degree of accuracy to ensure the sunlight is directed precisely at the focal point of the reflector. At the same time the mechanical drive and electronic controls must ensure smooth transitions during stepwise or continuous movement to allow the tracking system to lock onto the source or sun and to remain stable irrespective of changes in external environmental conditions.

The design of the control- and mechanical- drive systems of the parabolic dish therefore depends on elements such as the control strategy, control system inputs, sensor mechanisms, mechanical system behaviour, control system outputs and within the user defined specification parameters. This chapter discusses existing solutions found in the literature in more detail.

8.2 Electronic Control

One you have the mechanical aspects of your solar tracking system design completed, the focus shifts to the electronic circuits and the software controller for the solar tracking process.

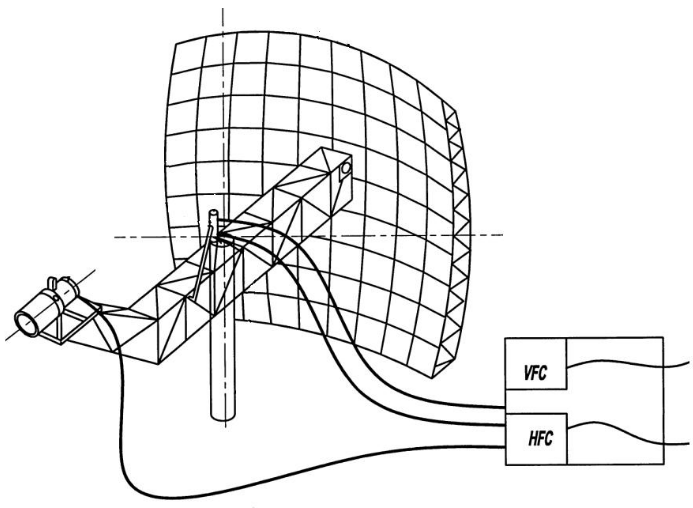


Figure 8.1 Control system to command the Azimuth and Elevation drives during solar tracking (Stone and Rodriguez, 2001).

Figure 8.2 presents a solar tracking mechanism block diagram where the input comes from a microcontroller, with feedback from the tracker angle encoders. The combination is sometimes referred to as a servo-tracking system. At the heart of the system is the solar tracking means. The controller feeds the return angular position signal or current tracker pointing position information and determines the location of the sun vector as target. The solar reflector is then rotated by motors which provides position feedback signals to a controller.

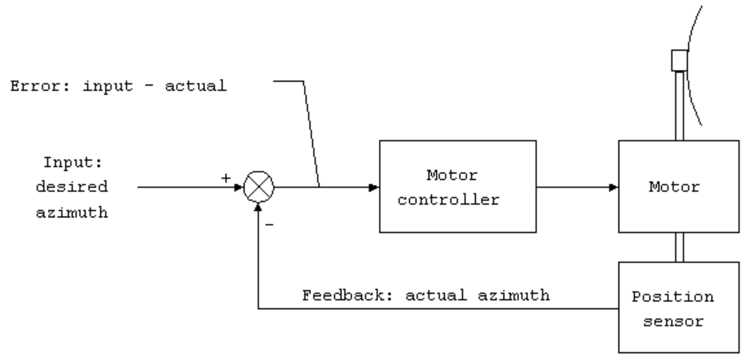


Figure 8.2 An example of solar tracking control architecture and block diagram.

The commanded input signal is the desired azimuth and elevation of of the solar reflector in terms of the solar vector parameters. The error signal drives the motors to reposition the solar reflector until the position feedback indicates the solar reflector is at the desired azimuth and elevation angles, at which point the error signal is zero and the motors stops. This servo-mechanism can be combined with an optical feedback from the solar tracking means, in which case the system can also use the optical azimuth and elevation signals as the input.

Figure 8.3 illustrates a typical block diagram for a microprocessor controlled dual-axis solar tracking system (Kcourtneynewark, 2014). This illustration shows the wind speed sensors, photoelectric sensors, sunlight intensity sensors (photo sensitive resistors), signal processing circuit (comparators, amplifiers and ADCs), microcontroller, optocouplers, motor drivers and stepper motors, LCD display, memory, and power management blocks.

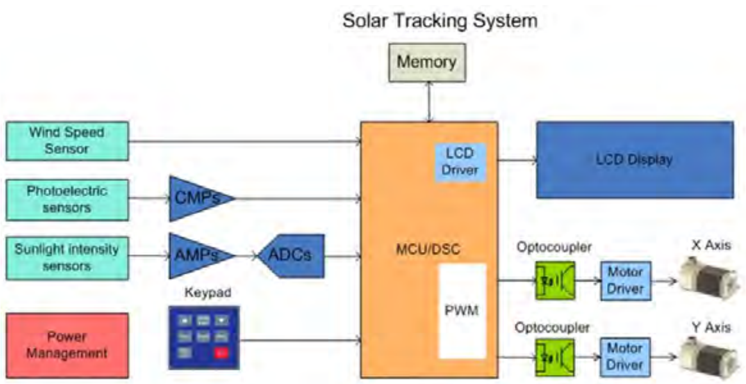


Figure 8.3 Typical block diagram for a microprocessor controller solar tracking system (Kcourtneynewark, 2014).

Th decision logic control for the solar tracking control system is presented in Figure 8.4, where there is shown the flow-chart with decision logic typically used in automatic solar tracking. The details of the flow chart will be discussed in a later chapter. At this stage it suffices to state that as the solar tracking control circuit is activated, the system performs continuous solar tracking. If the control algorithm is intelligent enough and uses an optical feedback means, then the system will further be able to compensate for external interference, such as weather influences and slight installation errors.

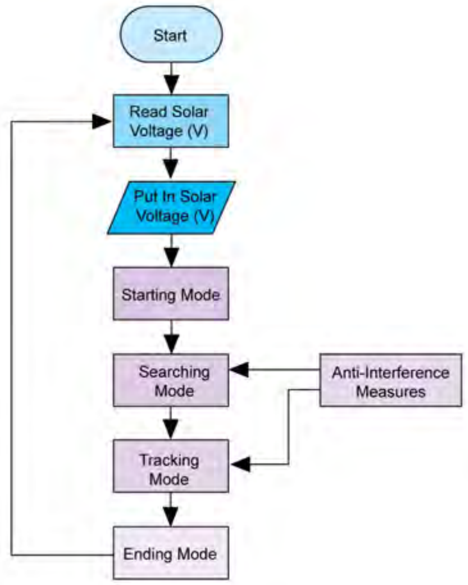


Figure 8.4 Typical solar tracking control flow chart (Xinhong *et al.*, 2007).

The tracking block consists of a controller and algorithms that implements a certain control strategy or philosophy. Tracker control algorithms typically incorporate a control strategy that is a hybrid between open-loop and closed loop control. The open-loop component is needed because the sun can be obscured by clouds, eliminating or distorting the feedback signals. The closed-loop component is needed to eliminate errors that result from variability in installation, assembly, calibration, and encoder mounting (Rockwell Automation, 2012).

Closed loop systems track the sun by relying on one or more photo-diodes, photo-resistors or other types of sensors with a limited field of view. The sensors are typically directed at the sun and may be fully shaded or fully illuminated by sunlight at all times. As the sun moves, the light begins to illuminate or shade one or more sensors, which the system detects and activates motors or actuators to move the device back into a position where all sensors are equally shaded or equally illuminated (depending on the sensor design).

Open loop systems track the sun without physically following the sun via sensors. Calibration may in some cases take place for which sensors may be used. These open-loop control systems typically employ electronic logic which controls device motors or actuators to follow the sun based on a mathematical formula, commonly known as solar positioning algorithms (NREL, 2008).

In general servo control addresses two fundamental classes of problems, namely command tracking and error correction or disturbance correction. Disturbances in a solar dish tracking application may be typically caused by the wind or misalignment of components during installation (Haniffin, 2005).

Command Tracking address how well the actual motion follows the commands of the controller. Typical commands in solar dish tracking solutions include aspects such as rotary motion, angle position, motor velocity, acceleration and torque. This part the control loop is often referred to as *feed forward loop* control.

The error correction aspect of the control loop is typically referred to as the *feedback loop*. The familiar *P.I.D.* (Proportional Integral and Derivative position loop) and *P.I.V.* (Proportional position loop Integral and proportional Velocity loop) controls are used to combat the error correction aspect of the control system. Figure 8.5 shows the control diagram for typical P.I.D servo control.

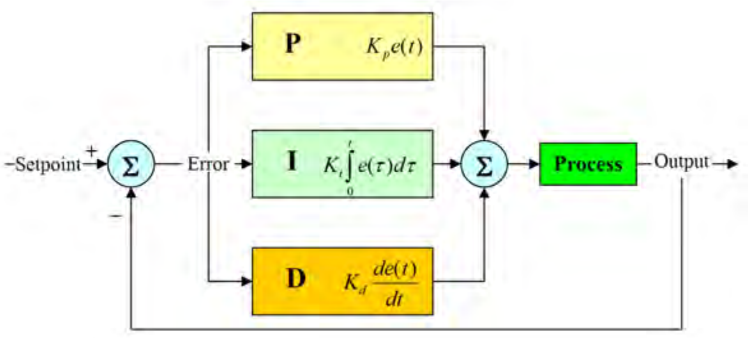


Figure 8.5 Typical layout of P.I.D control loop (Haniffin, 2005)

However, if the solar tracking platform actuators include gear drives with large gear rations, then the complicated P.I.D. control system of Figure 8.5 will not be required. Compared to control system for a gun-turret for example, where quick response and fine tuned P.I.D. control is required, the sun movement is slow. Since the sun moves very slowly throughout the day, only incremental corrections to the angle of the solar tracking system is required to accomplish solar tracking, meaning that quick response control will be an expensive overkill solution.

An understanding of the differences between these two topologies will be gained and an appropriate solution proposed for the solar dish tracking solution. The advantages of dual-axis trajectory tracking control systems will also be evaluated in the solar dish tracking application.

8.3 Solar Tracking and Control Strategies

Solar tracking control is required to continuously reflect the maximum amount of incident solar energy towards the concentrator focal point where the solar receiver is located. Solar tracking accuracy and stability are two of the primary design parameters for a CSP solar tracking system. In order to improve solar tracking accuracy, various control strategy options can be followed, including open-loop control systems, closed-loop control systems and in some cases an integrated or hybrid-control system where open-and closed- loop control configurations are combined.

8.3.1 Open-loop Control

The block diagram in Figure 8.6 shows the operational principles of an open-loop solar tracking control strategy according to the principles described in the literature study (Section 3.4). In this control mode, the PLC controller keeps record of the angular positions of the actuator drives to determine the present solar concentrator position and compare this to the sun angles in order to determine any required motor control signals. In this configuration, the PLC can perform solar tracking in open-loop controller mode, where the solar position can be calculated from an astronomical algorithm (Reda and Andreas, 2008*a*).

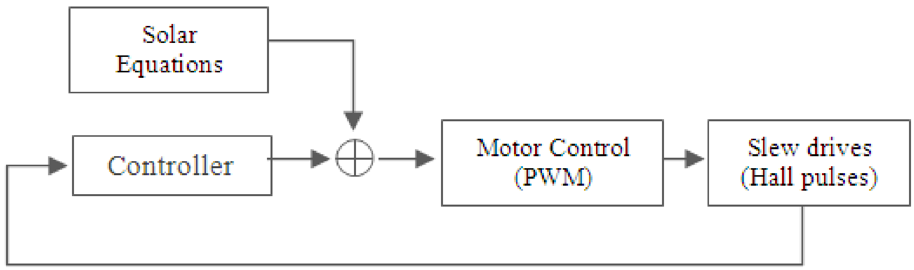


Figure 8.6 Operational principles of open-loop solar tracking control (Prinsloo, 2014*b*).

Given the longitude and latitude coordinates of any position on the earth, the position of the sun can be calculated with the aid of the astronomical algorithm as a solar vector. The solar vector $S_Q(\gamma_s, \theta_s)$ describes the required concentrator azimuth angle for the horizontal alignment and zenith angle for the vertical alignment. Solar position algorithm software is available for the Siemens Simatic S7-1200 series controller. This algorithm is based on NREL SPA and ensures 64-bit arithmetic accuracy with precise azimuth and zenith solar positioning control through an accurate astronomical algorithm. The algorithm is specified with leading edge accuracy of $\sim 0.0003°$ and supports solar tracking accuracies better than $\sim 0.05°$ (Reda and Andreas, 2008*a*).

The software essentially implements the SPA on an S7-1200 controller as a function block with inputs shown in Figure 8.7(a) (Siemens, 2011*a*), through which the PLC software compute solar vectors $S_Q(\gamma_s,\, \theta_s)$ for a specified location and time in relation to a high-accuracy PLC time-clock. The SPA function block can also be used to generate a sun-path diagram as shown in Figure 8.7(b). This diagram reflects the solar trajectory during the summer solstice, winter solstice and solar equinox. This diagram is helpful in setting up and configuring a solar tracking controller for a particular site as it provides a visual representation of the required solar concentrator movements and stipulates the border regions and angular motion safety margins.

The calculations used in the Siemens PLC function block are based on the SPA of National Renewable Energy Laboratory (NREL) and is classified as an astronomical algorithm because of the high degree of accuracy (Siemens, 2011*a*).

The flow chart in Figure 8.8 represents the decision logic and software sequences used in open-loop control mode. In this mode, the PLC uses the logic in Figure 8.8 to verify day/night mode before monitoring the present position of the dish and compare this to the solar vector calculated through the SPA (check sensors on flow diagram). Should a calculated positional correction be required on any of the axes, the decision logic issues

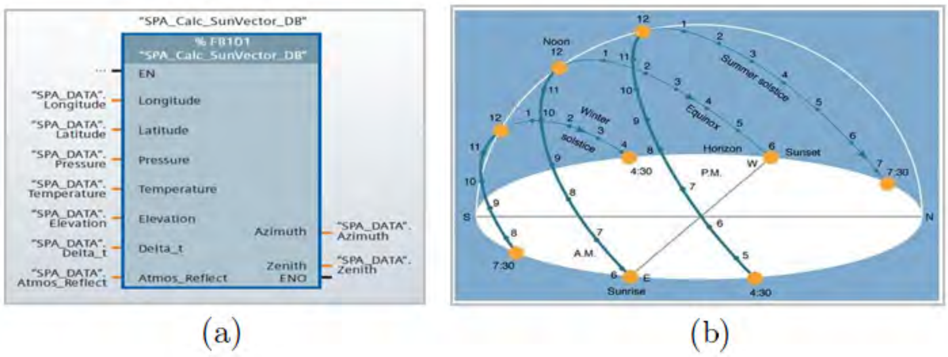


Figure 8.7 Block diagram of (a) Siemens S7-1200 function block $CalcSolarVector$ to calculate (b) the solar vector and sun path diagram (Siemens, 2011a).

PLC commands for the DC motors on the relevant axes actuator drives to move the solar collector system to the new position (Figure 8.9).

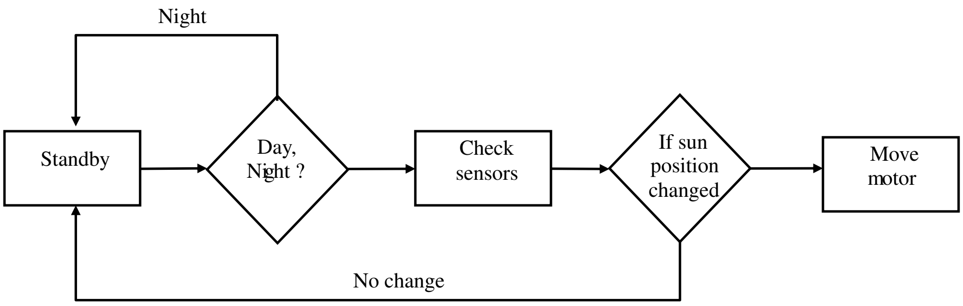


Figure 8.8 Flow diagram used in PLC decision logic to conduct open-loop solar tracking control through an astronomical algorithm (Prinsloo, 2014b).

A major disadvantage with open-loop solar tracking control using only astronomical algorithm parameters, is that the PLC control system is unable to detect or correct disturbances caused by an imperfect installation, calibration, setup or time-clock parameters. In the absence of an optical observation means, the PLC control system simply accepts all parameters to be correct and blindly follows the sun path based only on solar vector parameters computed by the astronomical algorithm.

The underlying solar tracking control concept programmed into the PLC controller to command the physical slew drive actuator motors during solar tracking will be discussed in more detail in Section 8.3.2, while operational principles of the PLC solar tracking controller in closed-loop mode as well as the component section for optic hardware interfacing with the PLC for closed-loop mode will be discussed in Section 8.3.4 and Section 8.3.5.

8.3.2 Solar Tracking Control Concept

An underlying solar tracking control concept is required to command the physical slew drive actuator motors during solar tracking control and is programmed into the PLC controller to manage the hardware interfaces underlying the PLC solar tracking control intelligence and decision logic presented in Figure 8.8. The solar tracking concept physically commands the collector movement by way of defining PLC signals sent to the actuator DC motors for each new sun position in accordance with the angle deviation between the sun and the solar concentrator pointing direction.

A precise control concept, such as proportional integral and differential (PID) control, is not really suitable for slew actuator driven solar tracking control since the sun movement is quite slow and the large gear-ratios of the slew drive actuator ensures very slow dish movements. The integrated actuator DC motors in the slow response actuator drives can be easily controlled in on-off control steps through pulse width modulated (PWM) control signals.

In this approach the tracking resolution parameter (termed Δ) sets the travel interval of the solar concentrator and describes the approach to logically realise concentrator movement by intermittently driving the actuator DC motors within a certain allowable angle deviation window. The solar tracking resolution window (angle intervals) are specified for each of the azimuth and elevation axes as part of the software configuration set-up. Figure 8.9 presents an illustration of how this approach achieves solar tracking motion with the PLC solar tracking controller and how this approach is logically realised during the solar tracking process (Figure 8.8).

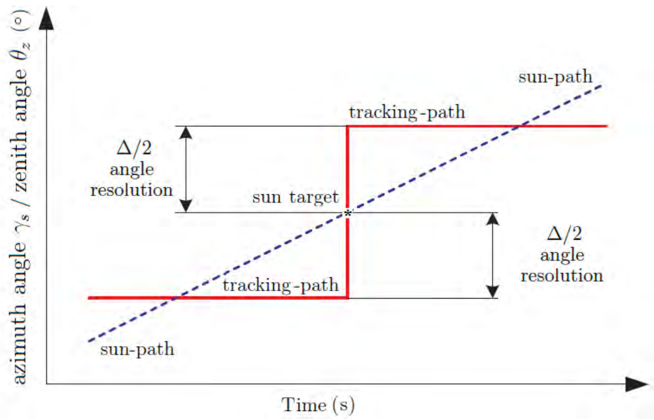


Figure 8.9 Illustration of decision logic used to control the actuator DC motor in following the sun path at tracking resolution $\Delta/2$ on each control axis (Prinsloo, 2014*b*).

In this solar tracking concept (Figure 8.9), the PLC essentially moves the solar concentrator slightly ahead (angle $\Delta/2$) on the sun track, waiting for the sun to "catch up" with the concentrator position. When the sun "catches up", and progresses on its track beyond the last solar concentrator position (by an angle larger than $\Delta/2$), the solar concentrator in turn "catches up" with the sun by subsequently moving it to a new position slightly ahead (angle $\Delta/2$) of the sun on its track. In following this solar tracking approach throughout the day, azimuth and elevation slew drive actuators (under PLC control) are constantly driven in a step-wise fashion and in such a way that the pointing direction of the solar concentrator physically overtakes the sun position by a very small pre-configured angle margin on both axes ($\Delta/2$), waits for it to pass by the same margin ($\Delta/2$), before the concentrator again overtakes the sun again by the predefined margin ($\Delta/2$), waiting for the next passing of the sun, continuing in this way in a step-wise incremental fashion. The optical solar tracking error sequences resulting from this approach is anticipated to be a slowly varying oscillating-type saw-tooth pattern, slowly varying up and down within the pre-configured error band of $\pm\Delta/2°$.

In more technical terms, the tracking resolution parameter Δ sets the travel interval of the solar concentrator slewing drive actuators in terms of an angle resolution Δ. During the solar tracking process (Figure 8.8) the PLC will independently activate the slew drive actuator motors during every control cycle on either the azimuth or elevation axis, but only if the concentrator on that axis lags behind by the sun angle by an angle of $\Delta/2$ (i.e. $\Delta = 0.25°$ then $\Delta/2 = 0.125°$). The PLC will end that cycle of concentrator movement on that particular axis when that actuator axis movement exceeds the sun position by an angle $\Delta/2$ on that axis. During the next PLC control cycle, the process is repeated, carrying along in the same fashion in following the sun movement throughout the day.

8.3.3 Solar Tracking Action

To provide the reader with an understanding of the practical actions associated with solar tracking using the control concept in the previous section, we refer the reader to Figure 8.10 (Prinsloo *et al.*, 2013*b*). This graph represents the true difference between the angle of the optically measured sunrays and the pointing direction of the solar tracking platform, for the azimuth and elevation axes, during actual solar tracking operation. This is referred to a the sun-pointing error.

Figure 8.10(a) presents the results for a full day demo run to show the optically measured solar tracking or sun pointing error for the *azimuth axis* for the solar tracking system operating on the principles of the control concept presented in Figure 8.9. Figure 8.10(b), in turn, presents an example of the optically measured solar tracking/sun pointing errors for the *elevation axis* using the same control concept and settings.

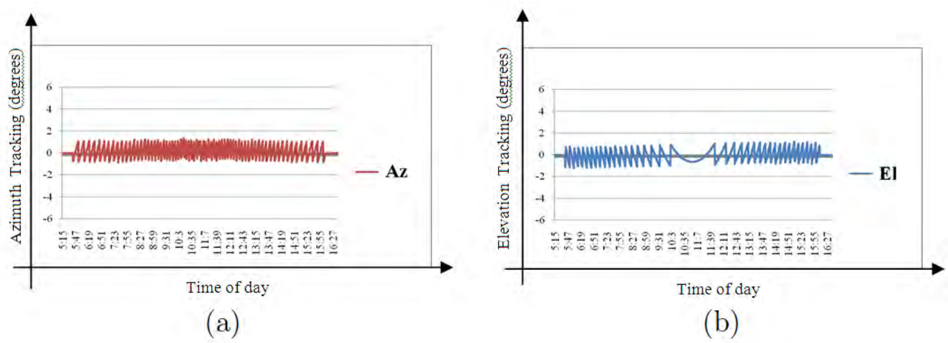


Figure 8.10 Examples of optically measured azimuth and elevation solar tracking/pointing errors (Prinsloo *et al.*, 2013*b*).

The tracking resolution setting on both axes in this example was set at $\Delta/2 = 2°$, meaning that the solar tracking errors measured with an optical device (sun sensor) is expected to swing around $0.0°$ and remain within the band $-1.0°$ and $+1.0°$ on both axes. The notation used to express this error rate mathematically is $-1.0° < \epsilon_{az/el} < +1.0°$.

Note that the short-term oscillating pattern in the tracking *movement patterns* (swinging movement), observed in the azimuth and elevation error time sequences of Figure 8.10(a, b), is an inherent characteristic of the solar tracking control concept of Figure 8.9. This is because the amplitude of these sun pointing error oscillations relates to the solar tracking resolution setting (Δ) in the control concept.

Other identifiable characteristics in the solar tracking movement patterns of Figure 8.10 are the relatively high rate of activity in azimuth slew drive movements around noon (highest rate of sun movement on the azimuth axis), compared to a relatively slower rate of azimuth slew activity in the morning and afternoon (relatively slow rate of movement of the sun). Conversely, on the elevation axis, the relatively slower rate of slew drive activity around noon (slowest rate of sun movement), compared to a faster rate of elevation slew drive activity in the morning and afternoon.

It is important to note that if the long term solar tracking error offset varies over time, or moves outside of these predefined resolution boundaries, or if the error band does not swing around $0.0°$, then it is an indication that there are external influences that disturbs the solar tracking platform system and needs to be corrected. Time varying offset solar tracking errors could emanate as a result of one or more of a variety of factors. The range of known inter-dependent factors can include one or a combination of: pedestal tilt errors, reference biases, linear azimuth and elevation errors (gear drive ratios and configuration settings), non-orthogonality in the slew drive axis mountings, bore-sight errors (optical axis misalignments), and so forth (Khalsa *et al.*, 2011).

This intermittent type solar tracking control concept and resulting tracking motor activity (Figure 8.10) in combination with PWM signal control, reduces the energy requirements for moving the solar tracking system. The DC/AC motors on each axis move independently but are not moving continuously throughout the day and it only moves and consumers power in incremental steps, and intermittently in pre-configured error margin increments.

However, if the amplitude/resolution setup configuration parameter (Δ) is set too large, it would result in the solar tracking losing its focus on the sun, and effect that would cause solar energy spillages. On the other hand, if set too small, it will be at expense of more frequent DC/AC motor movements and increased power consumption during the solar tracking operation. In this respect, a balance needs to be struck between tracking resolution and solar energy spillage or so called solar energy intercept factor. This balance is mainly a function of the solar receiver shape and design, but also related to the solar collector design.

Figure 8.11 presents an example of a solar receiver sensitivity function determined by Sandia Engineers for one of their earlier Stirling dish designs (Kinoshita, 1985). This function relates the solar thermal energy spillage to the solar tracking error in degrees. It shows that the demo solar tracking resolution setting of $\Delta/2 = 2°$, relating to a maximum solar tracking error of $+1.0°$, would result in only 70% efficiency in solar energy capture if the solar receiver associated with the graph was used with the tracking platform (solar energy intercept loss of 30%).

A more accurate tracking resolution would be $\Delta = 0.2°$ on both azimuth and elevation/zenith axes. Although the solar energy capture efficiency would be a function of the solar receiver, this resolution is comparable with similar field tested systems and provides for efficient use of power resources (Mancini, 1997). It would further ensure sufficient error margin when the system operates in open-loop control, helping to circumvent the effects of mechanical tolerances, and subtle mechanical defects (Kinoshita, 1985).

The idea is to set the solar tracking resolution for maximum solar energy harvesting at minimum solar tracking power consumption. For this one would choose an acceptable solar capture intercept % (Figure 8.11), with an associated maximum tracking resolution so that the solar tracking motors would move less frequently and save maximum energy.

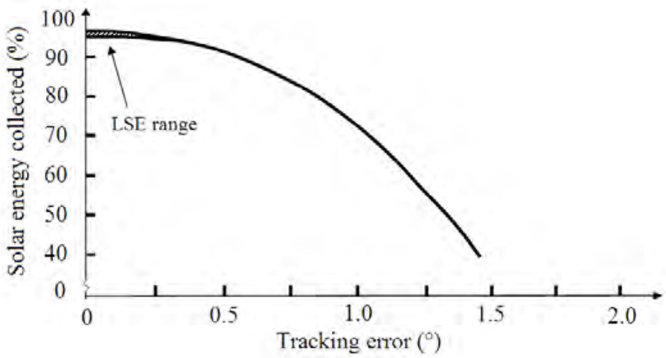


Figure 8.11 Solar energy capture sensitivity in terms of solar tracking errors (as function of the solar concentrator and receiver design) (Kinoshita, 1985).

Compared to continuous solar tracking DC motor movement, that may drain a stand-alone solar tracker's energy reserves, the tracking approach described above has the benefit of reducing solar tracking energy consumption in proportion to the parameter Δ. This concept is thus especially valuable in autonomous and standalone solar tracking systems where intermittent cloud activity may result in battery drain if the system is not intelligent enough.

The chapter on *Intelligent Solar Tracking Control* in this book deals with a non-static or dynamically adjustable solar tracking resolution. The opportunity was seen to experimenting with an improvement to this control concept, wherein the PLC/microcontroller adjusts solar tracking power consumption levels through (dynamic) variation of the angle resolution Δ. Intelligent control with dynamic tracking resolution features are valuable in an off-grid stand-alone solar systems that operates in overcast conditions, as it will be able to sacrifice accuracy in exchange for preserving backup energy reserves in an intelligent manner (Prinsloo *et al.*, 2013*a*).

Furthermore, by using PWM control technology in combination with intermittent solar tracking control, the motors and slew drives on both axes are fed in time intervals associated with the solar contour movements. This ensures that each DC/AC motor only draws current during the required movement intervals. PWM is an efficient method to control and vary the power and speed of the DC motors, while the DC motors in-turn controls the azimuth and zenith/elevation angles of the solar concentrator through the slew drives in accordance with the approach described above (Figure 8.9).

Other than operating the solar tracking platform in open-loop control mode, the system can also be driven in closed-loop control mode, where optical feedback can support tracking accuracy, as discussed in the next section.

8.3.4 Closed-loop Control

In closed-loop solar tracking control, optimal solar tracking precision is ensured with the aid of light sensitive electronics to enable the controller to observe the movement of the sun. Through optical feedback, the solar concentrator system can be directed in a dynamic fashion to achieve the optimal sun pointing position. The level of intelligence of the controller system as well as the type and sensitivity of the sensors are crucial in these systems.

This method of control is typically implemented to give feedback to the PLC under closed-loop solar tracking control mode and optically assists to eliminate or at least reduce some of the tracking errors brought on by an imperfect installation, minor mechanical defects or small misalignments. Optical or image processing techniques described in the literature study (Section 3.4) may be used to direct the solar tracking controller to observe and lock onto the position and movement of the sun. An optical solar observation means, such as the MEMS ISS-CYPA sun sensor (SolarMEMS, 2013), can be used.

In a closed-loop solar tracking control application, the MEMS analogue sun sensor (model ISS-AX detailed in Appendix 5.3) is installed in a small housing and mounted onto the frame of the solar concentrator system. In this way, the PLC controller can monitor the present position of the dish and compare this to the true position of the sun observed/measured through the sun sensor. The sun sensor is then used as input means to closed-loop solar tracking control.

Instead of calculating the solar vector/position of the sun through an astronomical algorithm, the PLC control algorithm in closed-loop control mode computes the sun position $S_Q(\gamma_s, \theta_s)$ from sun sensor signals (Appendix 5.3) and compares this to the sun vector (Figure 8.8) to direct the solar tracking motions of the concentrator platform (Figure 8.9). The solar collector movement approach is still used by the PLC solar tracking controller (Figure 8.9) to drive the actuator DC motors by way of intermittently moving the solar collector system for each new sun position in accordance with the angle resolution window parameter setting Δ (see Section 8.3.2).

Figure 8.12 Operational principles of the sun sensor (SolarMEMS, 2013).

By using the MEMS ISS-CYPA sun sensor, the difference in angle between the position of the solar vector can also be recorded on a personal computer (through a PIC processor and a USB interface), in order to store or log the azimuth and zenith elevation "pointing error" using optical measures and the sun sensor calculations (SolarMEMS, 2013).

Camera image processing, instead of light sensitive devices, can be used in robotics to control complex movements along directed paths. Image processing techniques determine the solar vector $S_Q(\gamma_s, \theta_s)$ from web camera images for closed-loop camera based solar tracking evaluation (Appendix 5.4). Camera based augmented tracking systems offer some benefits in terms of accuracy, but these systems are not popular in industrial scale commercial solar tracking systems. Most robust industrial PLC based control systems simply does not always have the processing capability to perform complex image processing required to determine the position of the sun more accurately. Typical operating environment hazards such as dust, rain, static electricity and lightning are all enemies of camera based solar tracking augmentation systems.

One disadvantage of closed-loop solar tracking control is that the PLC system would find it problematic to recover from prolonged periods of cloud cover. In the absence of guidance from an astronomical algorithm, the optical observation means may find it difficult to determine the solar vector once the sun moved outside the field of view of the sun sensor/imaging camera, or if the sun path is no longer in the field of view of the optical device. To overcome this problem, an optical feedback means can be employed more efficiently in hybrid-loop control strategies, wherein the solar reflector tracking system use solar positioning algorithms to direct the reflector system by computing the direction of the solar vector at any specific location at a particular time using astronomical coordinates as basis of computation, while providing for a homing sequence to focus any sun-tracking error remaining through the MEMs sun sensor.

Hybrid open-loop/closed-loop tracking control, as a means of overcoming the limitations of closed-loop control, will be discussed in the next section.

8.3.5 Hybrid-loop Control

Hybrid-loop control mode systems are used to control the dynamic behaviour of a solar collector system, using a combination of both open-loop and closed-loop control strategies. The control system may be driven by discrete-valued signals or continuous signals, while some of these input/output signals may be time-driven or event-driven. Optical light sensing devices, such as those used in the closed-loop control system.

The hybrid control approach follows the sun path with the assistance of an astronomical algorithm, while simultaneously using the sensors to monitor and improve solar tracking pointing accuracy. The hybrid-loop mode of control has the advantage over open-loop and closed-loop systems in that the positioning of the solar collector remains in close proximity to the real-time position of the sun.

In this hybrid mode of control the PLC receives input on the sun's position $S_Q(\gamma_s, \theta_s)$ from both the astronomical algorithm and optically, by means of a sun sensor or imaging camera. The block diagram in Figure 8.13 illustrates the flow diagram used by the PLC to achieve solar tracking with better accuracy in an integrated open-loop/closed-loop control mode.

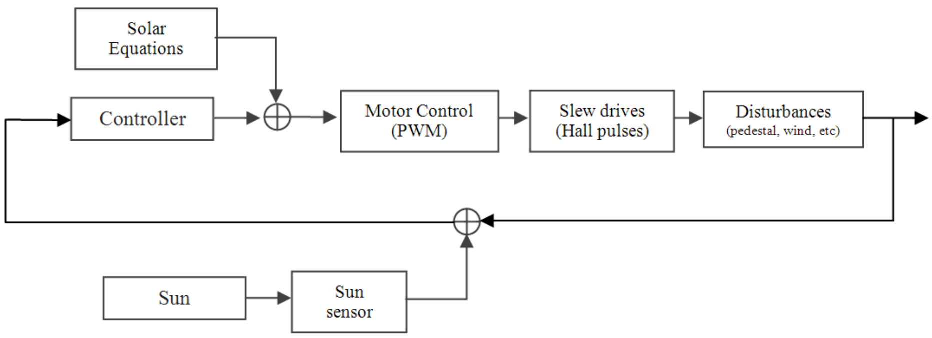


Figure 8.13 Operational principles of hybrid open-loop/closed-loop motion control (Prinsloo, 2014*b*).

In the hybrid open-loop/closed-loop control mode, the PLC uses the logic in Figure 8.8 to verify day/night mode before monitoring the present position of the dish and compare this to the solar vector calculated through the SPA and the solar vector provided by the MEMS sun sensor. Should positional correction be required, the decision logic issues PLC commands to the DC motors and actuator drives on the relevant axes. The flow chart given in Figure 8.14 represents the decision logic and software sequences typically used in the hybrid open-loop/closed-loop control mode.

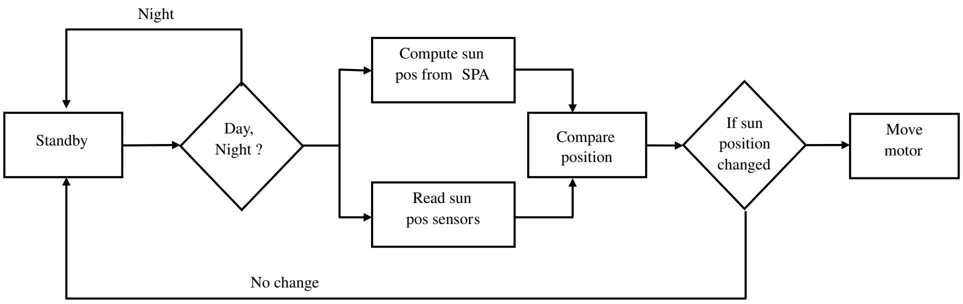


Figure 8.14 Flow diagram used in PLC decision logic to conduct hybrid open-loop/closed-loop solar tracking control (Prinsloo, 2014*b*).

Once again, the solar collector movement approach of Figure 8.9 can be used by the PLC solar tracking controller to drive the actuator DC motors by way of intermittently moving the solar collector system for each new sun position in accordance to the angle resolution window setting (Δ).

An optical sensor can be employed in a hybrid open-loop closed loop control philosophy wherein the solar reflector tracking system use solar positioning algorithms to direct the reflector system. This can be done by computing the direction of the solar vector at any specific location at a particular time using astronomical coordinates as basis of computation, while providing for a homing sequence to focus any sun-tracking error remaining through the sun sensor.

Certain camera images suffer from the same optic deficiencies. However, certain camera devices are able to process the infra-red spectrum of the image separately. In such imaging systems, the above problems with solar tracking control can be are overcome by directing the reflector tracking with a supplementary infra-red based camera homing system.

8.4 Modes of operation

Whilst solar tracking designs focus on the incorporation of tracking theorems, the design of a altitude-azimuth drive system and a electronic tracking system which defines the various modes of operation, it is important to defines states of control as well as an algorithm to achieve self-tracking in a carbon efficient manner. Thus, in order to systematise solar tracking control, the control logic should differentiate between various *modes of operation*, which operational modes are typically a function of the solar lighting conditions and operating environment.

Typically a solar tracking controller has two main modes of operation, namely an *automatic mode* and a *manual mode*. In automatic mode, the tracking controller will ensure sun tracking during the day and revert to sleep mode at night. In manual mode, the controller is commanded by an operator who can set-up, configure, test, manually direct or prepare the system for maintenance.

Some solar concentrator systems defined a *standby* or *not safe to operate* modes to handle unusual conditions such as extreme weather events (Meyer, 2010). For example, excessive wind loading on solar concentrators can be reduced by allowing a solar concentrator controller the freedom to move towards a dish orientation where it presents the least wind resistance when at stow. This phenomenon is often referred to as *windmilling* and can be realised by implementing an automatic *windstow* control mode option. This control mode can for example be automatically activated when a wind sensor alerts the tracking controller to proceed from automatic solar tracking (or any other mode) to the *windstow/standby* mode of operation.

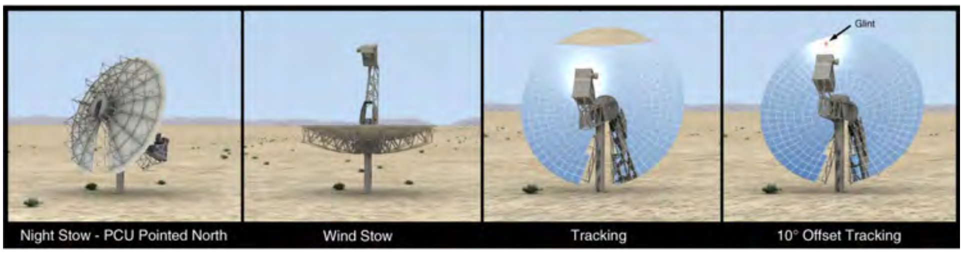


Figure 8.15 Positioning of the *Suncatcher* system during various modes of operation (Meyer, 2010)

As part of this literature study, a deeper insight into other more complex control modes found in practice can be gained by studying some of the special SunCatcher system control modes (Meyer, 2010). This solar concentrator system for example provides modes of operation illustrated in Figure 8.15, namely:

- Night Stow: SunCatcher moves to the night stow no tracking position after sundown;
- Wind Stow: During strong winds SunCatcher will cease operations and move into a position with the reflector pointed towards the sky (to minimize wind resistance on the parabolic dish);
- Sun Tracking: SunCatcher automatically follow the sun path throughout the course of the day;
- Offset Tracking (Cloud Cover): When the sun is blocked by clouds, SunCatcher will move into offset tracking position. This 10° elevation offset track is required to protect the Stirling equipment and bring the concentrator back to the sun-focus position when clouds have passed;
- Offset Tracking (Night Stow to Operation Transition): SunCatcher moves from night stow to tracking position at sun up and back into stow position after sundown;
- Unsafe to Operate Mode: In the event of equipment failure SunCatcher may move immediately into a wind stow position and remain offline until repairs or maintenance is performed.

Concentrated solar power system developers have implemented a variety of extended modes to meet spesific operational requirements. One popular mode is the *Teaching/-Training Mode*. In this mode of control, the operator can move the concentrator to point towards a specific reference point which corresponds to the position of certain sensor coordinates as part of the system set-up or configuration. Another teaching mode would be to manually move the concentrator to a position that would point the dish directly at the sun in order to lock solar tracking onto the sun coordinates at a given time.

With the development of the PowerDish system (Infinia, 2012*c*), a new set of modes was defined, following the logical steps from start-up to shut-down. The modes or steps of operation include:

- Operation: Typical operation starts with a system self check; the system then *wakes up* and slews to the sun. Based on user defined inputs (time of day or elevation of sun), the unit tracks the sun throughout the day and will then (based on a predefined user input) slew to stow at the end of the day.
- System Check: Inverter, Rectifier, Motor (Azimuth, Elevation) Controllers, and Sensors perform self tests at Operational Wake-Up and when initialized by the user.
- System Calibration: At initial start-up, an electronic calibration table is automatically built to ensure solar tracking accuracy.
- Standby: Based on data supplied by the project (DNI, temperature, wind speed) and data from the system (ambient temperature), the system automatically responds to environmental conditions, processes algorithms and makes decisions (e.g. Slew to Sun, Stay in Standby).
- Tracking Sun: Using algorithms, calibrations, current sensor data, and based on the project site meteorological input, System Control automatically monitors environmental conditions and system alerts/faults, processes algorithms (Tracking Sun), and makes decisions (Slew to Stow, Adjust Tracking).
- Slew to Sun: System Control initiates using algorithms or User Initialization.
- Slew to Stow: System Control initiates using algorithms based on: User Initialization, Monitored Environmental Conditions, or System Faults.
- Inverter: Power output is set and produced compliant with the utility voltage.
- Protective relay functions ensure safe system shutdown in the event of grid failure or if system operates beyond specification limits.
- When the system is off, the unit enters the stow position and remains connected to the grid. When the grid is not present, the 24VDC battery provides power to the system electronics and stows the system until the grid is present.

Various other *modes of operation* can be defined and the designer has the freedom to ensure optimal safety and environmental impact by way of defining a pre-determined set of modes during the design phase.

8.5 Photovoltaic Maximum Power Point Tracking

To end off this chapter, an important comments needs to be made about PV tracking systems, namely the concept of Maximum power point tracking (MPPT). Sometimes prospective experts entering the field of solar tracking may confuse this with solar tracking.

A PV system is one of the promising renewable energy technologies that has the advantage that the operating cost is free, very low maintenance and pollution-free. MPPT is a significant part of PV systems and a number of novel intelligent MPPT controllers for PV systems have been proposed. Intelligent MPPT algorithms may for example include optimized fuzzy logic or neural network architectures to optimize the power output of the PV system.

MPPT is required because solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve (current/voltage curve or power curve). The purpose of MPPT algorithms is to monitor the output of the cells and apply the proper load resistance to ensure maximum power on the total system for any given environmental conditions.

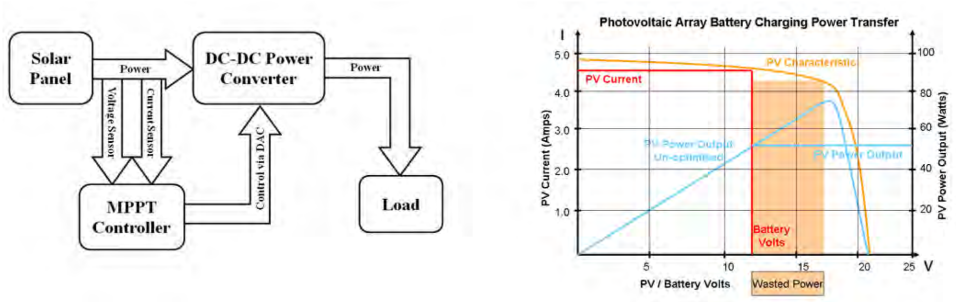


Figure 8.16 Maximum power point tracking in PV systems (Buckley, 2014).

With reference to the block diagram and Voltage/Current curve shown in Figure 8.16 (Buckley, 2014), a MPPT algorithm attempts to balance the voltage and current so that the cell operates at its peak capacity in terms of voltage/current power delivery. To do this, the MPPT algorithm analyses the maximum power point as an average across all of the panels connected to the system. If the panels are note identical, imperfections or perhaps slight shading of one panel will cause the system to be less efficient. If one panel is experiencing a decrease in power for any reason, the MPPT averages the decrease across the board to compensate, meaning the remaining panels are treated as having a lower capacity as well.

Maximum power point tracking (MPPT) algorithms is thus a soft tracking means (not hardware tracking system) and provide the theoretical means to achieve the maximum power point of solar panels in terms of voltage, current and load balance. In order to maximize a photovoltaic (PV) system's output power, it is necessary to continuously track the MPP of the overall system. This is because the MPP depends on solar irradiance conditions, the panel's temperature, and the load. These algorithms can be realized in many different forms of hardware (microprocessor type device) and software.

A MPPT device can help maximize the efficiency of solar collection and can boost solar array efficiency by up to 30%, especially during cold weather or on cloudy days. Even in situations where the sun is at a low angle or when a backup battery bank is low, MPPT is a helpful technology.

8.6 Summary

This chapter detailed various aspects related to the harvesting of solar energy and the importance in following the sun on its apparent movement trajectory throughout the sky. It shows the importance of solar tracking accuracy as a design parameter is solar harvesting means, as well as the energy gains tracking the sun in two dimensions and to retain the focus on the sun as solar resource for maximum energy yield.

PART IV

SOLAR TRACKING HARDWARE INTEGRATION

CHAPTER 9

TRACKING AUTOMATION AND HARDWARE INTEGRATION

9.1 Introduction

In this chapter, concepts around the automation of a solar harvesting means and its associated solar tracking system will be discussed. Solar power systems require a high degree of accuracy to ensure that the sunlight is directed directly onto the photovoltaic panels or at the focal point of the reflector. At the same time the mechanical drive and electronic controls must ensure smooth transitions during stepwise or continuous dynamic tracking movement to allow the tracking system to lock onto the source or sun and to remain stable irrespective of changes in external environmental conditions.

The automation solution thus requires the integration of the dynamically controlled solar harvesting means with self-positioning capabilities for both the horizontal and vertical axes. The automation of the dual axis tracking capability is extremely important since the system needs to automatically track the sun in a three-dimensional space.

In CSP systems, the automation solution needs to auto control both the azimuth and elevation drives to dynamically focus the sunlight directly onto the focal point of the reflector where the power conversion unit (PCU) is mechanically suspended. The integrations needs to harmonize the operation of the altitude-azimuth drive system with an electronic control system which defines the states of control as well as an algorithm to achieve self-tracking in an energy efficient manner.

9.2 Automation Hardware Platform

In some systems, a slew drive element to direct the motion of the concentrated solar power system is mounted on the main boom. It has a rotary output shaft aligned with the elevation pivotal axis and accordingly controls the solar concentrator up-and-down movement. The second slew drive element is mounted to the pedestal pole and has a rotary output shaft aligned with the azimuth pivotal action, accordingly controlling the solar concentrator left-right movement. Each slew drive element includes a DC electrical motor and a planetary gear unit to drive the main ring gear of the slew units.

The attention of the discussion is now directed towards the PLC hardware integration of the software control logic principles discussed above. Figure 9.1 shows a layout of the interfacing between the PLC automation software and the hardware for the slew drive positioning and tracking mobility mechanism. With reference to this layout, the current azimuth and elevation angle positions of the solar concentrator can be detected using either a tilt sensor, angle sensors, shaft encoders, or Hall magnetic pulse encoder.

It may be important to select slew drives that include brushless DC motors with its own integrated Hall magnetic pulse position encoder. The number of Hall pulses can thus be recorded via the digital PLC controller and corresponds with the distance the drives has moved. The PLC control signals for determining the travel distances of the azimuth and elevation axes are computed from the Hall encoder pulses through the relevant formulas.

Digital interfacing on the PLC controller (Figure 9.1) includes Hall encoder input ports and motor driver output ports to communicate with the azimuth and elevation actuator brushless DC motors. The specifications and performance curves of the DC motors integrated with the slew drive mechanisms needs to be stored as parameters upon PLC configuration, as these setup parameters are used in the slew actuator/DC motor travel distance computations. During the solar tracking operation each DC motor movement is commanded by the PLC using 24 Volt DC PWM signals.

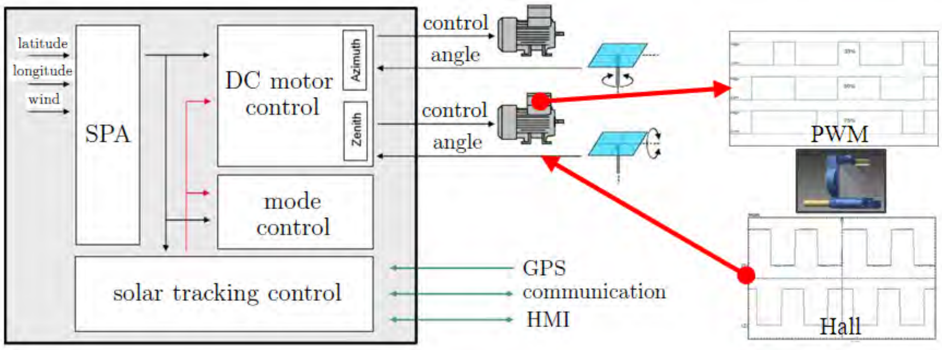


Figure 9.1 Siemens S7-1200 control block commanding a solar concentrator through DC motor driven slew drives (Siemens, 2011*a*).

An example of the software display for an antenna positioner controller is presented in Figure 9.2, showing how similar azimuth elevation type soft=ware controls and display can be used in solar tracker orientation displays (RA Mayes, 2014).

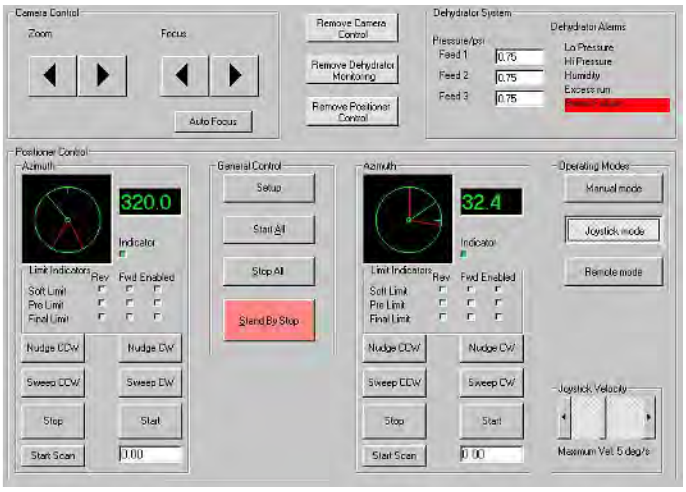


Figure 9.2 Example of the software display for an antenna positioner controller, similar type displays used in solar tracker orientation display (RA Mayes, 2014).

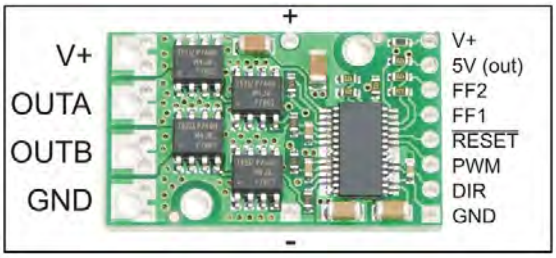
For solar tracking applications, the PLC or microcontroller should preferably meets the required industry standard (IP55). It should also have the processing power requirements to implement the solar position algorithm together with dual axis motion control.

9.2.1 PWM DC Motor Control and High Current Driver for Solar Tracking

The current output of a PLC or microprocessor is too low and delicate to drive a high current DC motor (except is it a very small stepper motor, but in most cases stepper motors also need a current driver). The motor will damage the controller since the output posts of a microprocessor or microcontroller is not designed to drive high current devices.

A high current driver interface is thus required that drives the motors from an external source such as a battery or mains supply. If a PWM control signal is used, such as in the example above, then the current driver chip or board needs to be of a special type that can handle high frequency current switching.

For example, Figure 9.3 shows a circuit board picture of a typical high-power motor driver (15 Ampere) used with Arduino or other microprocessers. This is the discrete MOSFET H-bridge which supports the Siemens PLC in digital PWM mode to drive the slew drive DC motors. The motor driver contains one N-channel MOSFET per output, with circuitry to manage PLC driven user inputs. This circuit supports a wide output voltage range (5.5 to 24 V) and is able to deliver continuous current levels of 15 A with no heat sink, and 21 A with a proper heat sink.



Motor channels:	1
Minimum operating voltage:	5.5 V
Maximum operating voltage:	30 V
Continuous output current per channel:	15 A[2]
Maximum PWM frequency:	40 kHz[3]
Maximum logic voltage:	5.5 V
MOSFET on-resistance (max per leg):	3.5 mΩ
Reverse voltage protection?:	N

Figure 9.3 Pin assignment and specifications for discrete MOSFET H-bridge motor driver for bidirectional PWM control of a high-power DC motor.

Pulse Width Modulation (PWM) is a very efficient way to change the direction and speed on DC motors for the solar tracking operation. PWM signals are used for a wide variety of control applications, such as controlling DC motors, valves, pumps, hydraulics, and other mechanical parts. Permanent magnet brush-less DC motors (PMBLDC motors) are commonly used in sun tracking due to its limited maintenance requirements (Prinsloo, 2014*b*).

In general, a PWM converter converts a fixed DC voltage into variable voltage DC, as depicted in Figure 9.4, whereby DC motor speed control is accomplished. The PWM method thus generates a digital output that is equivalent to an analogue signal of varying amplitude levels. Such digital signal control is extremely valuable in high-precision solar tracking applications, since it allows for extremely accurate angle control by way of counting the number of pulses.

Figure 9.4 Pulse Width Modulation (PWM) DC motor speed control.

The current driver in Figure 9.3 supports dual mode operation, namely (a) sign-magnitude for the PWM duty cycle to control the motor speed while the DIR pin controls the direction, and (b) locked-antiphase where the PLC control signal is applied to the DIR pin while the PWM pin is logically high. The motor driver further supports PWM frequencies of up to 40 kHz, but requires a restoration time of around 3 microseconds per cycle. High duty cycles is therefore not available at frequencies above 40 kHz. Gradually ramping the PWM input from 0-100% will result in the output ramping from 0-88% after it will switch to 100%. If the PWM pin is held logically low to activate the brake operation and logically high for the motor output to be controlled through the DIR input.

This digital PWM signal typically consists of two main components that define its behaviour, namely the duty cycle (average amplitude) and the frequency (time spacing between pulses). The duty cycle describes the amount of time the signal is in a high (on) state as a percentage of the total time of it takes to complete one cycle (Figure 9.5).

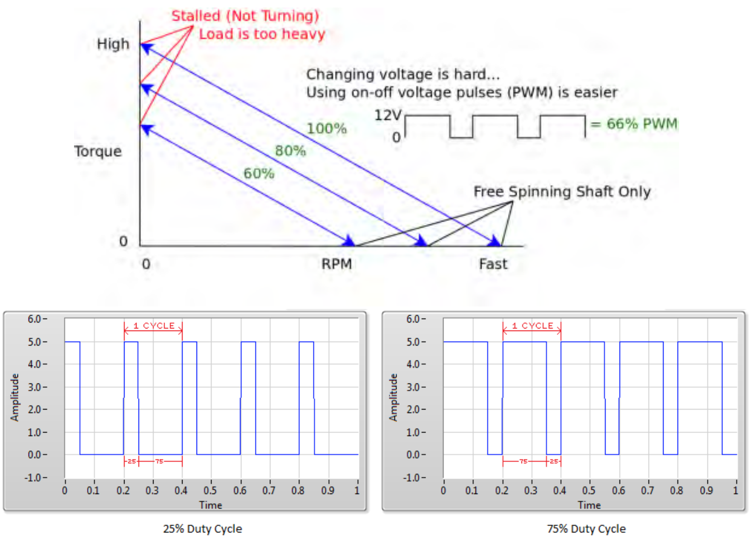


Figure 9.5 Example of PWM Torque vs RPM for various duty cycles (top) and time domain PWM signal (bottom) (National Instruments, 2014*b*).

The frequency determines how fast the PWM completes a cycle (i.e. 1000 Hz would be 1000 cycles per second), and therefore how fast it switches between high and low states. By cycling a digital signal off and on at a fast enough rate, and with a certain duty cycle, the output will appear to behave like a constant voltage analogue signal when providing power to devices (National Instruments, 2014*b*).

The main advantage of PWM motor control is that power loss in the switching devices is very low. This is especially valuable in off-grid solar tracking applications where the power budget is critical for survival of the system. Any unnecessary current drain should be limited, and with PWM control, when a switch is off there is practically no current. When PWM is on and power is being transferred to the load, there is almost no voltage drop across the switch. Since power loss is the product of voltage and current, for PWM control both cases are close to zero. PWM thus works well with digital solar tracking control, because of the on/off nature of PWM the duty cycle can easily be selected or the angular movement can be directly computed in terms of the number of PWM pulses counted.

Figure 9.6(a) shows an oscilloscope display of a sequence of PWM pulses generated by a PLC, to command the solar tracking operation through DC motor control signals on one of the axes. Two such PWM signals are fed into two discrete MOSFET H-bridge motor drivers, which enables bidirectional control on each of the two high-power DC slew drive motors. This motor driver supports 5.5 V to 24 V voltage range and can deliver a continuous 15 A without a heat sink.

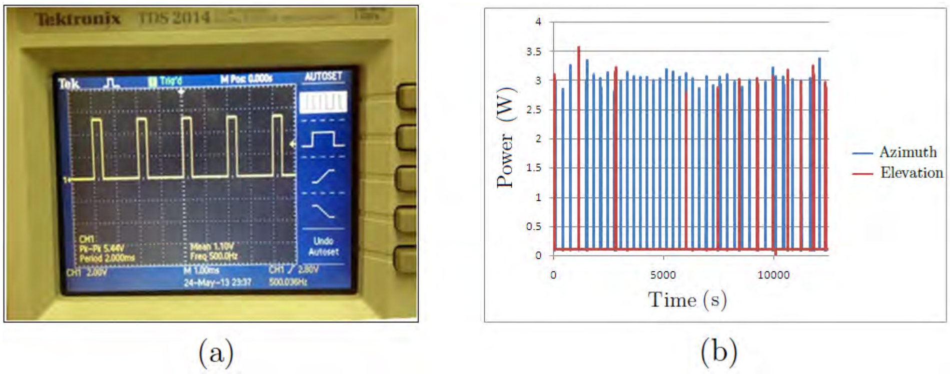


Figure 9.6 PWM control signals driving slew actuators shown on (a) oscilloscope at PLC output port and (b) power datalogger at motor current driver output port (Prinsloo, 2014*b*).

Figure 9.6(b) shows the datalogged PWM time sequences sampled at the azimuth and elevation MOSFET H-bridge motor driver outputs, measured where the motor drivers feed directly into the azimuth and elevation axes slew drive motors. The power levels in these real-time measured PWM time sequences highlight the power output delivered at the motor driver PWM signal outputs, and represents the slew drive actuator DC motor's power consumption levels.

In the PLC software, the control speed of the DC motor is varied around the optimum set-point speed of the motor (see Figure 2.25. DC motor PWM control signals should be wired through a shunting capacitor to the ground in order to reduce radio frequency interference commonly caused by PWM control (Lopez and Stone, 1993*b*).

While the DC motors draw current during each motor start-up phase, the Stirling engine also requires kick-start power to enable PCU operation with each sun re-appearance. These surges of energy may drain the backup battery, especially if the system operates in cloudy conditions and engages through multiple stop/start sequences.

The link `https://embeddedmicro.com/tutorials/mojo/pulse-width-modulation/` provides a tutorial on PWM control, for those who want to understand a little more. The site also includes sample code for those interested in micro controller or microprocessor PWM control. Just remember that a high current driver interface is required that drives the motors from an external source such as a battery or mains supply.

Follow on sections describe power analysis to estimate the operating times of the system elements in order to determine the backup battery capacity.

9.2.2 Variable Frequency Control AC Drives for Solar Tracking

In general, variable-frequency drives operates with AC power and uses special electronics to make speed adjustments to AC induction motors by way of changing or modifying the supply frequency to achieve a suitable rotational speed and torque. Such adjustable-speed drives are connected to a PLC processor or microcontroller to drive the high current end of electro-mechanical drive systems, such as for example a solar tracking system.

Once again, the current output of a PLC or microprocessor is too low and delicate to drive a high current AC motor. The AC motor is driven directly from the mains but is connected to the mains through the variable speed drive. The control logic of the micro-controller or microprocessor is then in turn wired to the variable speed drive, but only in terms of light digital or analogue signals.

A variable speed drive converts a fixed frequency and voltage amplitude into variable frequency and voltage signal, as depicted in Figure 9.7.

Figure 9.7 Variable frequency speed drive control.

The speed and torque of the azimuth and elevation axis AC is thus controlled by varying the motors input frequency and voltage.

In Figure 9.8, the is shown an example of a solar tracker variable speed drive (left) with an illustration of its operational principles (center, right) (Cowie, 2008). The signal representation on the right hand side of this representation shows that it is possible to achieve different frequencies and voltage equivalents (blue) by way of time-slicing or chopping the original mains (50/60 Hz) sine wave voltage into into high frequency square waves (red).

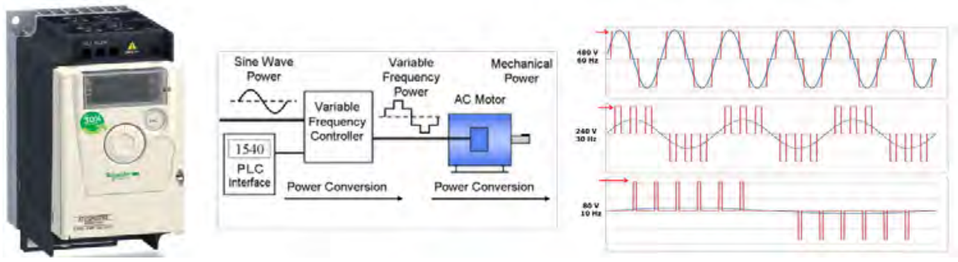


Figure 9.8 Example of a variable speed drive (left) with an illustration of its operational principles (center, right) for application in solar tracking (Schneider, 2014*a*)(Cowie, 2008)(VFDs, 2014).

Similar to DC motors in the slew drive application described earlier, a variable-frequency drive can also be used in a solar tracking application. The PLC processor is connected to the speed drive to control the rotational speed of an AC induction motor that drives the slew drive or any other actuator or transmission system. In the AC induction motor case, the speed of the AC motor is controlled by changing the frequency of the electrical power supplied to the AC motor as illustrated in Figure 9.8.

Schneider Electric recently developed a solar variable-frequency drive (SVFD) that can run a 3-phase AC motor directly from photovoltaic panels (see illustration Figure 9.8(left)) (Schneider, 2014*a*). During period of significant cloud activity, the variable speed drive automatically reduces the frequency output that drives the motor to reduce its speed.

This solar variable-frequency drive is ideal for water pumping purposes in deep rural areas, but may also find application in off-grid stand-alone solar tracking systems. Traditionally, DC motors are used in solar power units since photovoltaic panels produce DC. The new SVFD allows for existing AC electric motors to run off PV systems in remote areas.

Variable frequency drives are sometimes also referred to as electronically controlled variable-speed drives, adjustable-frequency drive, micro drives, inverter drive or AC drives. The examples illustrated in this chapter shows only limited variable-frequency drives and there are a number of different models and technologies in the market.

9.2.3 Pneumatic Solar Tracker Drives

Closed pneumatic-based solar tracking systems have been proposed to maximize energy intake and reduced corresponding losses (Jaafari *et al.*, 2013). This system by Jaafari *et.al* accomplish timed solar tracking rotation controlled by a microcontroller that drives a very low consumption closed pneumatic system. In this way accurate motion control is accomplished with a pneumatic means, with feedback from rotational position sensors in the pneumatic cylinders. Increased accuracy of the rotation and tilt inclination maximizes the overall stored energy while minimizing the loss in heat with the considered closed pneumatic scheme. The system ensures reduced energy consumption, while a draft cost analysis is also presented.

Hydraulic devices can also help solar collectors to track the sun. For example, at the Nevada Solar One energy field, hydraulic actuator drives are used to rotate and tilt solar collector assemblies as it tracks the sun's motion each day through the desert sky (Pneumatics, 2014). These actuators also control minor adjustments to the position of the arrays to compensate for the effects of wind pressure, as well as locking them for safe storage against high wind and dust storms (Parker Hannifin, 2014). The lifetime of the actuators is increased due to the high ingress protection rating, up to IP69, to withstand extreme heat, cold, dust, moisture and UV exposure that might be common in a solar energy application. Figure 9.9 show examples of pneumatic and hydraulic actuators available for solar trackerand sun steering mechanisms (Parker Hannifin, 2014).

Figure 9.9 Examples of pneumatic and hydraulic actuators for solar tracker applications (Parker Hannifin, 2014).

Pneumatic Rotaries, or so called Pneumatic Robohand Rotary Actuator Rotaries are also available for solar tracking applications. These actuators are available as shaft or flange output, high or low precision, and is suitable for light-duty and heavy-duty applications (Destaco, 2014). Manu of these actuators are flange mount rotary actuators are used in turntable type positioner systems, for example used in CNC milling and automatic welding positioners, and therefore allow the payload inertia to stop directly through an independent hard stop mounted in the turntable, rather than through the drive mechanism. This precision control makes these type of drives suitable for solar tracking applications while CAD Drawings for the actuator drives are commonly available.

9.3 Aligning the Solar Tracker with the Solar Vector

During the solar tracking control operation each of the two slew drive DC/AC motors is powered on independently through each of the microcontroller interfaces, while high-speed axis counters monitor the feedback from each slew drive DC/AC motor Hall encoder. The counted encoder pulses correspond with the desired travel path, while the particular motor movement will immediately be stopped when the desired slew angle has been reached.

Following each slewdrive movement sequence, or during power down, the final axis counters are stored in order to continue with subsequent travel instructions from the previous angular positions. During this process, the PLC keeps record of the absolute azimuth and elevation axis angular positions, if the solar concentrator pointing position is accurately referenced relative to the sun-vector position during configuration.

Sun position setup synchronization is done by moving the concentrator's azimuth and elevation axis actuator slew drives until the concentrator position is absolutely orthogonal to the sun vector $S_Q(\gamma_s, \theta_s)$ at the moment of synchronization. At this instance, the absolute azimuth and elevation axis angular positions are saved as sun vector reference points.

From that point onwards, the PLC controller can determine the travel distances of the azimuth and elevation axes slew drives, in terms of the Hall encoder pulses through the formulas given in the rest of this section. This process aligns the absolute pointing angles of the solar concentrator relative to the sun vector angles (Figures 8.8 and 8.9).

Given the gear ratios ($slew_{ratio}$ and $planet_{ratio}$) of the selected transmission system azimuth and elevation drives, a mathematical calculation is required to determine the number of DC motor revolutions required to move the solar concentrator from its present position to the position of the sun. In this calculation, the feedback magnetic pulses received from the DC motor encoders ($Hall_{az}$, $Hall_{el}$) and the difference/error angle between the sun vector and the concentrated solar reflector (γ_{sun} or θ_{sun}) can be used to calculate the number of revolutions in DC motor movement required for each of the elevation and azimuth actuators. The required DC motor revolutions can be calculated through Equation 9.1 and Equation 9.2 for the elevation and azimuth axes respectively (Prinsloo, 2014*b*). Essentially the formulas equate to the relative solar movement differential in terms of the relative DC motor movement PWM intervals required for the solar tracking operation to catch-up with the sun movement.

$$\gamma_{az_{motor}} = \frac{\gamma_{sun}}{360°} \times slew_{az} \times planet_{az} \times \frac{Hall_{az}}{360°} \tag{9.1}$$

$$\theta_{el_{motor}} = \frac{\theta_{sun}}{360°} \times slew_{el} \times planet_{el} \times \frac{Hall_{el}}{360°} \tag{9.2}$$

These computations also relate directly to the solar tracking offset and is required to draw graphs representing the solar tracking error and to relate the solar tracking error to the amount of motor movement required to move the solar dish to each new sun position.

A sun-path diagram with daytime sun-path vectors for the summer solstice, winter solstice and solar equinox for any given location and is helpful in setting up and configuring a solar tracking controller for a particular site of installation as it provides a visual representation of the required solar concentrator movements and stipulates the border regions and angular motion safety margins.

9.4 Automation Platform Integration

The PLC platform and software solution further provides for inputs to ensure error correction on mechanical tolerances and installation deficiencies. The central PC-based HMI can be connected through Ethernet/TCP connection and allow for configuration setup and calibration control inputs as well as for monitoring and control of the actual status of the solar tracker unit.

The solar tracking automation solution describe the components and interconnection diagrams for three types of drive variants, namely DC motors, Induction motors with frequency converters and Induction motors with reversing contactors. The DC solution will be implemented in the present design.

Figure 9.10 Wiring diagram for Siemens S7-1200 to control DC Motor Slew Drives (Prinsloo, 2014*b*).

Figure 9.10 shows the basic wiring configuration and demonstrate how the LC software platform is associated with the slew drive tracking movement mechanism. An industrial grade PLC power electronics platform inherently provides for lightning protection, especially when the PLC is housed in a grounded metal enclosure.

For solar tracking applications, good wiring techniques and shielded power and communication cabling in solar tracking automation applications has proven to be valuable in harsh environmental field systems. The PLC processor or microcontroller should preferably meets the required industry standard (IP55). It should also have the processing power requirements to implement the solar position algorithm together with dual axis motion control.

Ideally, the user simply needs to connect the two cable connectors wires between the panel box and the two slew drives and power up the systems after which it will automatically track the sun. Such a design allows for a modular setup in which measuring devices can be added/removed from the system without interfering with the solar tracking process tracking.

The control electronics should be housed in a metal enclosure fitted and property earthed through the to the pedestal support structure. Potential lightning damage to the solar concentrator system and PLC electronics is further alleviated through the use of external earthing. In this regard, provision is made for a stainless steel stud at the base of the pedestal structure to allow for interconnection to an external grounding.

9.5 System Configuration and Calibration

The solar tracking controller should be working as an autonomous unit which, once configured, requires minimal interaction. The final tracking precision is largely dependent upon the accuracy of configuration and calibration.

Figure 9.11 is intended to give the reader an idea of the typical elements included in a solar tracker display, and shows examples of screenshots displaying the control configuration and operator interface for two arbitrary solar tracking systems. Th operator interface for most solar tracking systems allow for a set of Configuration or Calibration Settings, Basic/Advanced Operation Settings and the display of a set of System Monitoring Parameters. In some cases, the operator has the option to download these parameters to an external file on disk to study the temporal variations in the data for example.

Figure 9.11 Examples of screenshots displaying the control configuration and operator interface for two arbitrary solar tracking systems (National Instruments, 2014*a*)(GoshLab, 2011).

A solar tracking software configuration process includes the step of configuring the micrpoprocessor. The gear ratios of the actuator system (planetary and slew gears) are programmed in the micrpoprocessor or PLC configuration setup, while the control system is referenced and synchronised relative to the true sun position. The system parameters as well as referencing the solar position in relation to the orientation of the tracking platform is then calibrated.

These steps ensures that the control electronics and equipment could be disconnected from the main structure at any point to be stored. The control electronics should be housed in a panel box that can be mounted onto the pedestal or balancing boom. In such way, the micrprocessor or PLC and the tracker platform are stand-alone units that can be connected in a plug-and-play fashion and are not in need of any other computing devices to perform the solar tracking.

A solar tracking controller would typically have three main modes of operation, namely an automatic control mode, manual/maintenance control mode and safe operating mode (GoshLab, 2011). In automatic control mode, the tracking controller will track the sun during the day and will switch to sleep configuration at night.

In the manual mode, the solar tracking controller can be configured, tested or setup for maintenance. The system will enter into the third, or safe operating mode, when it is not safe to operate the solar tracking system, for example to handle unusual conditions such as when a system error is detected, high-wind conditions prevail or other extreme weather events may risk the safety of the solar tracking system (Prinsloo, 2014*b*).

Configuration parameters is a set of operating parameters configured during the setup of the solar tracking controller. The configuration parameters include the location, equipment and dynamic ratio aspects of the behaviour of the controller. Calibration, in turn, is the process of refining the control model in terms of the specific geometry of the solar tracking system and technology configuration. This is typically done through the analysis of observations and measurements as well as by collecting optical and other data during trial operations. The calibration process is used to determine some of the configuration parameters of the tracking controller that allow precise pointing in the world.

The development of a user guide for solar tracking configuration setup and calibration for a two-axis controller is essential. These procedures generally allow for the solar tracking system to be configured by pointing the Stirling payload directly at the sun and setting the parameters for solar tracking from this point. Alternative procedures can be developed to reflect the sun with a mirror onto a target, or a combination of the two procedures to support both direct and reflective types of setup and calibration.

The calibration procedure typically allows for calibration data points to be recorded by the controller during a trial operation. It thus forms part of the calibration process as it is associated with the setup and maintenance of the solar tracking system and involves the recording of measured datapoints under particular operational conditions. Automation controllers may be configured to collect different types of data, for example to fit the automation control output to the solar angles angles by pointing the concentrator directly at sun (GoshLab, 2011).

9.6 Hardware Protection and Angle Range Limit Switches

Trip switches or limit switches is a recognized way to prevent cable wind-up or other damage to the solar tracking platform if any software errors may occur. A common software bug that causes the solar tracking system to run away occurs when the solar tracking azimuth axis runs through North (for example solar tracking systems in the Southern Hemisphere). At this point, the azimuth angle encoder output typically changes output/signal/reading from $0°$ to $360°$ (or the other way round) for a normal $1°$ azimuth change. If the tracking controller software does not make provision for this fact, then the solar tracking system could swing around $360°$ in either direction to compensate for the angle encoder reading. This is a common mistake made by programmers not experienced in practical solar tracking software programming.

There are two ways to prevent this as an emergency protection measure. The first is to use hardware trip switches or limit switches, and the second is to include secondary measures in the software, or so called software limit trips or switches. The azimuth hardware trip switch typically allows a certain angular motion range as provision to limit exceeding motion range. Similarly, an elevation hardware trip switch serves as provision in the hardware wiring to limit the tracking system from exceeding a certain elevation (or zenithal) motion range.

Figure 9.12 shows the recommended physical installation configuration for hardware/-software limit switches and angle encoders for solar tracker installation sites in the southern hemisphere (left) and the northern hemisphere (right) (Siemens, 2010*b*). Similar to the physical location of the limit/trip switches in the figure, it should be noted that the task for the programmer is simplified if the (absolute) angle feedback position encoder is physically installed in such a way that the angle encoder output transition point (from 0° to 360°) sits on the South (compass direction) side for a tracker installed in the southern hemisphere, and on the North (compass direction) side for a tracker installed in the northern hemisphere. This is to help avoid keeping track of $0- > 360°$ transition jumps in angle feedback registers, which can become quite tricky in tracker software code (however, at locations closer to the equator, the elevation angle extends beyond 90°, meaning that software should should make provision for the $0- > 360°$ transition jump).

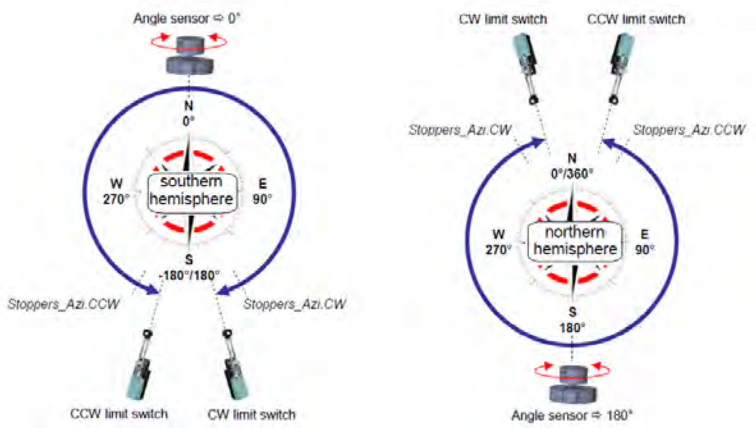


Figure 9.12 Limit switch positions for solar tracker installation sites in the southern hemisphere (left) and the northern hemisphere (right) (Siemens, 2010*b*).

In the northern hemisphere, the sun moves azimuthally over the South, meaning the trip switches must be installed on the North facing side of the tracking system (see Figure 9.12). This is because the daily solar tracking operation for the azimuth axis moves as follows: N .. E .. S .. W .. N or in terms of angles 0° .. 90° .. 180° .. 270° .. 360°. Conversely, in the southern hemisphere, the sun moves azimuthally over the North, meaning the trip switches must be installed on the South facing side of the tracking system. This is because the daily solar tracking operation for the azimuth axis moves as follows: S .. W .. E .. E .. S or in terms of angles −180° .. −90° .. 0° .. 90° .. 180°.

In addition to hardware limit switches, the programmer may also make provision in the software for so-called soft-trips. Software trips for azimuth cable wind-up protection may be set around angle limits of 340° to make software provision for cable wind-up and protection. Software procedures may also include elevation cable wind-up protection adjustable around 340° to protect dish damage in case of elevation run away.

Moreover, it is a good idea to include a hard trip (red button trip) to help protect the system during experimentation. If the system runs away during experimentation with a prototype for example, then the system developer has one safety measure to shut down power. Do remember to consider all connections as live during this stage and also keep in mind that components on a concentrated solar system may be very hot and cause physical injuries (see Section 17.1 for Health and Safety tips for solar tracking systems).

9.7 Summary

In this chapter, we presented details of the digital electronic automation hardware and software, the electronic control system, control logic, and the hardware/software integration. With the solar tracking platform and digital automation aspects completed, the next chapter will consider power budget calculations to ensure system survival during long periods of non-solar activity in off-grid and stand alone applications.

CHAPTER 10

SOLAR TRACKING POWER BUDGET

10.1 Introduction

In autonomous, stand-alone, self-tracking concentrated power generation systems, the instantaneous power resource requirements associated with various modes of operation are not always in synch with the availability of solar irradiation. When the solar power generating system is unable to yield sufficient power to sustain the solar tracking capabilities of the system, the system would lose its link to the solar power source and will eventually end in a dysfunctional state from which the solar power system will be unable to recover on its own.

10.2 Stand-alone Off-grid Power Budget

In solar power systems, cloud transients causes intermittent power generation level changes and interruptions due to passing clouds. This is due to the screening effect of the clouds leading to temporal changes in levels of solar radiation available to the solar receiver. This interrupts the operation of the power conversion unit (PCU) as the clouds causes the PCU to lose its connection to the sun and energy source.

Weather effects are the Achilles heel of CSP systems, especially passing clouds. Cloud transients are therefore one of the effects which the designer needs accommodate for in the power subsystem design of a self-tracking solar tracking system as it directly impacts on the power source to drive the solar tracking and power generation subsystems.

The original developers of the Powerdish solar power system (Infinia, 2012*b*), for example, stated that their solar power system is not suitable for stand-alone operation in areas where connections to the national grid is not available at the site of installation. The control system is dependent upon a main grid electrical supply line to accomplish solar tracking through storms/cloudy conditions, and to kick-start the Stirling engine at the onset of every power generation cycle.

This leaves remote stand-alone and off-grid power systems and deep rural communities in the dark with respect to power generation through such commercial concentrated solar power generating systems. However, if the power resource can be managed more intelligently, through intelligent control strategies, then it may be possible to realise a self-tracking solar power generating system suitable for Africa.

One study hypothesised that a more intelligent control strategy would support solar operations independent from grid infrastructure (Prinsloo *et al.*, 2013*a*). This study advocates that next generation systems should reflect better reduction of CO_2 emission while there is a wide divergence in embodied CO_2 emissions for solar thermal electricity generation systems and that *differentiated modes of operation* can improve the environmental impact of solar power systems.

Power budget and carbon aware energy management is not uncommon in the automotive and computer -efficient solutions where it is used to address energy consumption challenges in automotive mobile platforms and computing platforms. In automotive industry applications, the demand for onboard electrical power consumption in a stand-alone platform is often balanced through a power optimization control strategy (Butzkamm *et al.*, 2012). In a computer system application, one proposed carbon/power based scheduling control strategy was able to achieve better power savings than profit based scheduling policies, leading to higher profit and less carbon emissions (Garg *et al.*, 2011).

Power budget and CO_2 awareness control approaches are potential solutions to overcome challenges with stand-alone self-tracking concentrated solar power generation systems in off-grid areas, where solar tracking and on-board power/carbon management are mission critical control elements.

10.3 Power Budget Aware Automation

The estimated total electrical energy produced by a solar concentrator and the total energy consumption by the sun-tracking system should be calculated to ensure that the power budget of the system balances in the context of intermittent solar energy.

Taking into account of the total mirror area, the optical efficiency as well as the conversion efficiency from solar energy to electrical energy for certain direct solar irradiation levels, one will be able to potential generated output power for the available hours of sunshine in a day. The solar incident radiation models for the Ecotect (or Vasari) Planar Solar Radiation analysis tools, shown in Figure 10.1 (Krymsky, 2013), can be used as part of the solar radiation study to compute the available supply side solar power budget for a particular day or month of the year. Weather prediction models such as the Siemens Spectrum Power TG Weather Adaptive Load Forecast microgrid module (Siemens, 2013*b*) can also be used to supplement the supply side power budget model accuracy.

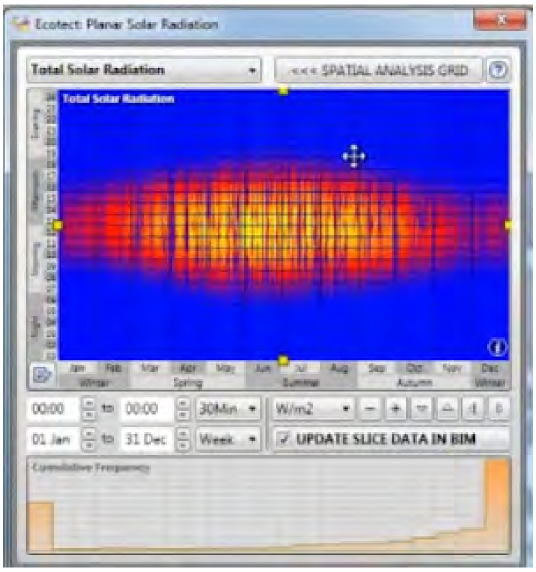


Figure 10.1 Display of the thermal temporal power budget levels over four seasons of the year (Krymsky, 2013).

In a typical solar tracking and harvesting system, one would have to consider the power consumption from all the components, including for example tracking motors, motor driver, encoders, microcontroller, power conversion unit (kick-start action), wireless interfacing and data monitoring computers. Typically solar tracking should use around 3.5% of the rated generated output power of the overall solar tracking system, meaning it is essential to pick technology components that would help reduce the energy consumption of the system.

Control and automation forms an integral part in the design of solar power conversion systems for stand-alone village installations as well as for industrial scale grid-connected installations. Some control designs employ digital implementation platforms such as robust industrial standard Programmable Logic Controllers (PLC) with remote control/access capabilities.

Prinsloo *et.al* describes issues around a CO_2 impact optimization algorithm as control concept for the automation of the solar power generation and tracking system wherein a digital power budget principle forms the basis for artificially intelligent decision architecture to maximize CO_2 impact of the solar power system. This and other intelligent control strategies could be of value to both off-grid rural power generation systems and commercial solar farms where CO_2 impact optimization eventually impacts directly on the carbon footprint of a solar farm.

The proposed solution is unique in terms of the design philosophy which is proposed to achieve inherent mechanical and electronic control stability, while ensuring optimal energy efficiency to cater for off-grid self-tracking capabilities. An energy or power-budget principle (which optimizes the CO_2 footprint of the system) is proposed and implemented through electronic control logic in order to realize the "self-tracking" feature while ensure energy self-sustainability for this stand-alone solar power generator system.

10.4 Temporal Power Budget Requirements

For a stand-alone, self tracking solar tracking and power generating system, the concept of a solar tracking energy budget and energy cash flow can help to realise self-tracking features in stand-alone solar power generator and control system. Similar to using cash flow in a financial budget, an energy budget in the context of solar tracking is proposed to operate on the principle of energy income and energy expenditure, managing energy expenditure in accordance with energy (income/generation) potential and energy (backup/storage) levels.

A power budget typically allocates strict power margins according to which on-board tasks are managed. Subsystems are assigned fixed, maximum power allocation and are managed in accordance with the available solar generated and operational task schedules. A power-aware control strategy then increase the capability of on-board processing while assigning certain on-board tasks a greater degree of flexibility (Liu *et al.*, 2001).

In order to meet the demand for on-board power requirements such as tracking and control, the graphical illustration in Figure 10.2 highlights the importance of power budget management, especially within the context of weather effects such as interrupting clouds.

In concentrated solar systems, solar tracking is a mission critical function. When the solar power generating system is unable to yield sufficient power to sustain the solar tracking capabilities of the system throughout the day (Figure 10.2), the system would lose its link to the solar power source and will eventually end in a dysfunctional state from which the solar tracking system will be unable to recover on its own.

On the solar supply side, the power harvested by the solar Stirling generator (Figure 10.3) is mainly dispatched as supply transmission to the user and to recharge the on-board energy storage system in order to meet the demand for on-board power requirements such as tracking and control.

Figure 10.3 shows a graphic illustration of typical solar power generator supply levels (height) as well as the daily hour supply range wherein solar radiation is available. The user supply as well as battery power levels available for solar tracking further depends on weather conditions and the site of installation, meaning reliable supply calculations should ideally include average solar exposure, location, and weather patterns.

Figure 10.4 shows the power consumption and torque characteristic curves for a typical permanent magnet DC motor to be used to drive the Azimuth and Elevation transmission

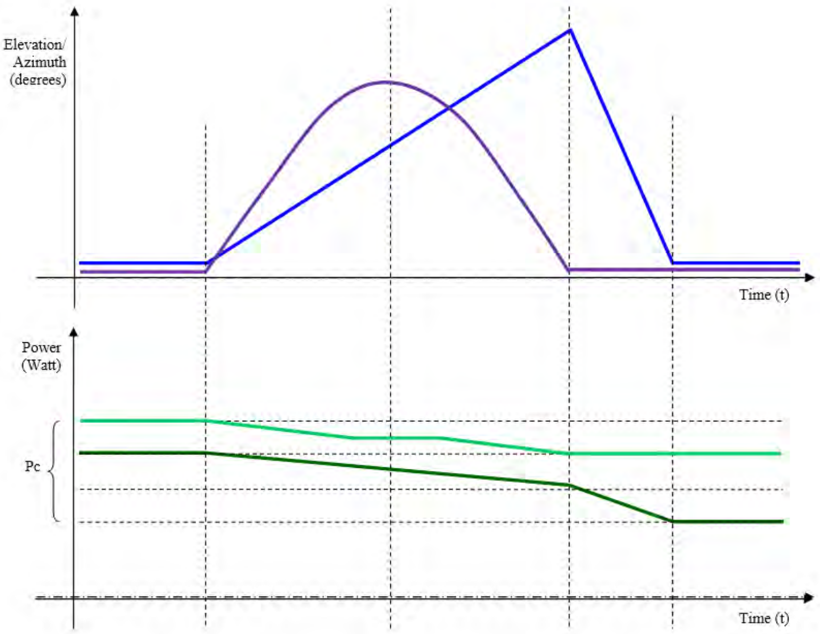


Figure 10.2 Typical solar tracking motions on the azimuth and elevation axes (top), with associated power supply requirements (bottom) over a 24 hour solar tracking period.

drives. In a power optimization or carbon optimization solar tracking control strategy, one objective will be to optimize the solar tracking motion activities to that of the DC motor energy and efficiency characteristics (input or current efficiency, output or torque efficiency).

The motor curves shows that power input efficiency and power output efficiencies occurs at different motor speeds, where power input efficiency is achieved at a slower rotational speed. In a self tracking concentrator system, one of the objectives is to choose DC motor settings and to smooth out instantaneous power needs or usage to preserve the backup power resource in order to ensure self tracking.

This also illustrates the benefit of a power optimized control strategy wherein the slew drive speed at various pulse width settings power can be used to as well as to a slow and precise solar tracking application. The controller should constantly manage on-board power demand in accordance with available power budget using differentiated modes of operation that makes maximum use of parameter settings to run at either optimal power consumption or optimum speed levels.

Figure 10.5 shows the solar tracking motions on the azimuth and elevation axes (top), with associated power supply requirements (middle), and power generation levels (bottom) for solar tracking in the presence of cloud activity. This illustration shows the influence of transient clouds on the temporal solar tracking power budget as a result of the power demand required to kick-start the Stirling engine following an interruption of its operation as a result of cloud activity.

Typically, solar tracking mobility, control automation and Stirling kick-start power pulses dominates the demand side of the power budget. These solar tracking and instan-

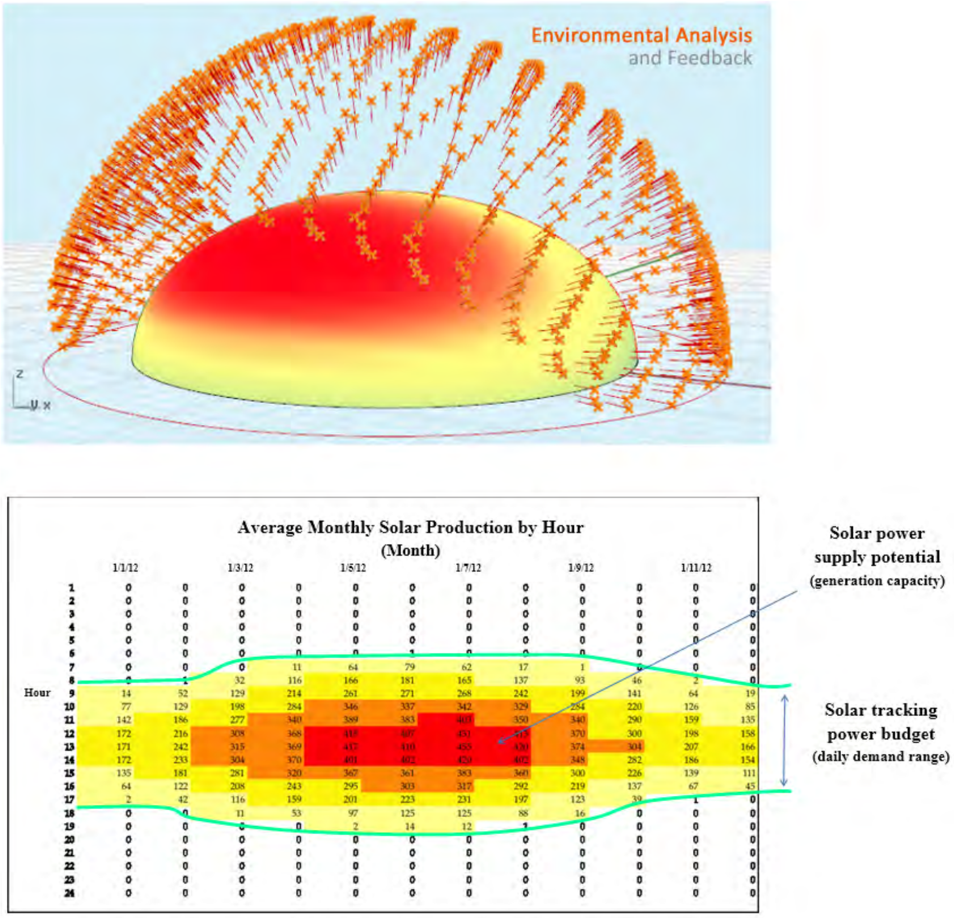


Figure 10.3 Solar concentrator thermal power budget daily/montly radiation time with sun flux levels over a 12 month period (with no clouds) (Krymsky, 2013).

taneous start-up/shut-down sequences of a Stirling device demand significant energy from the back-up battery supply when a grid connection is not available. Frequent cloud passes may thus result in a situation where numerous start-up sequences can consume more of the power budget than the Stirling is able to supply, especially during periods of low solar exposure.

10.5 Power Budget Control Principles

Considering the success with solar Stirling power generation technology experienced in the NASA satellite and space programs (Linden, 2007), an intelligent control automation system for solar tracking can learn from automation principles used in satellite platform design, especially aspects related to power budget control (Liu *et al.*, 2001).

Power budget management on a satellite system is, similar to stand-alone solar tracking system, a mission critical parameter seen from a control perspective. A satellite is also an

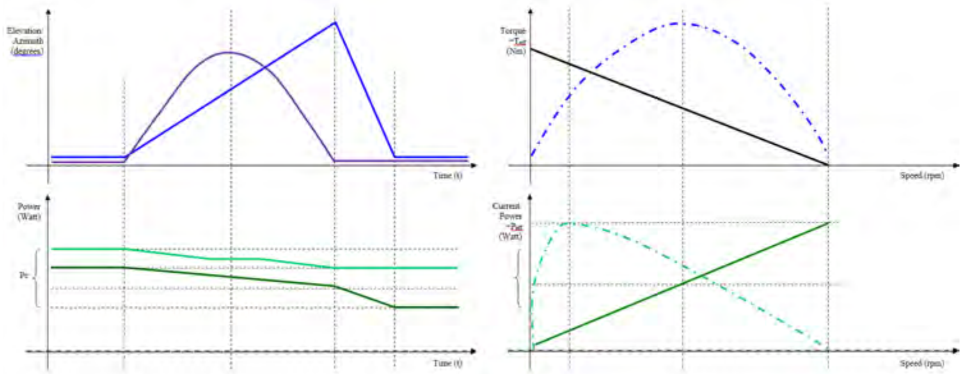


Figure 10.4 Solar concentrator azimuth and elevation drive demand with actuator drive operating curves and adjustable operating points.

autonomous mobility platform embedded on a battery dependant attitude control system, isolated from grid infrastructure and supplemented through a solar supply. This means that solar tracking developers has much to learn from satellite based solar power budget and mission critical power control.

Power budget analysis for a satellite/solar tracking system includes the process of completing solar power supply and system demand spreadsheets in order to determine the power requirements of the various system components. Such detailed analysis is required to determine the demand for each system block.

To develop a model for mission critical control analysis, one can consider the simplified power supply and demand system represented in Figure 10.6. This figure shows an idealised power supply curve, overlaid by typical DC motor power demand as curves/lines. The curves in the figure may for example represent the power budget variables for a typical Stirling solar generator with permanent magnet DC motors driving the Azimuth and Elevation slew drives over a 24 hour daily solar cycle.

In this illustration, the power requirements for each drive were determined through empirical measurements at various motor speed/torque settings. It should further be noted that the power supply curve is a function of the geographical location of the installation, and the time-of year, while the operating point, PWM and speed settings of the DC motor drives has a direct bearing on the instantaneous demand on the power budget.

In a power optimization solar tracking control strategy, one objective will be to optimize the system characteristics (input or current efficiency, output or torque efficiency). It is well known from the performance curve of an electric DC motor that the power input (V x I) efficiency is typically rated at a slower rpm than the rated maximum power output (torgue) efficiencies. Different PLC control strategies could thus operate the DC motors at different PWM duty cycles and frequencies.

A power manager may use power budget information to calculate the sustainable drive speed a drive control application can use for execution, given its current power budget. A sustainable speed may typically be a motor setting that consumes less power at a certain available power budget. This demonstrates the potential for differentiated control modes as potential solution for various environment and power budget conditions.

In satellite system design, engineers rely on design-for-power design strategies in combination with design-for-performance at all layers of satellite system design. In these de-

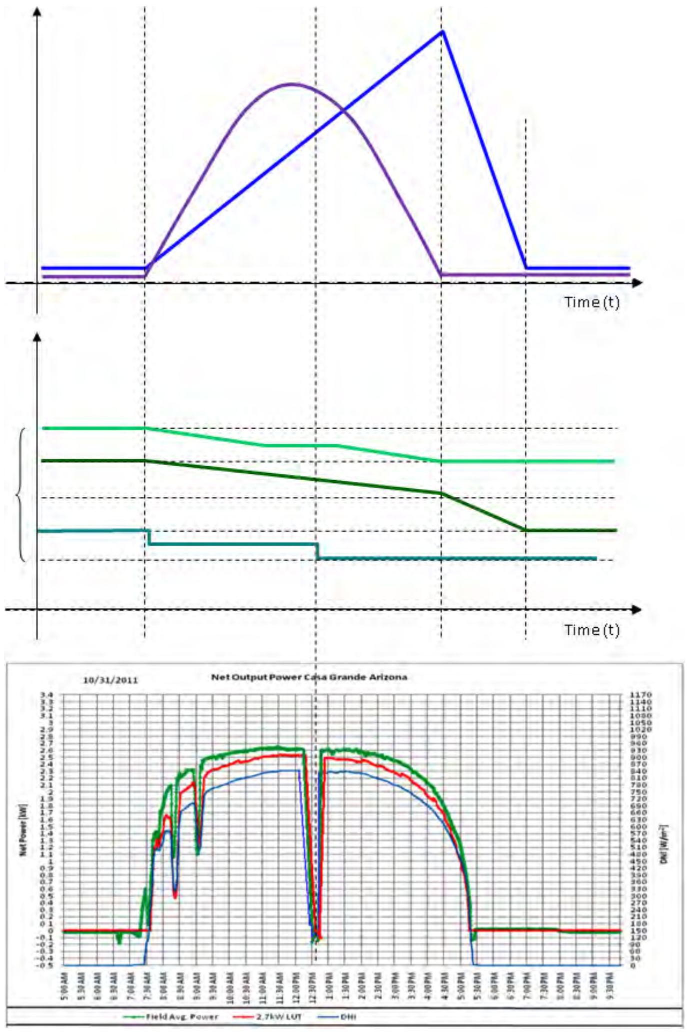


Figure 10.5 Solar tracking motions on the azimuth and elevation axes (top), with associated power supply requirements (middle), and power generation levels (bottom), to show the influence of transient clouds on the solar tracking power budget.

signs, certain constraints are placed on the battery usage, while power budget management is used in the conservation of power for control automation (Liu *et al.*, 2001).

Power budget principles and scheduling required for a solar tracking system is however slightly more complex that satellite control, as satellites are not required to cater for clouds interrupting the link with the solar source. Cycles of solar visibility are more predictable and battery recharging cycles more reliable.

With self-tracking solar concentrators, one of the main control objectives for a PLC controller is to preserve the backup power resource to ensure self-tracking, while smoothing out instantaneous power needs or usage. The control philosophy would be to constantly manage controller operation and power dissipation by the user in accordance with available power budget.

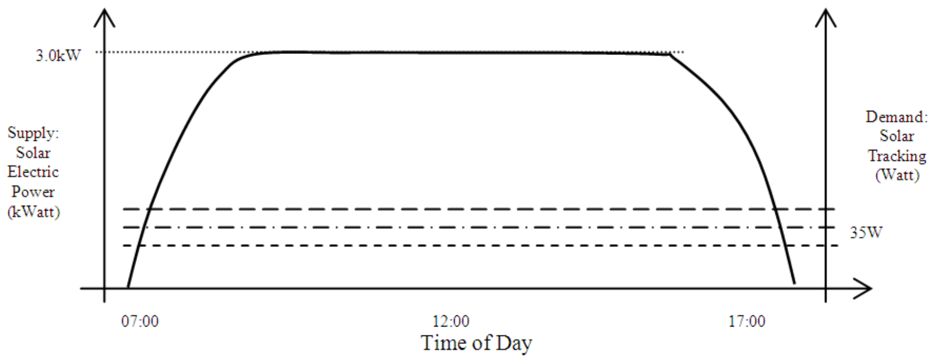


Figure 10.6 Solar concentrator power budget supply and demand levels over a 24 hour period with no clouds (Prinsloo *et al.*, 2013*a*).

The intention with an intelligent control strategy in autonomous off-grid solar tracking and power generation is to smooth out spikes in the power demand and to smooth voltage and current consumption to realise tracking in order to utilize the power budget optimally. The system thus has to find a balance between power budget and movement and characteristics of the motors and drives with available solar irradiation (intensity) and potential power gained through solar tracking efficiency.

A power budget analysis will help to optimize the design of the control system as well as to determine a basis for dynamic power control during operation of the solar tracking process.

10.6 Power Budget Analysis

Power budget and carbon footprint analysis are linearly dependent concepts. Even in the design and operation of renewable energy systems, carbon footprint analysis of the as-built system is of importance and the demand side CO_2 footprint should be quantified. In this regard, Table 10.1 presents a power budget analysis, namely a list of concentrated solar positioning system components plus an estimate of the relative times dedicated to each task.

This information is used to analyse the power budget reserve as well as the CO_2 footprint of the concentrated solar power system, and is at the same time required for calculating the backup storage capacity required by the system in a stand-alone application. A summation of the estimated power requirements for each task represents the averaged power demand of the stand-alone concentrating solar power system and also needs to be accommodated for in the battery backup selection and electrical sub-system design.

Solar power calculators can also calculate the solar power system components, inverter sizing, battery capacity and ratings `http://www.solarpanel.co.za/solar-power-calculator.htm` and `http://www.wholesalesolar.com/StartHere/OFFGRID/OFFGRIDCalculator.html`. Solar calculators such as the NREL PVWatts Calculator can further help to compute the power budget supply side as it can estimate the energy production and cost of energy of energy systems throughout the world (NREL, 2014*c*)(PlanMyPower, 2014).

A battery backup system is most effective when used in conjunction with permanent magnet DC motors as these motors are more power efficient. However, continuous engage-

Table 10.1 Power Budget and CO_2 impact analysis for a typical concentrated solar positioning system and components (Prinsloo, 2014*b*).

Power Budget and CO_2 impact analysis					
Task	**Current**	**% Time**	$\overline{\mathrm{Amp}}$	**Power(W)**	**CO_2(g)**
Solar tracking subsystem					
PLC control	56 mA	100%	56 mA	1.34 W	0.95 g
Azimuth motion	2.92 A	50% PWM	7.7 mA	185 mW	0.13 g
Azimuth Hall encoder	0.8 mA	50%	0.4 mA	10 mW	0.007 g
Elevation motion	2.92 A	50% PWM	5.5 mA	132 mW	0.093 g
Elevation Hall encoder	0.4 mA	50%	0.2 mA	5 mW	0.003 g
Homing sensors	1.2 mA	50%	0.6 mA	15 mW	0.011 g
Communication	208 mA	1%	2.1 mA	50 mW	0.035 g
Subsystem Total			**72.4 mA**	**1.737 W**	**1.229 g**
Power subsystems					
PCU power up	1.5 A	0.2%	3 mA	72 mW	0.051 g
Charge control	6.0 mA	50%	3 mA	72 mW	0.051 g
Power inverter	65.0 mA	100%	65.0 mA	1.56 W	1.1 g
Subsystem Total			**71.0 mA**	**1.704 W**	**1.202 g**
User interface dispatch					
User supply/demand	12.5 A	100%	12.5 A	300 W	211.66 g
Subsystem Total			**12.5 A**	**300 W**	**211.66 g**
System total					
System Totals			**12.64 A**	**303.44 W**	**214.6 g**

ment and disengagement of the dish of a stand-alone system and in the absence sufficient solar irradiation (i.e. cloudy conditions) can drain the backup power supply. This calls for a power demand and power budget analysis to ensure that there is sufficient power storage capacity to feed the solar tracking and harvesting system components.

The power demand analysis for a concentrated solar power system detailed in Table 10.1 presents the list of automation control hardware components as well as an estimate of the time needed to perform its duty during clear-day and cloudy-day conditions. The relevant percentage of time dedicated to each task is used to estimate the automation power requirements.

The next section shows that a typical solar tracking system of 3 kW capacity calls for a backup battery capacity (BBC) of at least 140 Ah for 10 hour user/solar tracking operation. Often a standard deep-cycle-type backup battery with a capacity of around 200 Ah is required to meet stand-alone operational requirements.

10.7 Battery Capacity Analysis

In the power budget analysis of Table 10.1, the power demand of the system is estimated to be around 1.737 Wh (Watt hours). With the estimated hourly energy demand for solar tracking control and automation to be around 1.737 Wh, and the total estimated system demand (with an assumed constant user load of 300 W) to be around 303.5 Wh (Table 10.1), the battery power storage medium can be selected. As a practical consideration, it should be taken into account that theoretical battery capacity does not allow for 100% use of any battery. The actual battery life should rather be computed with an efficiency (η) of 75% of the battery capacity to allow for a 25% recharge reserve (Excide, 2013).

$$BBC = \frac{Demand\,load\,(W)}{Voltage\,(V)} \times \frac{Reserve\,capacity\,(h)}{\eta_{battery}} \tag{10.1}$$

Equation 10.1 can be used to calculate the required backup battery capacity (BBC). The first part of this equation computes the theoretical BBC for which the designer specifies the average demand load (Wh), the operating voltage (V) and the Reserve capacity (hours), while the battery efficiency ($\eta_{battery}\%$) is brought into the equation to calculate the actual BBC capacity.

For solar tracking system with an operating voltage of 24 V, a demand load of 303.33 W (computed in Table 10.1), a required run-time operation reserve of around 10 hours and a 75% battery efficiency, the actual BBC is calculated as follows:

$$BBC = \frac{330\,W}{24\,V} \times \frac{10\,h}{0.75} = 183\,Ah \tag{10.2}$$

From Equation 10.2 the actual battery capacity is calculated to be at least 183 Ah. A battery capacity should be sufficient to provide for around 10 hours solar tracking capacity in the absence of available sunlight (the re-charging resource), typically requiring at least a 140 Ah backup battery (Boxwell and Glasbey, 2014). This page includes valuable information related to batteries in solar systems http://www.itacanet.org/a-guide-to-lead-acid-battries/ (ITACA, 2014).

A battery is normally rated in terms of Amp hours over discharge rate. For example, a battery specified as ”100 Ah at C20” is able to produce 100 Ah when discharged over 20 hours. Other than car batteries designed to produce a short burst of power to start the engine, solar applications typically use heavy duty deep cycle batteries, such as deep cycle lead acid batteries. Deep cycle batteries are designed to provide power over a far longer period of time and is able to ensure deep discharges (Excide, 2013). These batteries are typically only available in terms of standard 50 Ah, 100 Ah, 150 Ah and 200 Ah ratings.

From Equation 10.3 the actual time of operation available with a backup battery capacity with a standard rating of 150 Ah is calculated to be 8.2 h, while a battery rated at a standard capacity of 200 Ah would deliver around 10.9 h of operation, computed in Equation 10.4.

$$OperatingTime_{hours} = \frac{150\,Ah \times 24 \times 0.75}{330\,W} = 8.2\,h \tag{10.3}$$

$$OperatingTime_{hours} = \frac{200\,Ah \times 24 \times 0.75}{330\,W} = 10.9\,h \tag{10.4}$$

For a 3 kW electrical solar tracking system that requires a battery with capacity to ensure at least 10 hours of user and solar tracking operation calls for a certain battery capacity (Prinsloo, 2014*b*). The calculated capacity requirement for the as-built system with an estimated 10 hours of user/solar tracking operation is computer 183 Ah.

A cost-benefit analysis must be performed to fulfil the second part of the battery requirements. This centres around a choice between the available deep cycle battery capacity options, namely a standard 150 Ah or standard 200 Ah (24 V) deep cycle battery. Calculations above show that the **200 Ah battery** would be able to deliver an estimated 11 hours of operating time, compared to the estimated 8 hours of operating time with the **150 Ah battery**, both cases where the concentrated solar power system operates in the absence of sunlight (zero re-charging resource).

In a solar power system, the charge controller takes care of the batteries, ensuring that they give an optimal life. The power budget data may also be used with storage capacity and battery life specifications to calculate parameters for an emergency solar PV charger if this is required by the user. The photovoltaic modules required for a solar PV standby backup generator can be calculated. In general, a photovoltaic panel should provide at least 10 times the average power needed. For example the power output required for a 12 V 50 mA charging system requires a photovoltaic system of minimum 6 W (10 x [current x voltage] = 10 x [50mA x 12 volts] = 6000 mWatts or 6 Watts) (Boxwell and Glasbey, 2014).

10.8 Carbon Footprint Analysis

Considerable attention is given to climate change. Internationally, governments are increasingly implementing measures to reduce the potentially devastating effects of climate change. The government of South Africa, for example, is of the view that *"in pricing the external costs associated with carbon-emissions, an incentive is created to change behaviour and encourage energy-efficiency measures"* (Treasury, 2010).

Carbon footprint and power budget analysis are essential concepts in any off-grid stand-alone system as it relates to the survival of the system. Moreover, researchers are questioning the claims of zero carbon-based solar power generation and the call is out to consider the "full-chain" environmental impacts of solar thermal and photovoltaic power conversion (Norton *et al.*, 1998).

The system and user demands presented in Table 10.1 is equated to the carbon impact in terms of grams of CO_2 per hour. The CO_2 impact (grams) for each task, presented in the far right column of Table 10.1, is computed by multiplying the Power (W) consumption with the GHG conversion rate of 0.70555 kgCO_2/kWh (Environmental Protection Agency, 2012) `http://www.epa.gov/cleanenergy/energy-resources/refs.html`.

It should be remembered that the CO_2 conversion factor is country specific, as it is a function of the power generation technology mix of a specific country. In south Africa, for example, the CO_2 conversion factor is close to 1.0 kgCO_2/kWh, simply because the country's power generation capacity relies heavily on coal. The conversion factor is thus dependent on the negative carbon impact of the main power generation capacity resources (Carbon Trust, 2013).

The CO_2 column in Table 10.1 (right) gives an indication of the carbon impact or carbon footprint for each of the concentrated solar power system components during daytime operation (using EPA factor of 0.7). The added total gives the overall CO_2 footprint of the proposed concentrated solar positioning system and equates to a concentrated solar power system demand side carbon footprint of around 214.6 g/h (grams of CO_2 per hour). The footprint of the system is relatively small, although this CO_2 impact will only be brought into perspective once the Stirling power generation system is available as this will offset the automation power demands through Stirling renewable energy power generation.

The demand-side power budget analysis of Table 10.1 also provides a foundation for determining the CO_2 footprint/impact of the concentrated solar power system. The right-hand column of Table 10.1 presents a detailed analysis of the CO_2 impact of each of the system components and shows that the total estimated CO_2 impact of the overall mechatronic platform and automation system hardware is around $CO_2 = 214.6$ g/h (grams of CO_2 per hour).

10.9 Summary

A summation of the estimated power requirements for each task provides an indication of the averaged power demand of the solar reflector system which needs to be accommodated for in the battery backup selection, photovoltaic solar power emergency charger and electrical sub-system design.

CHAPTER 11

INTELLIGENT POWER BUDGET CONTROL

Solar Tracking, First Edition.

11.1 Power Budget Aware Automation

Control and automation forms an integral part in the design of solar power conversion systems for stand-alone village installations as well as for industrial scale grid-connected installations. Some control designs employ digital implementation platforms such as robust industrial standard Programmable Logic Controllers (PLC) with remote control/access capabilities.

This chapter describes issues around power budget optimization as control concept for the automation of the solar tracking platform system. A digital power budget principle forms the basis for artificially intelligent decision architecture to conserve the power budget of the solar power system. An energy or power-budget principle can be implemented through electronic control logic in order to realize the "self-tracking" feature while ensure energy self-sustainability for this stand-alone solar power systems.

11.2 Intelligent Automation

Conventional automation philosophies in dual axis solar tracker systems is often unable to to stand on its own when used in a grid connected application. Control algorithms often do not sufficiently cater for stand-alone control challenges introduced by prolonged cloud transients and thunderstorms. Without proper adjustments, a conventional control solution will eventually lead to jumpstart problems and in turn to escalated maintenance costs at remote rural sites.

A tiny solar photovoltaic battery emergency recharge module is the first element that needs to be added to the automation solution control block. Backup power is critical for the solar tracker system operation and will lead to catastrophic failure if the backup supply in a stand-alone system would be totally depleted. The photovoltaic charger therefore acts as rescue mechanism to refuel the backup battery in case of unexpected battery drain situations, while supplementing battery storage levels to help maintain levels required for tracker operation.

By following an intelligent power budget control approach, power budget and on-board power budget management is treated as mission critical control components. A discrete set of differentiated modes-of-operation may be introduced as solution to incorporate control intelligence into the control solution.

11.3 Differentiated Control Scenarios

For a stand-alone solar power system powered through rechargeable batteries, the design challenges to reserve on-board energy resources and to reduce energy consumption are very important to ensure autonomy of the system.

This section emphasise the fact that a conventional control philosophies do not always optimize the power budget of a stand-alone system. When used blindly in a stand-alone application system, commercial automation may eventually lead the system down a path of catastrophic failure and inability of the system to re-establish a connection with the sun, severely impacting on the system operations sustainability.

In order to demonstrate the limitations of control philosophy that lacks decision intelligence, for example those used in commercial solar tracking solutions, the mode-of-operation or control scenario can be conceptually displayed in a hypothetical two-dimensional place, as illustrated in Figure 11.1.

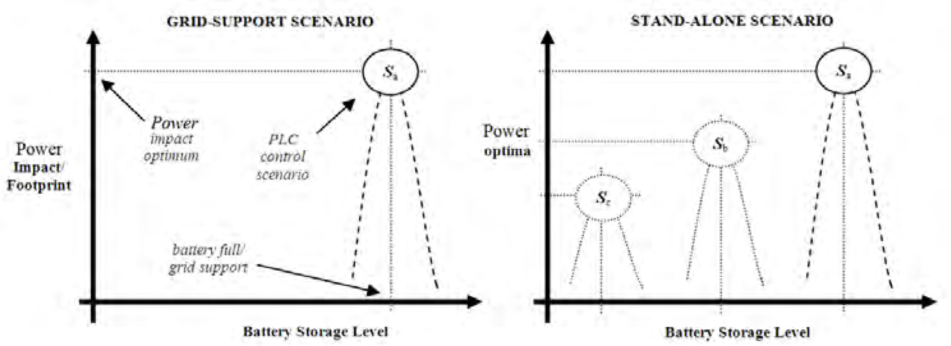


Figure 11.1 Conceptual principles behind the conventional and power budget control philosophies.

On a conceptual level, Figure 11.1 compares the selected control scenarios in a grid-connected system with those in a non-grid connected system through a demonstration of the relationship between one of the operating parameters (battery storage level) and the control scenario (chosen to maximize the carbon impact of the system). Figure 11.1 (left) depicts a fixed control philosophy, wherein the battery power level is assumed to be kept relatively constant through a supply grid feeding back into the solar tracking solution. In this philosophy, a fixed control scenario (Sa), with a fixed set of optimum control parameters can be chosen during the design configuration phase in order to maximize the power output (and CO_2 impact) of the solar concentrator system.

By comparison, in a stand-alone solar power/tracking system, the lack of grid infrastructure may cause the battery storage level to vary over time due to user-demand, cloud cover, wind impact, etc. Ideally the control scenario should then be a function of the available resources and operating environment of both the internal/on-board (Stirling operation, battery level, battery discharge rate, motor efficiency, etc.) and external factors (clouds, wind, weather predictions, etc.). Such conceptual variations are illustrated in Figure 11.1 (right).

Since the survival of the solar concentrator was shown to be dependent on available resources such as for example the battery level, the control scenario should be aware of its operating environment and resource requirement, and should constantly aim to balance these. One solution is to use a set of differentiated control parameters, intelligently chosen to ensure power budget conservation.

11.4 Power Aware Automation Intelligence

In a stand-alone solar tracking solution, user demand affects the supply source of the solar tracking solution, a situation requiring a more intelligent control philosophy to ensure the survival of the system. By building artificial intelligence into for example a PLC or microcontroller, the controller will be able to emulate the decisions of a human expert, especially for more complicated stand-alone control scenarios.

In the case of stand-alone concentrated solar power generator automation, the knowledge and decisions of an intelligent human operator, under various control scenarios, could be pre-defined into a set of intelligent control states. A set of rules can then be programmed into the decision architecture so that the microprocessor would produce a control mode decision similar to what an experienced operator would have selected for the survival of the system/power budget.

With a more intelligent control philosophy, a complete set of on-board (Stirling operation, battery level, battery discharge time, motor efficiency curve, etc.) and external (clouds, winds, weather predictions, etc.) operating environment input variables could be monitored and an intelligent decision taken on the optimum set of control parameters in relation to the solar tracking and user demand patterns. By further processing real-time meteorological data and predictions supplied through the remote control and wireless communication interfaces of the controller, a more intelligent control system will be able to ensure the survival of the tracking systems through prolonged cloud cover, bad weather or stormy days.

A relatively simple control solution would be to use principles behind discrete machine intelligence. Such automation intelligence is generally modelled through fuzzy logic or Finite State Machine (FSM) representations. Figure 11.2 represent the proposed discrete optimized states for a range of control scenarios in terms of a FSM representation. Each operating mode or scenario represents a discrete state with certain mode change- or transition-rules. The states and transition rules are defined by an intelligent operator during the design phase.

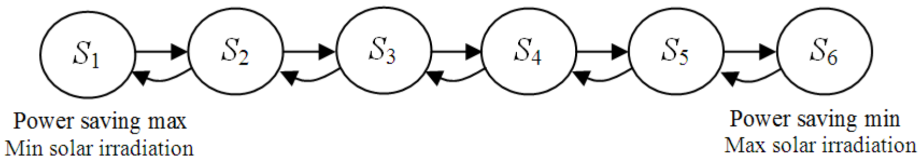


Figure 11.2 State diagram of discrete control scenarios for an intelligent solar tracking controller (Prinsloo *et al.*, 2013*a*).

Each FSM state represent a power budget optimized control scenario based upon predefined operating environment scenarios for a dual-axis solar tracking concentrator. Depending on a set of input symbols, the state of the controller can change from one state to another when initiated by a triggering event or condition. The trigger events are driven by control input variables, shown in Table 11.1. These variables are mapped onto a multi-dimensional plane while an Euclidean distance measure is used to determine the closest state scenario cluster. State transitions represent a change in control scenario in accordance with state transition rules of Figure 11.2.

Figure 11.3 illustrates a flow diagram of the FSM state diagram to show in how the artificial intelligence rules underlie the main Siemens solar tracking solution. Following each main control loop sequence, the operating environment variables are mapped to determine the control scenario, or control state (Sx) of the control system, in order to determine of a state change would ensure an improved CO_2 impact optimized solution.

The flow chart illustrates the integration of intelligent decisions to command the solar tracking automation solution on system level. This intelligence is aimed at ensuring the survival of the system in terms of power budget balance while ensuring CO_2 impact optimization as a function of operating environment variables.

Current state	Input Variables	Next State	Output Variables
S_b	Battery storage level	S_a	PWM frequency setting
	Battery discharge rate/curve	or	PWM duty cycle setting
	Solar power generation rate	S_b	PWM frequency setting
	Time of day	or	Siemens tracking resolution (Δ)
	Weather input	S_c	Camera homing enable/disable
	Light intensity		Daytime azimuth sweep limit
			Grid power dispatch rate

Table 11.1 Section of state transition table to illustrate the state diagram and control variables.

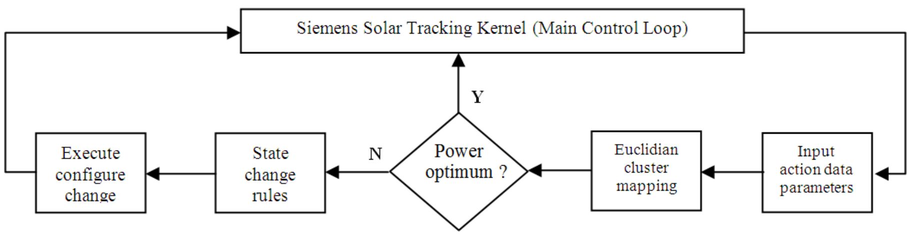


Figure 11.3 Flow chart for implementation of state diagram rules to implement intelligent tracking (Prinsloo *et al.*, 2013*a*).

11.5 Controller Logic Philosophy

The control philosophy should meet the specification of the system for which the requirement to develop a self-tracking is heavily biased toward the power consumption budged available to the pointing controller. The available power and potential gain with every move needs to be weighed for every planned motion in order to achieve optimum use and gain of pointing motion energy.

In power budget impact optimization, energy management and the management of the available energy budget is of primary control. The energy budget typically comprises the backup energy storage available for tracking control, which storage is supplemented only when the is fully engaged with tracking the sun.

A constant source of thermal energy is required to ensure successful start-up and continuous operation of the Stirling generating device. Depending on the weather conditions, intermittent cloud passes may be experienced during which the PCU will be forced to go to through repetitive shut-down and a start-up sequences as a result of the loss of connection to the sun as solar thermal energy source. These instantaneous start-up/shut-down sequences demands significant energy supply, typically drawn directly from the utility power grid or from a back-up power supply if a grid connection is not available. Frequent cloud passes may result in a situation where numerous start-up sequences can consume more power than that generated by the Stirling during periods of solar exposure.

Therefore, for a stand-alone self tracking solar reflector system to continue operation in partially cloudy conditions, power control or management is critical for the survival of system's operation. One of the primary tasks of the controller system will thus be to give consideration to the energy levels available in the backup supply source as well as to the potential of the system to generate sufficient energy following a start-up energy drain. Some decision logic and mechanisms are thus required to predict the energy generating potential during intermittent cloud passes in order to ensure that sufficiently fill-up generating capacity will not cause the backup power source to drain below certain reliability margins.

11.6 Control Platform Implementation

Figure 11.4 illustrates how the proposed intelligent system level control block can be practically integrated into an existing automation solution.

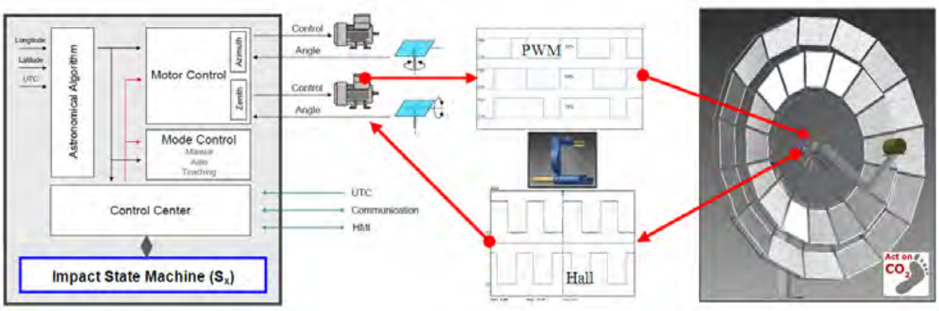


Figure 11.4 Intelligent control configuration for a solar tracking system (Prinsloo *et al.*, 2013*a*).

Figure 11.4 shows the control automation system connected to the slew drive tracking movement mechanism. It also illustrates how the added intelligence supports the existing automation control. This control block operates on system level and underlies the Siemens Solar Tracking Control kernel, while carbon management is now treated as mission critical control elements.

At any discrete time instance, the power budget optimization control philosophy of Figure 11.3 and Figure 11.4 can be conceptually visualised as a balancing telescopic cantilever beam consisting of telescopically interconnected sections adjustable around certain set-points (intelligent control states), as displayed in Figure 11.5.

In Figure 11.5, the proposed system level power budget control automation intelligence aims to maximize the power output of the solar power generating system as a whole by continually mapping input variables to intelligent operator defined states, through state transition rules illustrated in Figure 11.2, in order to balance the (a) power impact, (b) positional accuracy, and (c) power budget in the context of power availability.

It was stated that the commercial Siemens solar tracking automation solution on its own was not designed for autonomous, stand-alone solar tracking systems, and that power storage drain problems will be experienced during storms or periods of cloud transients.

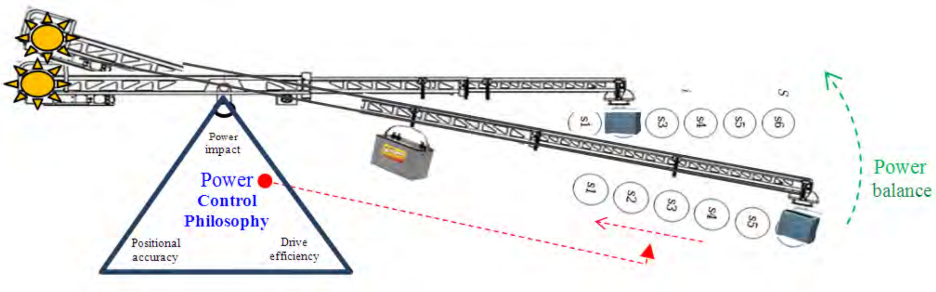


Figure 11.5 Intelligent control philosophy depicted as telescopic structural beam with adjustable control modes.

By implementing intelligent mode control or state changes on the basis of a digital power budget principle which strives to maximize power output of the system, an intelligent automation can be visualised in terms of state transitions in Figure 11.5 and Figure 11.6.

Figure 11.6 (left) shows the balancing triangle for the intelligent control strategy, while Figure 11.6 (right) represents a visualisation of the temporal state transition variations for the sequence of state transitions illustrated in Figure 11.5. This is a type of multi-objective control strategy (Sharma and Zhang, 2013).

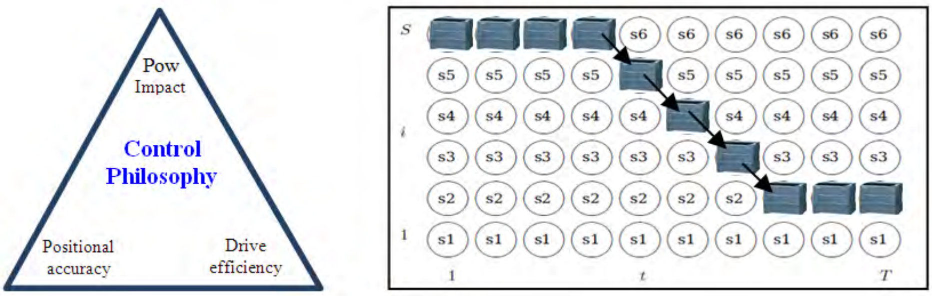


Figure 11.6 Flow diagram implementation of the state diagram rules on an intelligent solar tracking controller (Prinsloo *et al.*, 2013*a*).

Most control strategies used in the automation of commercial concentrated solar power generating systems is not much concerned with the impact of these modes of operation on the power budget impact of the overall system. The general argument holds that the power demand of a solar tracking system is significantly less in than the power generation of the overall system (power for operation less than generation capacity of the overall system). The argument is true, but is true provided there is sufficient sunlight and the system is intelligent not to track during days or rain or weather activity.

11.7 Summary

Solar harvesting systems require a dynamically controlled solar tracker system with self-positioning capabilities for both the horizontal and vertical axes. The design needs to focus on the altitude-azimuth drive system and on an electronic tracking system which defines the states of control as well as an algorithm to achieve self-tracking in an energy efficient manner.

Intelligent control is an essential component in reducing the risks of depleting the battery backup storage. This chapter describes intelligent principles of operation which includes differentiated pre-defined modes of operation to optimize the use of the power budget, by way of dynamically applying different modes of operation through the use of artificial intelligent state diagrams using finite state machine principles.

CHAPTER 12

REMOTE CONTROL AND ONLINE MONITORING

12.1 Introduction

In this chapter, concepts around the remote control and remote monitoring aspects of the automation of a solar harvesting means and its associated solar tracking system will be discussed. Remote control functionality is of particular importance in remote solar power systems as it helps to identify potential breakages, ordering of replacements parts, and remote repair procedures. Remote monitoring, data acquisition, digital datalogging and online measurement and verification equipment on the other hand assist the operator to monitor the efficiency of remote renewable energy resources and systems, convenient for diagnostics through internet, WiFi and cellular mobile links, while it may be used to provide valuable feedback in terms of CO_2 and clean development mechanism (CDM) reporting.

12.2 Remote Control System Functionality

While many rural areas in Africa, Brazil, India, China and Argentina experience high levels of solar radiation, rolling out reliable solar solutions for tapping into this renew-able energy resource in rural areas pose a number of challenges. For example the cost of maintenance at far-off and remote sites escalate significantly due to travel cost and delays. This makes remote monitoring crucial and should be considered equally important to ensure reliability and robustness of the design in any solar tracking project (Collier *et al.*, 2008).

In off-grid or stand-alone type solar tracking power systems, the digital electronic automation hardware can be classified as a mission critical component in a solar tracking system design. Any tracking automation defect or operational problems would cause the concentrator system to lose its connection to the solar resource. Any prolonged failure will result in battery drainage, causing remote wireless communication link failure, leaving a remotely located stand-alone CSP system being cut off from the control room or maintenance reporting centre.

A high level diagram of a typical remote control configuration is shown in Figure 12.1. This demonstrates how functionality can be incorporated into the solar racking solution to further provide for Remote Control and distant Remote Monitoring functionality through communication links.

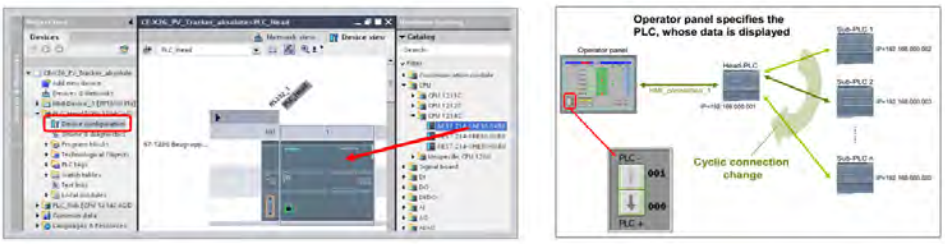


Figure 12.1 Example of components of a remote control automation platform for controlling the dual axis solar harvesting through a communication link (Siemens, 2010*a*).

With the example Siemens S7-1200 Remote Control Panel setup shown in Figure 12.1 (Siemens, 2010*a*), one or more individual solar trackers can be monitored or controlled remotely through a Head-PLC configuration. Such remote solar trackers can thus be networked according to the PLC IP addresses, wherein the Head PLC could sequentially establish a web or TCP communication connection with each Sub-PLC.

In addition, the PLC also provide solutions that allow for other PLC's to be remotely controlled through a built-in web server. This provides for interaction with the controller through a web browser. If this feature is required, then the solar tracker can be linked to a web interface, through which the IP address of the PLC solar tracking controller can be used to interact with it.

Maintenance costs at remote rural sites are known to escalate due to slow reaction times combined with high logistical and replacement costs. At remote site locations, the failure of any component in the solar tracking platform would result in catastrophic operational failure from which the solar concentrator system would not be able to recover until reached by a maintenance team. Some failures may cause the sun tracking system to lose its connection with the sun, eventually leading to battery drain and automation system communication failures and the system eventually becoming non-functional.

These effects need to be taken into account when the design robustness is considered since some of these solar generating systems might be deployed in areas that are not easily accessible to maintenance crews. A flexible remotely accessible control panel is a logical solution to assist the operator with general monitoring, maintenance and fault finding procedures.

By including remote control and monitoring features in a solar tracking system design, the designer will greatly simplify the task of the operator. Solar power generation output trends can be monitored or controlled remotely. Such features would also be valuable for data acquisition, remote metering or for collecting historical data on solar irradiance, weather patterns, wind/storm alerts. The Siemens software platform, for example, includes a feature where sensor data and operating parameters can be remotely downloaded for each tracking system onto an excel or csv-file (Siemens, 2010*a*).

In off-grid CSP solar power generation solutions, a combined stand-alone and remote control platform and software solution provides attractive benefits. It can be used in stand-alone self tracking systems operating in remote rural areas, while the remote control features of the Siemens PLC platform would be valuable for remote wireless monitoring and fault-finding interfacing may assist in the preparation for repairs at remotely distant sites.

12.3 Remote Energy Monitoring Functionality

In general, a smart meter is an electronic device that records solar power generation and the consumption of electrical energy in intervals of minutes or hours. In solar tracking and power generation systems smart meters are typically used in conjunction with datalogging units that provides the user with access to historical data on for example atmospheric (temperature, humidity, wind, etc.) or weather conditions at the site of solar system installation.

Remote monitoring, data acquisition, digital datalogging and online measurement and verification equipment assist the operator to monitor the efficiency of remote renewable energy resources and systems, is convenient for diagnostics through internet, WiFi and cellular mobile links, while it may be used to provide valuable feedback in terms of CO_2 and clean development mechanism (CDM) reporting.

Power quality analysis also requires local and remote data capture of RMS values and output power waveforms to determine how the voltage, current and frequency values are interacting and energy monetization and cost of energy waste due to poor power quality (Fluke, 2014). Such analysis will also be valuable in frontline troubleshooting and predictive maintenance, where quick diagnostic analysis is required to detect and prevent power quality issues before causing power downtime.

Originally smart meters developed from an energy management and for use in predictive load studies (i.e. verify electrical system capacity before adding loads on the microgrid). Such systems employs computer-aided tools to assist operators of electric utility and microgrids to monitor, control, and optimize the performance of the generation or transmission system. Such monitor and control functions are typically used as Supervisory Control and Data Acquisition (SCADA) interfaces.

Figure 12.2 presents an illustrative example of how the SunPower SCADA system provides the visibility to better manage energy output and to monitor solar tracking sensitivity for both the azimuth and elevation axis dynamic sun chasing movements (SunPower, 2014*b*).

Figure 12.2 SunPower SCADA provides the visibility to better manage energy output and to monitor solar tracking sensitivity (SunPower, 2014*b*).

Such a supervisory system may be combined with smart meters and data acquisition systems which uses coded signals transmitted and received over communication channels to acquire information about the status of the remote equipment for display or for recording functions. Such system typically includes a humanmachine interface (HMI), an apparatus or device which presents processed data to a human operator, and through this, the human operator monitors and interacts with the process.

In this book, we are particularly interested in smart meters from an off-grid, stand-alone remotely installed, solar tracking system monitoring perspective. From a solar tracking system monitoring context, smart meters have the ability to communicate the recorded information on a communication (mobile phone, wireless, satellite or internet) link to a central data acquisition server and data storage unit for for monitoring and data analysis purposes.

These meters typically use the two-way communication between the meter and the central system to convey the data to a central database, from where the information can be processed for reporting or action (Schneider, 2014*b*)(Vernier, 2014). Typical smart energy meter interfacing typically includes a display or web interface that allows the user to monitor system performance or parameters over time, as shown in Figure 12.3 (Tri-Sports Dasboard, 2014).

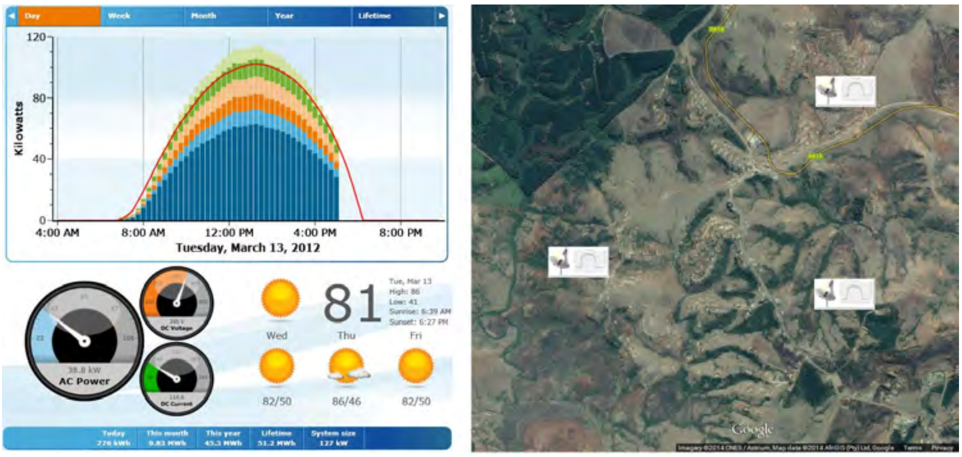


Figure 12.3 Solar power generation dashboard for remote wireless monitoring of solar harvesting systems (Tri-Sports Dasboard, 2014). In some systems the data may be accessible through click-able maps (Schneider, 2014*b*)(Vernier, 2014).

Certain mobile phone monitoring applications have also been developed to access the smart meter data in real time (see Figure 12.4). These mobile apps can typically be used in conjunction with a web interface to provide an at-a-glance view of system parameters, solar energy harvesting and solar power production (Schneider, 2012). Such functionality assist solar power system installers and owners in performing remote monitoring of any system in the field from a tablet, iPhone, iPod Touch, or similar mobile access devices. Authorised users will thus be able to keep an updated record of solar tracking system parameters from any place, simply by using a mobile phone or tablet type device.

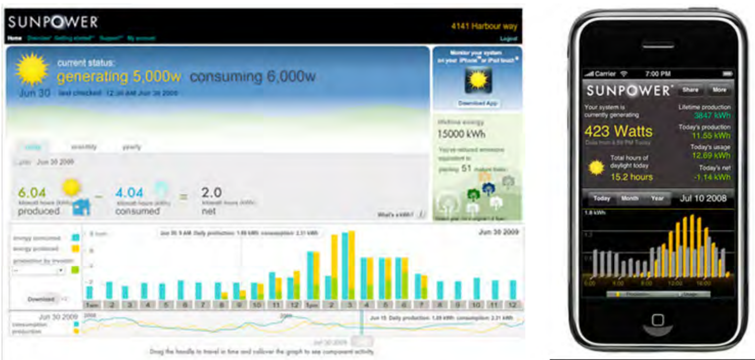


Figure 12.4 Example of solar system data acquisition and monitoring using the "SunPower Monitoring" app for mobile devices (SunPower, 2014*a*).

One engagement method that has recently gained popularity is the live monitoring or real-time dashboard display available in web applications. This is called an *I*ntelligent Dashboard online system interface and can typically be used to monitor system and environment parameters thousands of kilometres away from the comfort of your desktop or mobile phone. These real time dashboards typically display a wealth of information and in most cases allows for the authorised user to customize the display, for example to select the site of interest from a map from where the user can continue to select the data type, type of graph or display, sampling periods, access to historical data, conduct statistical analysis and so forth.

In most cases, the user do not need to develop their own interface but can subscribe to an online dashboard service. Certain service providers may be able to link billing tariffs, rates of cost and so forth to the data in order to provide more intelligent computations for cost analysis, and in some cases even generate pro-forma billing invoices.

For example, one such live monitoring online dashboard system was developed by Vernier (Vernier, 2014). One of their typical installation site dashboards is displayed in Figure 12.4. As an eco-friendly business, Vernier build their dashboard around carbon footprint analysis for those clients who may be interested in monitoring their carbon footprint reduction trends.

By accessing their website, `www.vernier.com/solar`, clients who has fitted the appropriate devices (camera, sensors, weather station, etc) will be able to see a live camera view of their installation (e.g. rooftop solar panels, weather station data, and a live display of the power production of their system. There are also tables and graphs the client will be able to use to investigate the performance of the system components, energy production and so forth over time, and to download any data that would be of interest on a personal computer or memory-stick.

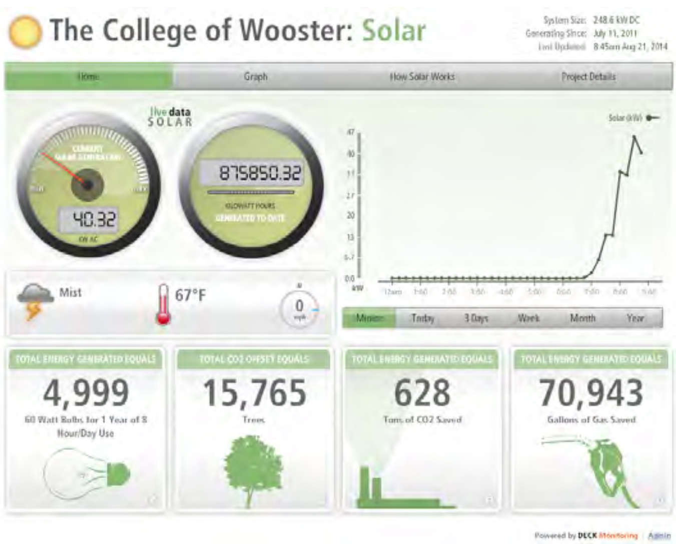


Figure 12.5 Solar power generation dashboard for remote wireless monitoring of all technical and environmental aspects of your solar harvesting systems (Vernier, 2014).

In the dashboard example of Figure 12.5 there is shown a dashboard created when certain solar panels was installed. The dashboard tracks power generated by the panels and can be customized to display by the hour, the day, the week, and so forth. An easy-to-use web-based interface lets the client examine the solar energy production and and compare data over hours, days, months, and years (Vernier, 2014).

There are a number of other solar installations that make their power output and profiles public on the internet through broadcasting and live monitoring web interfaces, some of which can be viewed on the links below:

SunViewer.net is an interactive tool that enables you to view the performance of solar power systems over the Internet www.sunviewer.net/

Deckmonitoring - Live data - College of Wooster example http://live.deckmonitoring.com/?id=the_college_of_wooster

Safersun Professional (weather station) http://www.meteocontrol.com/en/industrial-line/portals/safersun-professional/

Un-Analytics Google Solar Panel Performance Problem http://www.triplepundit.com/2011/09/analytics-google-solar-panel-performance-problem/

We believe that there is still a great market for software developers that may want to look into the development of Dashboard type systems. This is a great business opportunity, especially for those who may have some hardware development themselves or friends who has hardware development experience. Dashboard services offers interesting business opportunities in offering a service to companies and home-owners, services that can generate income for the entrepreneurial technical person who can charge on a subscription payment or debit order payment basis. Vernier for example wrote a custom C program to collect data from the users through scripts that run at certain time intervals and submit this data to an SQL database. To make the dashboard more usable, informative and visually appealing they used a charting package (e.g. http://simile.mit.edu/timeplot) with a large library of chart types, allowing for highly customizable chart type.

In the article entitle "Solar Energy Monitoring Systems The Next Big Thing in Solar?", the writer is of the opinion that government incentives and performance monitoring calls for monitoring systems that will form the next phase of innovations in renewable energy systems (ResidentialSolar, 2010). With a simple monitoring system, the homeowner will know if the installed system performs to standard and will alert the user if the solar electricity system is not producing energy at the required levels. In an article entitle Solar Power Systems Web Monitoring (Kumar, 2011), Kumar describes an innovative concept for web-enabled software that communicates data between the solar installation and a remote host computer. This concept is in the process of being developed in dynamic HTML and Java around web server principles.

In conclusion, remote monitoring functionality in any solar power or solar tracking system should include the functions of logging and accessing energy data from any remote solar power system for the use of monitoring, reporting and engagement. Such functionality is primarily intended to aid system owners in monitoring power generation and assessing solar tracking performance in order to pre-empt any requirements for maintenance before system failures sets in.

Intelligent monitoring may include trend analysis and tracking energy consumption to identify cost-saving opportunities, while reporting may include verification of energy data, benchmarking, and setting high-level energy use reduction targets. Engagement may be any real-time responses (automated or manual) towards maintenance, repairs or to promote energy conservation.

12.4 Carbon Equivalent Calculations

For those readers who may be interested in the calculations use to compute the data for the *T*otal Energy Generated Equals or the *T*otal CO_2 Offset shown in the example dashboard display of Figure 12.5, we briefly present the following information and formulas.

The carbon footprint, or carbon footprint reduction or savings by a renewable generation system, is measured in terms of tonnes of carbon dioxide equivalent or tCO_{2e} (Carbon Trust, 2013). The carbon dioxide equivalent or CO_{2e} allows the different greenhouse gases to be compared on a like-for-like basis relative to one unit of CO_2, as was illustrated in the remote monitoring system of Figure 12.5. CO_{2e} is calculated by multiplying the emissions of each of the six greenhouse gases by its 100 year global warming potential (GWP).

The Carbon Trust provides a range of online tools and computer spreadsheets with which certain CO offset equivalents conversions can be computed (Carbon Trust, 2013) and this link as reference `http://www.epa.gov/cleanenergy/energy-resources/refs.html`.

The CO_2 offset equals can be converted into any one or more of following equivalences or value factors, including Average CO_2 emitted to produce Electricity, Annual offset of One Growing Tree, 40 Years Offset of One Growing Tree, Medium Car CO_2 Pollution per Mile/Kilometre, Average Yearly Miles/Kilometres Driven, Annual CO_2 for Medium Car, Average Yearly Home Electricity, Average Yearly Light Bulb, Average Yearly Computer, or Emissions from a Gallon/Litre of Gas `http://americancleanenergy.com/about-solar/solar-environmental-benefits` (American Clean Energy, 2014).

Table 12.1 Various energy conversion factors (Badea, 2015).

Units	kJ	kcal	kWh	kg ce	kg oe	m^3 gas	BTU
1 kilojoule (kJ)	1	0.2388	0.000278	0.000034	0.000024	0.000032	0.94781
1 kilocalorie (kcal)	4.1868	1	0.001163	0.000143	0.0001	0.00013	3.96831
1 kilowatt-hour (kWh)	3,600	860	1	0.123	0.086	0.113	3412
1 kg coal equivalent (kg ce)	29,308	7,000	8.14	1	0.7	0.923	27,779
1 kg oil equivalent (kg oe)	41,868	10,000	11.63	1.428	1	1.319	39,683
1 m^3 natural gas	31,736	7,580	8.816	1.083	0.758	1	30,080
1 British thermal unit (BTU)	1.0551	0.252	0.000293	0.000036	0.000025	0.000033	1

Table 12.2 Various energy conversion factors (Badea, 2015).

Badea published the Table in Figure 12.2 allows for the conversion from one form of energy to another (Badea, 2015) and can also be used in conversion of carbon values provided that the carbon to energy conversion factor is included in the calculation (Carbon Trust, 2013).

By using these greenhouse gas equivalences and calculations, you can help the average person understand what reducing carbon dioxide emissions by way of solar energy power generation means in everyday terms.

12.5 Summary

In this chapter, we continued the discussion on digital electronic automation hardware and software integration with an emphasis on data acquisition and online remote monitoring. With the solar tracking platform and digital automation aspects completed, the automatic positioner and control system for a motorized parabolic solar reflector can now be used for solar harvesting. This will be discussed in the next chapters.

PART V

HARNESSING THE POWER FROM THE SUN

CHAPTER 13

HARNESSING POWER FROM THE SUN

Solar Tracking, Fisrt Edition.

13.1 Introduction

In order to harvest solar energy, an apparatus is required to convert or concentrate and convert the solar power into electrical power. The previous chapter emphasised the importance of the dynamics of solar radiation and sun movement as well as the cyclic nature of solar energy's daily availability. It also illustrated the sun's radiation of electromagnetic energy at levels that could supply in most of our electrical energy needs if it can be harvested effectively.

Some examples of those systems that will be discussed in this section includes Photovoltaic systems, Parabolic trough systems, Linear Fresnel reflectors, Stirling Dish systems, Concentrated PV systems, and Heliostat based Central receiver or Solar Tower systems as illustrated in Figure 13.1 (ThermoSolGlass, 2014).

Figure 13.1 Solar harvesting systems available for solar tracking energy applications (ThermoSolGlass, 2014).

Due to the dynamics involved in the solar system, solar harvesting work more effectively with accurate solar tracking, meaning the precise focusing of the optic device onto the centroid of the sun. With the exact solar coordinates and the trajectory path of the apparent movement of the sun known (i.e. the SPA or sun path diagram at any given geographic location of the surface of the earth), this information can serve as input to the positioning system controller.

This chapter describes some of the basic principles of solar harvesting as well as some mechanical solar tracking energy yield benefits when using the solar trajectory knowledge described in the previous chapter.

13.2 Solar Energy from Photovoltaics

Non concentrated photovoltaic systems, generally referred to as PV solar panels, directly converts sunlight into electricity at the atomic level. Such systems include materials that exhibit a property known as the photoelectric effect. This effect causes photovoltaic material absorb photons of sunlight and release free electrons that can be captured and used as electricity. Photovoltain systems produces maximum electrical energy from solar energy when the material faces the sun directly. This highlights the importance of solar tracking in PV systems. However, other than CSP systems, PV systems are still very useful in cloudy conditions as the conversion technology continues to work efficiently in the higher frequency bands (short wavelengths) where sunlight is typically scattered to a greater extent.

Figure 13.2 shows and example of a simple yet flexible dual-axis tracking of the platform that rotates in both the azimuth and elevation angles. This is one solution to ensure solar tracking throughout the day while being able to achieve maximum output power throughout the day.

In PV systems, the two axis solar tracker system is typically a self managed unit. It guides the PV array on two axis to optimize solar harvesting yield. A solar tracker increases

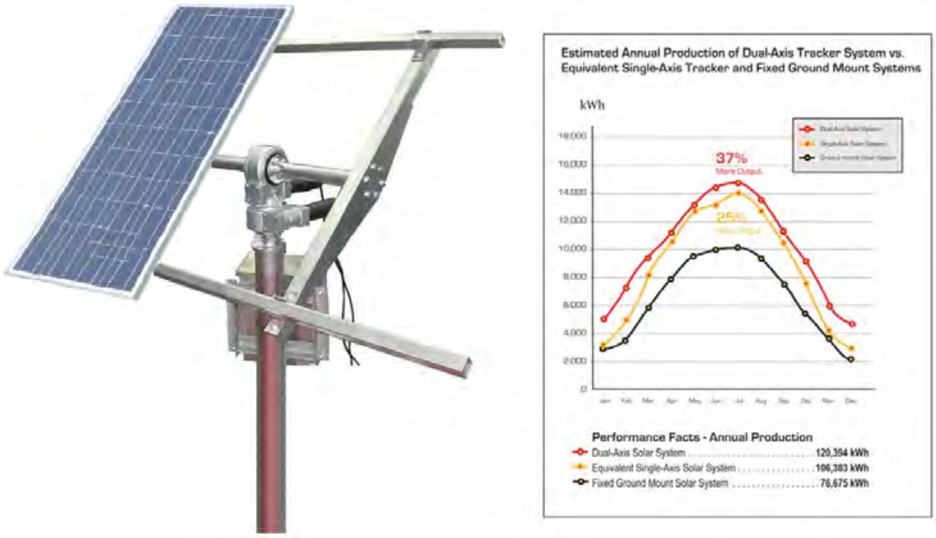


Figure 13.2 PV Trackers collect 22% to 54% more solar energy than single-axis trackers during midday for most of the year (Fang, 2013*b*)(SMA, 2014).

the performance of solar PV panels in the shoulder periods of the day, where a static fixed mount panel would only receive part sun exposure. This can be seen in the graph shown in Figure 13.2.

A solar tracking system can be used as single-axis which can increase the energy output of a photovoltaic collector by around 30% versus a fixed tilt, and dual-axis tracking this can increase the photovoltaic output to 50% (Kelly and Gibson, 2009). But these figures change from one location to another and depend strongly on the climate condition at the specific site. For the dual-axis tracking system, it has been found that the system can collect approximately 50% more energy in summer and 20% in winter; this is for clear sky countries. In cloudy conditions where there is a high volume of clouds in the sky the system would collect around 35% in summer and 5% only in winter and it has been found that in some conditions the use of solar tracking devices can decrease the performance of the energy capture (Messenger and Ventre, 2012). This can make the system a relatively ineffective approach in cloudy regions especially because the cost of such systems is more expensive than the cost of a fixed amount collector.

When a photovoltaic cell is irradiated with sunlight, electrons in the silicon get excited by certain wavelengths in solar light and leave their parent atoms. This photoelectric effect results in the formation of a so-called electron-hole pair, where the hole is the vacancy left behind by the escaping electron.

Figure 13.3 shows the solar irradiation divided in terms of color spectra in the solar radiation given in Figure 18.1. It shows that the direct radiation is more concentrated in the higher electromagnetic light energies, such as in the blue and ultraviolet spectrum. For CSP and CPV thermal systems, direct radiation is of more importance since this radiation energy (biased towards the thermal) can be optically collected and focused onto a solar concentrator to harvest mostly solar thermal energy. Its dependence on direct solar radiation in the long wavelength solar spectrum region is also the reason why CSP systems are known to be very sensitive to solar tracking and solar tracking errors.

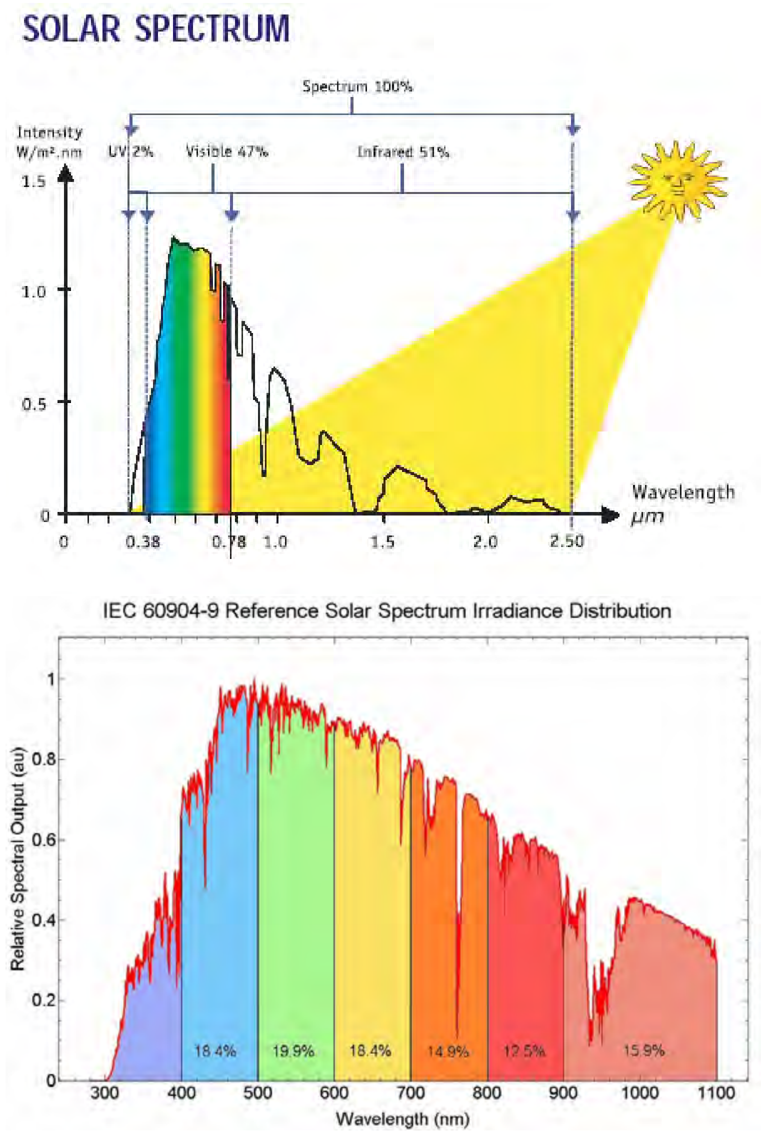


Figure 13.3 Color band spectrum for normally incident solar at sea level on a clear day (top) and solar spectrum color balance classification bands (bottom) (IEC, 2007).

Remaining with Figure 13.3, PV and CPV systems,are generally more sensitive to the short wavelength color and ultraviolet sections in the solar power bandwidth. The light wavelengths in these bands are easily deflected and scattered, meaning that photovoltaic systems generally remain very efficient in scattered sunlight conditions. This is also the reason why PV systems are known to be less sensitive to solar tracking and solar tracking errors.

Solar panel efficiency is determined as the ratio of electricity produced by the photovoltaic module relative to the amount of energy in the sunlight striking the module. The reference spectral distribution of sunlight (Air Mass 1.5) was illustrated in the previous chapter in Figure 18.1. Within the wavelengths from 400 nm to 1100 nm, the solar spectral bandwidth can be subdivided into six wavelength bands as shown in Figure 13.3. In the classification of any solar power conversion system these six wavelength bands is percentage assigned in terms of the total integrated irradiance (reference IEC 60904-9) (IEC, 2007). The spectral match of a simulation/test system can thus be classified in terms of its performance with respect to each of these six reference bands.

In terms of the solar-to-electricity conversion efficiency, an important factor to consider with photovoltaic systems is the negative influence of temperature on the electrical energy yield of the cell. On a typical hot summer day, a typical solar cell can reach temperatures of up to $70°C$. As a general rule of thumb, the efficiency of a solar cell decreases with 0.5% for every $1°C$ above $25°C$, meaning the efficiency of a solar cell could drop as much as 25% on a hot day (see Figure 13.4).

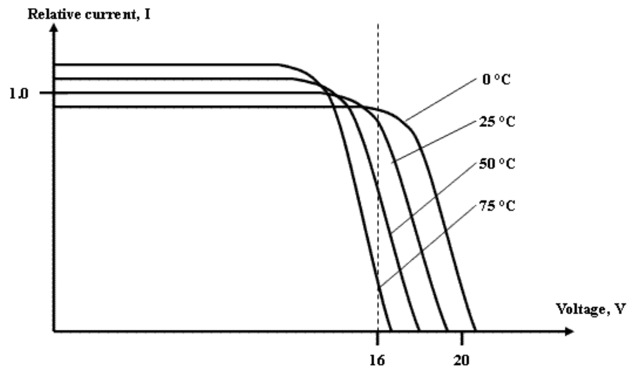


Figure 13.4 Solar cell efficiency variations, with increasing temperature the current increases slightly whilst the voltage decreases rapidly, resulting in a lower overall power yield (P=VxI) (den Haan, 2009).

It is therefore extremely important to ventilate solar panels and for any wind to cool on all sides (also the underside). For this reason, and in order to standardize the power rating of solar cells worldwide, the listed power of a solar cell is the power measured under ideal laboratory conditions, meaning the output power delivered at a prescribed rating temperature of $25°C$. To improve efficiency in hot conditions, some photovoltaic systems use liquid cooling which may in certain cases be used for household heating purposes (hot liquid).

Solar radiation emitted from the sun in the form of electromagnetic waves that enters the atmosphere is filtered by the gases and shaded by clouds. The atmosphere contains moving clouds that causes light to bounce off the clouds and operate as mirrors to deflect the light away from a solar receiver system. Figure 13.19 illustrates that, as the clouds are passing, the radiation levels decreases dramatically and diffuse radiation levels increases as a result of the deviation in the direction of the sunlight caused by the clouds.

The amount of solar energy captured or harvested further varies widely in a cloudy conditions, meaning that the efficiency of harvesting decreases as the volume of the clouds in the sky increases. Spectral shift in irradiance with sky conditions is studies in tan article on the measurement of solar variation and can be studied on this link `http://kippzonen-blog.nl/solar-energy/measuring-global-solar-irradiance/` (Lee, 2014*a*).

It has been established that normal solar tracking devices are useful for countries that is rich in sunshine and receive a significant amount of direct radiation. However, using a solar tracking system may not be that efficient in cloudy conditions or in countries that are assumed to be cloudy throughout the year. It has also been showed that the beam-to-diffuse radiation can vary dramatically in different locations and sky conditions. In general, photovoltaic systems are more efficient in cloudy regions, mainly as a result of the importance of diffuse radiation in cloudy regions. This draws attention to the type of solar harvesting means for a particular area and whether the optimum solar harvesting configuration option will be concentrated solar thermal, solar nano antennas, flat plate collectors or photovoltaic systems (Ayoub, 2012).

Figure 13.6 shows that a particular type of solar cell is responsive to a certain frequency bands of sunlight that depends on the type of material it is made of. Naturally, researchers have gone to great lengths to find and test various combinations of materials. Figure Figure 13.5 presents an illustrations of the different types of materials that have been found to be more efficient in harvest more solar energy from particular bands in the sunlight frequency spectrum.

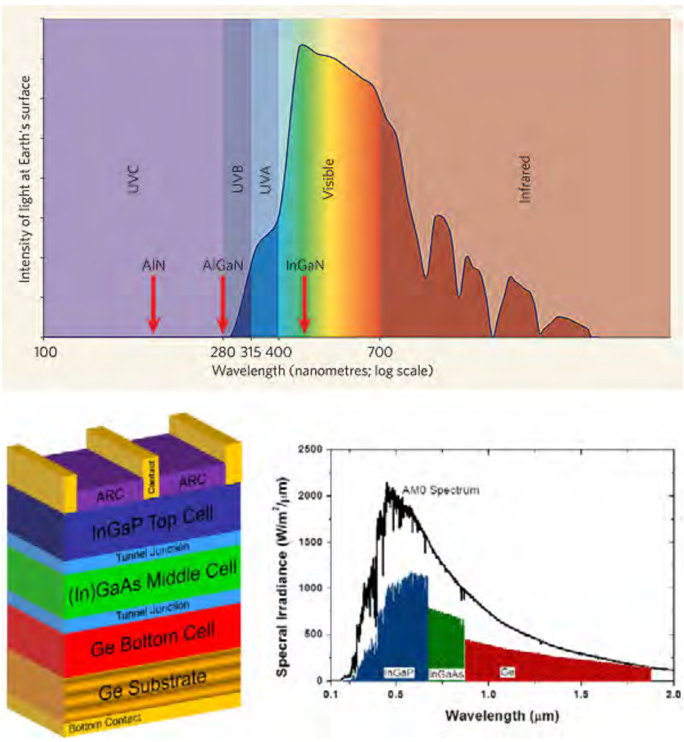


Figure 13.5 Solar cell light spectrum sensitivity relative to its material of manufacture and location in a solar cell stack (Khan, 2006)(Stan *et al.*, 2008).

In Figure 13.6, we see images of the impact of cloud presence on the solar spectrum as well as the influence that such spectral variations may have on the output performance on two type of silicon solar panels (Lindemann, 2014). This graph shows the relationship between solar panel material sensitivity and solar radiation for an Amorphous Silicon solar panel and a Crystalline Silicon panel (sunlight wavelength in nanometers (nm)). It is important to note the cloud presence influence on solar spectral variations and photovoltaic power spectral bandpass and bandgaps. This illustration shows that the material of manufacture of a photovoltaic cell is an important factor for consideration as the material may be atmosphere condition sensitive and may directly impact on the power generation performance of the system.

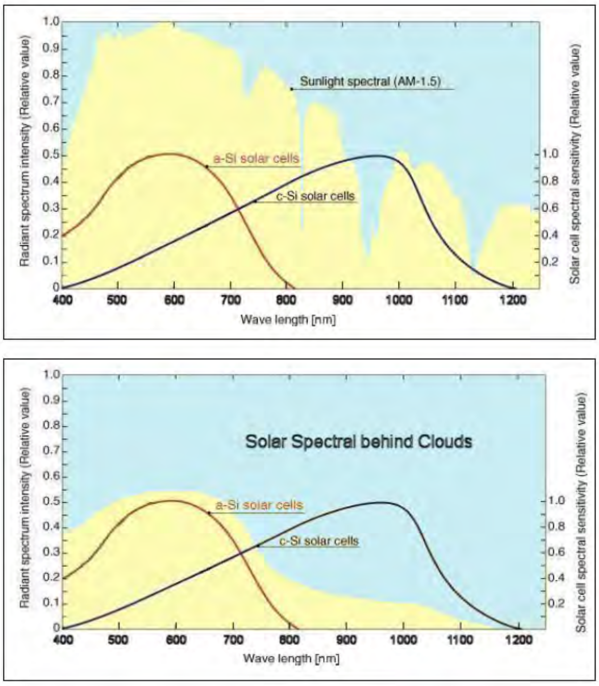


Figure 13.6 Influence of cloud presence on the outputs of amorphous silicon solar panels and crystalline Silicon panels (Lindemann, 2014).

The effects of spectral albedo on amorphous silicon and crystalline silicon solar photovoltaic device performance have also been studied extensively by Andrews and Pearce (Andrews and Pearce, 2013)(Pearce, 2014). In both graphs of Figure 13.7 we see the solar irradiance available to specific types of photovoltaic (PV) materials from surface albedo. In Figure 13.7 top and bottom respectively, the green lines and the blue lines are of particular importance to this discussion as it represents the direct and diffuse solar spectra for partly cloudy conditions. On this link (`http://www.appropedia.org/Spectral_effects_on_amorphous_silicon_photovoltaic_cells_literature_review`), a full review report on the effects on amorphous silicon photovoltaic cells can be studied (Andrews and Pearce, 2013).

To conclude the discussion on cloud effects on solar panels, there is some interesting webcam features on this link that shows images of the sun an cloud impact at various NREL stations `http://www.nrel.gov/midc/` (NREL, 2014*a*). This may be a very interesting means to use in a research project for any sun surveying experiment at any particular solar tracker location.

Interesting information about photovoltaic modules PV panels and how to interpret manufacture data and how to select the correct mounting angle is provided on this page `http://www.itacanet.org/a-guide-to-photovoltaic-panels/`. This article is based

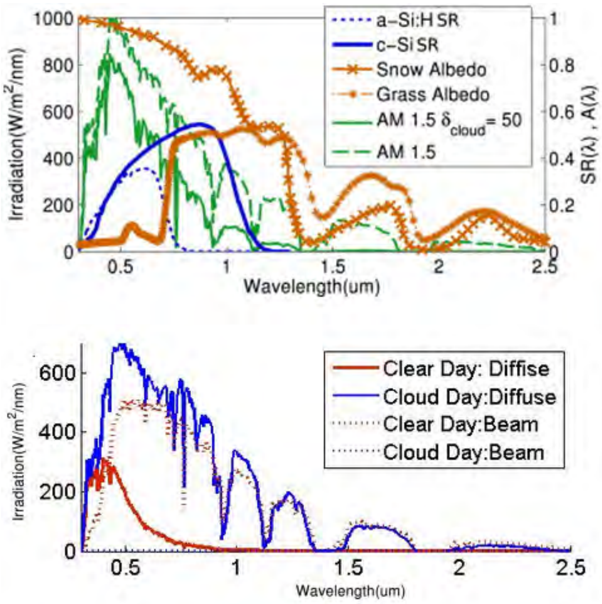


Figure 13.7 Spectral effect of albedo and cloud cover on amorphous silicon and crystalline silicon solar photovoltaic device performance (Andrews and Pearce, 2013)(Pearce, 2014).

around autonomous and semi-autonomous systems that use PV panels to charge a bank of lead-acid batteries (see also wealth of PV resources in Spanish Espaol `http://www.itacanet.org/esp/electricidad.html#1`) (ITACA, 2014).

The NREL websites (`http://www.nrel.gov/pv/` and `http://www.nrel.gov/ncpv/`) are good starting points for those readers interested in photovoltaic solar power systems and the latest developments in this field of technology. The next section details solar harvesting from a concentrated photovoltaic technology perspective.

13.3 Solar Energy from 3D Solar Cells

One drawback to most optical solar means is that the feedback configuration is normally flat. When the sun moves across the sky, the efficiency of the optical feedback means drops as the sun moves out of range. A new hemispherical solar cell is shown in Figure 13.8. It solves the problem by having collection units around all sides of a dome.

Figure 13.8 shows the unconventional Sphelar cell that takes on a spherical shape. This implies that the cell is capable of power generation with greater efficiency while the solar cells are only 2 mm across. The company Kyosemi also has spherical cells attached to pliable flat surfaces that can bend in any direction. This means it can be mounted on any surfaces and, with the rounded collection surfaces, it can collect solar energy from all sides (Kyosemi, 2012).

Of equal interest is the Dynamic Spin based solar cell products, a new alternative to solar panels and allow for a range of distinctive designs to be developed to suit the needs of various markets needs throughout the world (V3Solar, 2014).

Figure 13.8 Hemispherical solar cell with collection units around all sides of a dome matrix for solar tracking (Kyosemi, 2012).

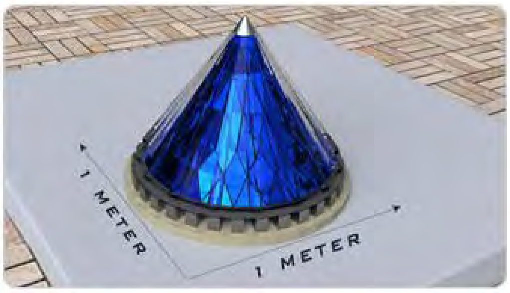


Figure 13.9 V3 Solar omnidirectional spinning solar cell reduces heat problems (V3Solar, 2014).

The V3Solar Spin Cell shown in Figure 13.8 uses a specialized lensing and a rotating, conical shape, the Spin Cell can concentrate the sunlight 30X onto one sun mono PV with no heat degradation. This increases the Power Density while lowering the Total Cost of Ownership and Levelized Cost of Energy (LCOE) (V3Solar, 2014).

Another interesting 3D solar harvesting means was developed by NOS Designs (NOS, 2013), wherein rainwater harvesting is combined with solar energy harvesting. The design Photoflow comprises triangular photovoltaic modules mounted on top of a water tank and integrates N-type and P-type silicon layers, as illustrated in Figure 13.10.

Figure 13.10 Photoflow solar cell configuration comprising solar cells over a water tank (NOS, 2013).

Although not strictly a solar tracking type system, readers will appreciate the principle. Especially in the case of developing countries where many communities do not have access to electricity and suffer from a lack of clean water, such a novel solar harvesting design concept may be quite valuable. During the night-time, solar panels are often cooler and can help precipitate water from the air, especially where moisture levels are high and temperature variations during daytime and night-time is significant.

13.4 Harvesting Solar Energy with Antennas

In the first part of this chapter, we discussed the harvesting of solar energy through the use of thermal devices (such as Stirling engines), for which it is known that these systems harvest more of its energy from the heat or infrared part of the spectrum and less from the ultraviolet part of the solar spectrum. In the second part of the chapter, we discussed solar harvesting by way of using 2D/3D solar cells (photovoltaic/PV systems), for which it was illustrated in Figure 13.5 that different PV materials harvest more solar energy from certain bands of the sunlight spectrum. This raises the question on whether it may be possible in future to develop a hybrid solar harvesting device that is able to collect solar energy more efficiently, by harvesting solar energy from the full solar power spectrum.

The principles of operation behind solar antenna technology are not commonly known, and to understand their operation one should consider the solar power spectrum once again. Figure 13.11 shows the intensity of sunlight over wavelength (left) or photon energy (right), measured above the upper regions of the atmosphere of the earth (black line) (Gueymard, 2004). The spectral bands for the sunlight colour frequencies are shown in each of the illustrations, from which it should be noted that the shape of the two representations of the solar spectrum is different. This is because the photons with long wavelength carry a smaller amount of energy than photons with a short wavelength, and one is able to distinguish the colors of light that have more spectral energy.

The illustration of the solar spectra in Figure 13.11 should remind many readers of their science teachers in school. Science teachers go to great lengths to make sure that scholars are aware of the fact that light, such as sunlight, displays properties of both (electromagnetic) waves and (atomic, photon) particles. Whereas PV panels operate on principles of harvesting particle type solar energy (knocking electrons out of a metal substrate) and heat based systems makes better use of wave type solar energy (thermal heat), there seems to be ample opportunities for a variety of yet undiscovered inventions to convert sunlight into electrical energy directly.

It thus seems logical that someone may have considered asking the simple question, "if light acts as an electromagnetic wave, is it not possible to develop a solar antenna that is able to harvest an increasing part of the solar energy spectrum ?". Since we know that electromagnetic waves in communication systems and mobile phones receive electromagnetic waves by way of antennas, it seems that this question may have some merit. Naturally, it will be logical to expect that the antennas to receive electromagnetic waves from solar sunlight will be extremely small, simply because of the short wavelengths (high frequency) of sunlight when compared to the relatively long wavelengths (lower frequencies) used in mobile phone systems.

This is exactly what led to the discovery of the nano solar antenna, or simply the nantenna. A nantenna works differently than a solar cell since it is an electromagnetic collector designed to absorb specific wavelengths that are proportional to the size of the nantenna. It acts as an antenna that absorb light of specific wavelengths and convert it into electricity.

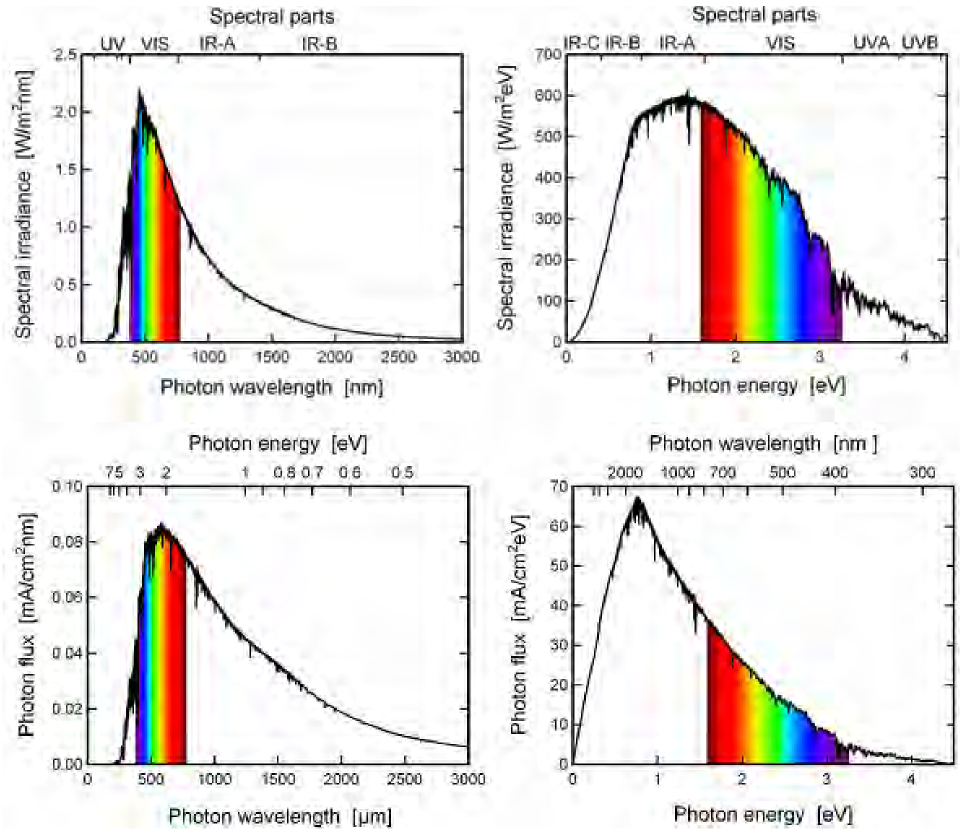


Figure 13.11 The AM0 spectrum, where spectral irradiance (top) and the photon flux (bottom) are plotted against wavelength (left) and photon energy (right). Data from (Gueymard, 2004).

Figure 13.12 shows an example of one type of nantenna. This nanoscopic rectifying antenna operates on new technology principles being developed to convert light to electric power. Unlike photovoltaic cells, which use photons to liberate electrons, the new antennas resonate when hit by light waves, and that generates an alternating current that can be harnessed. To build an array that could capture both visible and infrared radiation, researchers envision multiple layers of antennas, with each layer tuned to a different optical frequency.

To quote Berland (Berland, 2003): ”As a means for capturing or converting the abundant energy from solar radiation, an antenna is the ideal device because it is an efficient transducer between free space and guided waves. In the case of conventional PV cells, solar radiation is only absorbed if the photon energy is greater than the bandgap. Because the bandgap must also be tuned to minimize the excess energy lost to heat when the photon energy is significantly above the bandgap, a significant portion of the incident solar energy, up to 24%, is not absorbed by conventional PV. In contrast, an adequately designed antenna array can efficiently absorb the entire solar spectrum, with nearly 100% efficiency theoretically possible (efficiencies greater than 96% have been predicted for realistic systems with ITNs models). Rather than generating single electron-hole pairs as in the PV, the electric field (E) from an incident electromagnetic radiation source will induce a time-changing current(i.e., wave of accelerated electric charge) in a conductor. Efficient collection of in-

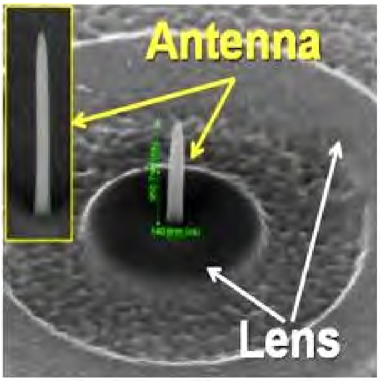


Figure 13.12 Coupled nanoantenna and plasmonic lens. Rings, etched in a gold film, act as a lens redirecting free-space light waves into focused propagating surface (Mikkelsen *et al.*, 2011).

cident radiation is then dependent on resonance length scales and impedance matching of the antenna to the diode to prevent losses". and "In simple microwave antenna theory, the resonant length of the antenna scales linearly with the incident frequency, and in theory the antenna can be scaled to resonate at IR and optical frequencies. However, at IR and optical frequencies, conduction is no longer ohmic, and these simple scaling laws are not accurate. Rather, a majority of the energy in the surface modes is carried in the dielectric above the antenna (often referred to as the skin effect, i.e., surface impedance losses become important). In addition, for solar energy conversion, the antenna must be designed to couple with a fairly complex waveform. The average power per unit area is about 1500 W/m^2, with a maximum intensity at about 0.5 m. Solar radiation has a moderately broadband electromagnetic frequency spectrum, ranging from a frequency of about 150 THz to about 1,000 THz, corresponding to a free-space wavelength of about 2 μm to about 0.3 μm. Over 85% of the radiation energy is contained in the frequency range from 0.4 to 1.6 μm. Efficient antenna/rectifiers, therefore, need to cover a frequency range on the order of 4:1".

13.5 Harvesting Solar Energy and Back-radiation with Infrared Antennas

Initial successes with nano solar antennas led many scientists to ask another important question, namely "Is the levels of solar radiation energy (infra-red electromagnetic waves) that is radiated back into space by the earth at night sufficient to be considered a potential source for energy and can it be harvested with nantenna type devices ?".

It was mentioned earlier that visible light energy coming from the sun is the only solar radiation wave that we can see naturally, and is made up of all colors (Red, Orange, Yellow, Green, Blue, Indigo, and Violet or ROYGBIV), while around 43% of the solar radiation output is visible light, 49% is infrared radiation, 7% is ultraviolet radiation and the remaining 1% is in the form of x-rays, gamma rays, and radio waves (ICC, 2014). To further quote the Earth Science 111 notes from Illinois Central College: "As solar energy reaches the Earth, much of the ultraviolet radiation is absorbed by the ozone layer. Some of the infrared radiation gets absorbed by the clouds and other atmospheric gases. Therefore most of the energy that reaches the Earths surface is in the visible part of the electromagnetic spectrum. The Earths surface absorbs the radiation, and then re-emits the radiation in the form of long-wave infrared as shpown in the spectral distribution of Figure 13.13.

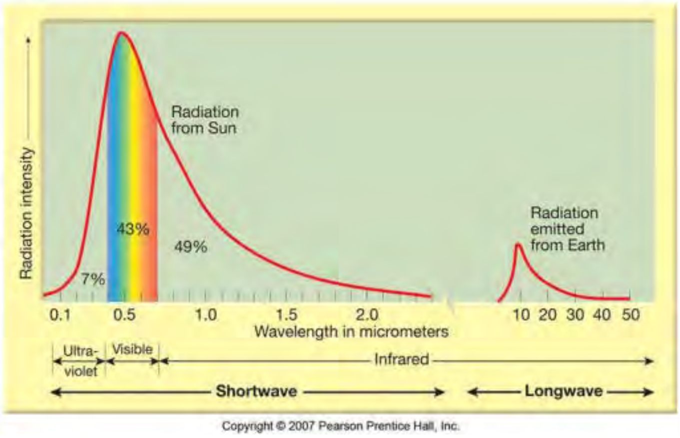


Figure 13.13 Earth surface absorbs solar radiation (short-wave radiation such as ultraviolet, visible, and short-wave infrared) and re-emits the radiation in the form of long-wave infrared (ICC, 2014).

"The infrared radiation that the earth emits is a longer wavelength of infrared than what the sun emits. So the earth emits long-wave radiation (long-wave infrared) and the sun emits short-wave radiation (ultraviolet, visible, and short-wave infrared)" (ICC, 2014).

Following some calculations, it was determined that this one source that we have not yet tapped as yet offers a total of 10^{17} W in infrared thermal radiation. This figure represents the amount of infrared heat energy emitted by the Earth into outer space at night time, as a result of the heat energy the Earth receives from the sun during daytime.

Such calculations caused great excitements and some entrepreneurs started asking the question, "Can nantennas be developed to harvest solar energy at daytime, and be flipped around at nighttime to harvest the infrared radiation at nighttime with the energy harvesting means". These were extremely important questions, considering the fact that solar energy is only available during the sunlight hours of the day (less than half the number of hours per day). It was argued that, if nantenna type devices could be integrated with PV systems, then the end result would not only be more efficient and cost effective solar harvesting means during the daytime, but also serving the dual purpose of harvesting the earth's infrared energy at night.

Some of the uninformed ridiculed the idea of developing solar cells that can work at night. However, a new breed of nanoscale light-sensitive antennas soon showed potential to do exactly this, heralding a novel form of renewable energy that avoids many of the problems that best solar cells.

It is thus not surprising that NREL commissioned a report entitled "Photovoltaic Technologies Beyond the Horizon: Optical Rectenna Solar Cell" (NREL, 2014*d*). In this report it is stated that "ITN Energy Systems is developing next-generation solar cells based on the concepts of an optical rectenna (see Figure 13.14). This optical rectenna consists of two key elements: 1) an optical antenna to efficiently absorb the incident solar radiation, and 2) a high frequency metal-insulator-metal (MIM) tunneling diode that rectifies the AC field across the antenna, providing DC power to an external load. The combination of a rectifying diode at the feedpoints of a receiving antenna is often referred to as a rectenna. Rectennas were originally proposed in the 1960s for power transmission by radio waves for remote powering of aircraft for surveillance or communications platforms. Conversion efficiencies greater than 85% have been demonstrated at radio frequencies (efficiency defined as DC power generated divided by RF power incident on the device). Later, concepts were proposed to extend the rectennas into the infrared (IR) and optical region of the electromagnetic spectrum for use as energy collection devices (optical rectennas)".

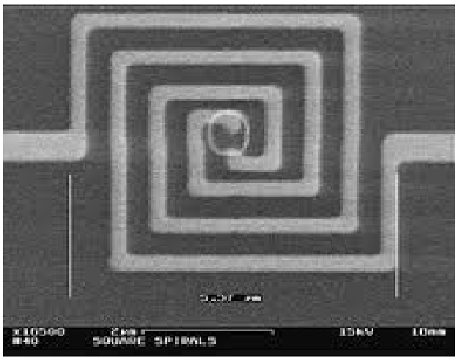


Figure 13.14 Coupled nanoantenna and plasmonic lens. Rings, etched in a gold film, act as a lens redirecting free-space light waves into focused propagating surface (Lin, 2007).

A technology startup company Sol Voltaics from Sweden reported recently that they developed a low cost way to make tiny nanowires out of the semiconductor gallium arsenide. The nanowires is absorbed into an ink, which can be layered onto basic solar panels and boost the efficiency of a standard panel by around 25% (Wallentin *et al.*, 2013). With around 30 times higher surface-to-volume ratio compared to a nanowire cell, the ink cell converts around 71% of sunlight into photo current (six times the limit in a simple ray optics, with a maximum open circuit voltage of 0.906 volt).

Pioneers of nano antenna technology such as Steven Novack and others (Novack *et al.*, 2008) argue that if nearly half of the available energy in the solar spectrum resides in the infrared band, meaning such infrared is re-emitted into space by the earth's surface after sunset. This implies that solar antennas may be used to capture such infrared energy during the night, thus utilizing one of the key characteristics of nano antenna devices - the ability to harvest infrared radiation. Their argument is that semiconductor diodes act like valves, and convert alternating current into direct current. Nano antennas are tuned to operate at frequencies that match the conductive properties of the antenna and have the potential to collect 84% of incoming photons with a potential overall efficiency of 46% (Novack *et al.*, 2008).

Byrnes and colleagues (S. Byrnes, Romain Blanchard, 2014) are of the opinion that infrared radiation can be harvested by means of a so-called emissive energy harvester that could extract some of the re-radiated infrared solar energy. Byrnes explains as follows: "In the first, solar thermal sunlight heats an object and a turbine runs on the temperature difference between the hot object and the cooler environment. If we can make a thermal EEH in an analogous way: an object radiatively cools and a turbine runs on the temperature difference between the cool object and the warmer environment". They argue that such devices may produce an average of 2.7 W/m2, or 0.06 kWh/m2 per day during the day and night (Byrnes *et al.*, 2014).

13.6 Solar Energy from Concentrated Photovoltaics

Concentrated photovoltaic (CPV) technology generate electricity by using optics such as optic lenses or curved mirrors to focus sunlight from a large area onto a small area of semiconducting material or solar photovoltaic (PV) cells to generate electricity. Due to the focussing of sunlight and the integration of lenses, CPV systems require direct sunlight to operate, so most systems employ single- or dual-axis trackers to follow the sun across the sky (BLM, 2010).

CPV is an attractive solar harvesting technology since it is based on full-spectrum concentrated solar photovoltaic and thermal power conversion. A typical CPV conversion system is depicted in Figure 13.15, wherein there is shown a proposed CPV system of the University of California Solar Group (Montgomery *et al.*, 2013). It comprises of a solar photovoltaic cell at the focal point of the solar concentrator lens, mounted over a thermal absorber. To illustrate the principle of operation, UC Solar can be quoted in saying: "The solar cell is designed to capture and convert high energy photons (those that correlate to blue and green wavelengths of light). All remaining photons will then pass through onto the thermal absorber, which will be a low-cost tungsten-based device designed to produce heat at 350°C. This heat will be partially stored for later use when demand increases, as well as used for electricity generation or direct heating applications. When combined, these components are capable of converting 40% of the suns energy into usable energy in the form of electricity and heat" (UC Solar, 2014).

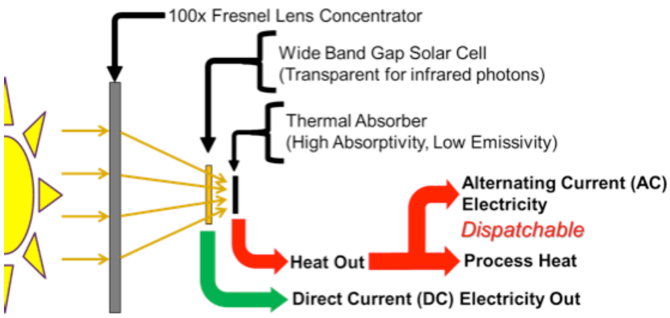


Figure 13.15 Full-spectrum photovoltaic-photothermal concentrator system (UC Solar, 2014).

Figure 13.16(left) shows the construction of a High-Concentration System (HCPV) module that includes (from left to right) the Fresnel lens, second condenser, receiver and cooling devices. The solar cell element comprises of a compound semiconductor material and a concentrating solar cell module onto which sunlight is focussed with a Fresnel condenser lens to converge the energy of sunlight on the solar cell element (Chengcong *et al.*, 2011). This solar concentrator system includes a tracking device to follow the sun.

The Soitec solar cell module which is built on the so-called Concentrix technology shown in Figure 13.16(right) (Soitec, 2014). This technology implements stacked multi-junction solar cells wherein different types of solar cells sensitive to different frequency bands are stacked on top of one another (see Figure 13.5). Each type of solar cell in the stack is designed to convert a certain range of the solar spectrum (short wave radiation, medium wave radiation and infrared) into electricity.

Concentrix technology, illustrated in Figure 13.17, employ Fresnel lenses to concentrate sunlight 500 times and focus it onto small, highly efficient multi-junction solar cells.

Figure 13.16 Examples of CPV modules made up of a matrix of lens plates (Fresnel lens) and receiver plates on which the high-performance solar cells are mounted (Chengcong *et al.*, 2011)(Soitec, 2014).

With this technology the rate of conversion is said to be 31,8%, which is a relatively high conversion efficiency (compared to conventional silicon photovoltaic modules).

In general CPV competes with concentrated solar thermal since it also turns sunlight directly into electricity. Concentrated solar thermal in turn converts sunlight into heat and then turn the heat into electricity, which allows for the two technologies sometimes to be combined in the same system as shown in the system of Figure 13.17.

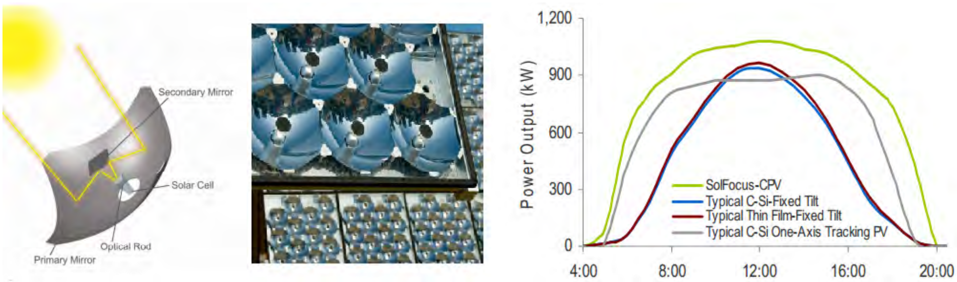


Figure 13.17 An example of CPV (concentrated photovoltaic) solar power system (Chong *et al.*, 2014)(Lopez and Stone, 1993*b*).

Since the rate of conversion in semiconductor CPV systems reduce as a result of increased temperature, CPV systems operate most efficiently if the solar cell is kept cool through use of heat sinks.

In high concentration photovoltaics (HCPV) systems, the focussing optics may consist of parabolic dish reflectors or Fresnel lenses that concentrate sunlight to intensities of 1000 suns or more (Kurtz, 2012). The solar cells require high-capacity heat sinks to prevent thermal destruction and to manage temperature related electrical performance and life expectancy losses. For this reason, CPV systems typically require two-axes solar tracking and must be combined with cooling (whether passive or active), which makes the technology more complex.

Ghosal *at.al* compared the performance of the Semprius HCPV system with that of alternative PV systems (Ghosal *et al.*, 2011). Some of their results are given in the graphs Figure 13.18(a), that shows Direct Normal Irradiance (DNI), Global Normal Irradiance (GNI) and Global Horizontal Irradiance at 0 degrees (GHI) for a sunny day in Tucson. On a sunny day, the direct normal insolation was about 90% of the global normal insolation and the global horizontal insolation was 76.6% of the direct normal insolation. The average daily direct normal insolation at this site for the ten months was 6.6 kWh/m^2 (Ghosal *et al.*, 2011). Figure 13.18(b) presents plots of AC and DC power on typical sunny days in December and May moths, showing seasonal effects on the DC energy output to be 8.1 kWh 10.2 kWh respectively (96% inverter efficiency). The plot also highlights the benefit of two-axis tracking, namely a relatively stable power output, for most of the day. In general, HCPV on a two-axis tracker is a much better match for a utilitys demand curve than untracked PV.

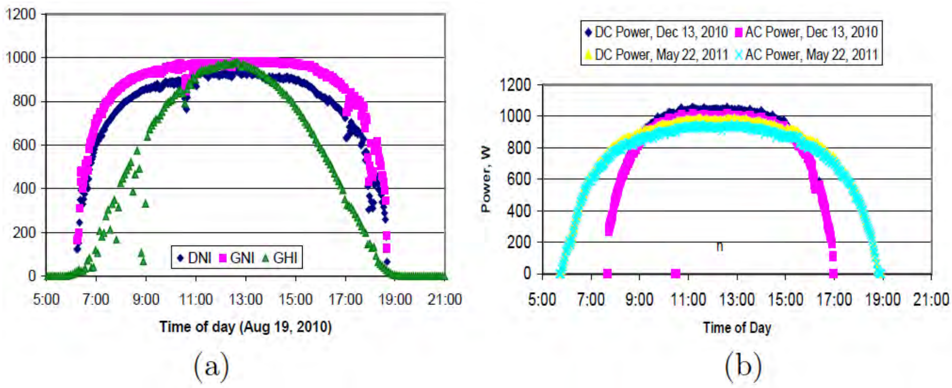


Figure 13.18 Effect of seasons on solar harvesting and power generation (Ghosal *et al.*, 2011).

In terms of cloud impact on an HCPV system, the sunny and cloudy condition outputs in Figure 13.19 can be compared (Ghosal *et al.*, 2011). Figure 13.19(a) presents the energy yield for all the systems on a bright and sunny day, whileFigure 13.19(b) presents the performance of the systems on a partially cloudy day (Ghosal *et al.*, 2011). The differences in energy yield between the 3 systems are because of cloud cover and two-axis tracking, module rating method and temperature coefficients. Flat plate PV performs better when shaded by high thin stratus clouds that only scatter light, while two-axis tracking systems capture a larger portion of the solar radiation than a non-tracking system (Ghosal *et al.*, 2011).

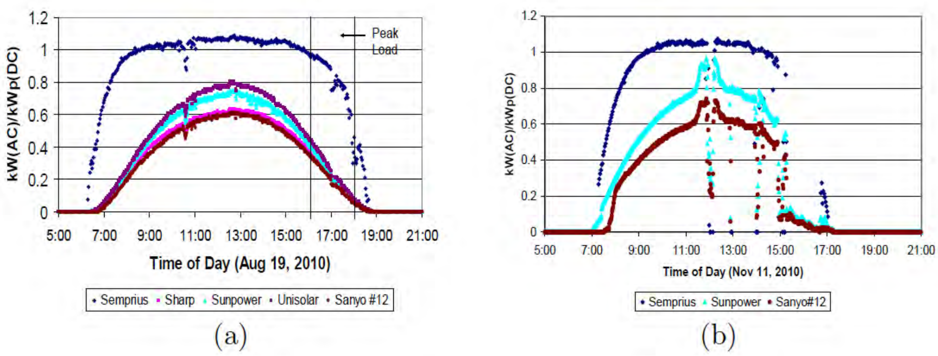


Figure 13.19 Energy yield on (a) a sunny day and (b) on a partially cloudy day (Ghosal *et al.*, 2011).

Compared to non-concentrated photovoltaics, CPV and HCPV systems can save money on the cost of the solar cells, since a smaller area of photovoltaic material is required. However, diffuse light, which occurs in cloudy and overcast conditions, cannot be concentrated. To reach their maximum efficiency, CPV systems must be located in areas that receive plentiful direct sunlight.

The NREL website (`http://www.nrel.gov/csp/concentrating_pv.html`) is a good starting point for those readers interested in concentrated photovoltaic systems and the latest developments in this field of technology. The next section details solar harvesting using three-dimensional technology.

In conclusion, the National Center for Photovoltaics (NCPV) at NREL keeps records of the highest confirmed conversion efficiencies for research solar cells. The centre records dates from 1976 to the present, and it shows a plot it maintains for efficiency values for a range of photovoltaic technologies, as illustrated in Figure 13.20.

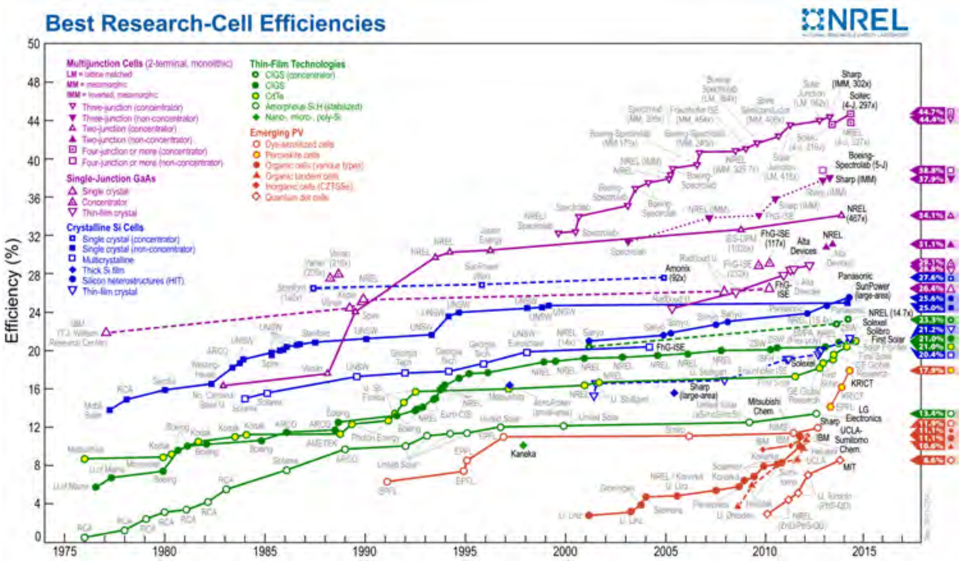


Figure 13.20 NREL plot of photovoltaic technologies that achieved the highest confirmed conversion efficiencies for research solar cells (NREL, 2014*e*).

It should be kept in mind that the efficiencies plotted by NREL is provided in good faith, but it is shown here to demonstrate the performance values of some of the photovoltaic systems described in this section. The graph for example shows that technologies such as those described for Soitec (Soitec, 2014) maintains a very high level of credibility and performance in terms of international efficiency levels (top right in plot). This plot is used in this publications, with a notation included that states: This plot is courtesy of the National Renewable Energy Laboratory, Golden, CO. (NREL, 2014*e*).

13.7 Harvesting Solar Thermal Energy

Stirling engine technology provides an efficient and robust solution for thermal to electrical power conversion. The United Nations Framework on Climate Change expresses the view that an autonomous off-grid low-cost Stirling or concentrating photovoltaic (CPV) solar power generating system has the potential to empower rural participation in economic development and to improve living conditions to help restore peoples' dignity within developing countries (Makundi and Rajan, 1999).

Figure 13.21 presents a comparison of the average solar-to-electrical power conversion efficiencies between four types of concentrated solar power conversion technologies (Greyvenstein, 2011). Stirling power systems has the highest efficiency of any form of CSP, converting up to 22% (even up to 32% (Linden, 2007)) of incoming solar power to electricity, compared to the average of around 15% or 16% for power tower or parabolic trough designs. Stirling power generation technology thus is one candidate that offers good conversion efficiency for implementing high-power, stand-alone power generating systems.

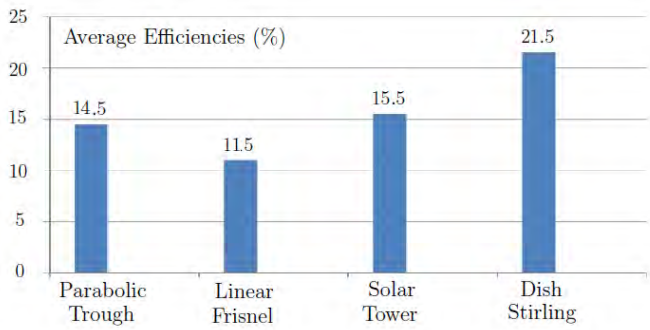


Figure 13.21 Average solar technology conversion efficiencies (Greyvenstein, 2011)

One type of Stirling engine, namely the *free-piston Stirling engine* illustrated in Figure 13.22, is of particular importance as it consists of only a few moving parts and does not have a direct internal mechanical linkage system. This means that the engine runs very silent and ensures optimum internal operation of a Stirling engine power supply unit. Apart from its relative mechanical simplicity, the device has no lubrication system, uses no mechanical seals and is deployed as a hermetically sealed unit. Free piston Stirling engines are thus regarded as being the most reliable and maintenance-free of all heat engines and most suitable for solar power generation in Africa (Tsoutsos *et al.*, 2003).

In terms of the climate change challenge, Stirling technology in combination with a reliable solar concentrator and automated solar tracking solution can generate high-power electrical energy with close-to-zero CO_2 or harmful greenhouse gas emissions. Such solar power systems are expected to reach energy conversions efficiencies above 32% by 2015 (Gary *et al.*, 2011) and by comparison, is considered to be amongst the most economic and green energy power generation technology platforms (Lopez and Stone, 1993*b*).

For a Stirling device to generate electrical power, it needs to be connected to a sun-concentrating optical device which focuses the light rays of the sun onto the *solar receiver* of the Stirling engine. A typical solar reflector system consists of a matrix of reflecting mirrors, often manufactured of reflecting polymer film, that are fixed onto a parabolic dish and arranged to concentrate the sun's energy onto a solar receiver. The solar reflector system also needs to be dynamically tilted at certain angles to continuously face the sun throughout the day. Mechanical drives and a control system are required to direct the dish structure to keep a tight focus directly on the sun as it moves across the sky.

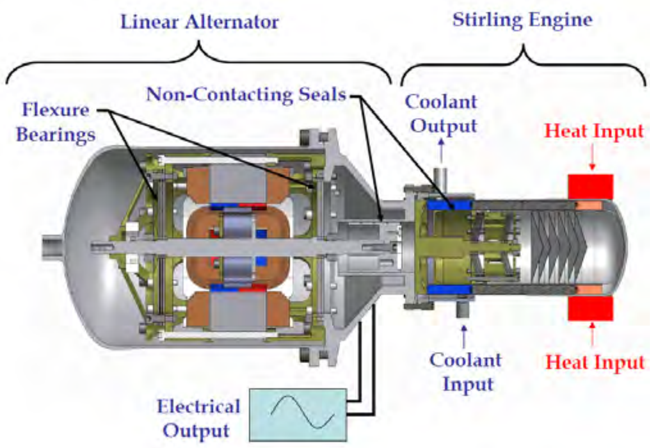


Figure 13.22 Stirling engine technology developed by Infinia/Qnergy (Smith, 2007)(Qnergy, 2013).

Harvesting solar thermal energy thus operates on the principle of optic reflection of a cross-sectional area of energy in order to concentrate the radiated/reflected electromagnetic energy onto a much single smaller cross-sectional area. The bulk of the sun's energy is radiated in the visible light spectrum, which is of such frequency content that direct line of sight is required to optimally reflect the visible light energy waves onto a smaller cross-sectional area. Different studies have been carried out to improve the amount of energy capture to increase the overall efficiency for solar applications. As a result of this, different applications have been invented that tend to maximise the utilization of solar power such as solar concentrators and solar panels. One of the applications that is currently being used very widely is the solar tracking system.

In the system shown in Figure 13.23, a Stirling engine converts any applied solar thermal energy into electricity. The thermal energy applied onto one end of the Stirling Engine is maintained through a parabolic solar reflector or concentrator which directs and focus electromagnetic sunlight energy onto the Stirling receiver. This results is high performance solar power generation with the ability to provide several kilowatt-hours of energy during daytime solar radiation (Greyvenstein, 2011).

Figure 13.24 displays the temporal power budget, showing the potential solar energy that could be harvested at a particular location over a one year period. This type of display, shows the level of solar energy in colour levels, spread over a 24 hour period on the vertical axis, and spread over a twelve month period on the horizontal axis. This three dimensional type of display is particularly useful when it comes to power budget calculations in stand-alone solar tracking systems, since one is able to make a quick visual assessment of the hours of sunlight and levels of solar radiation spread over a full year period.

When one works with CSP solar tracking systems then it must be kept in mind that there is significant solar scattering when the sun has just risen or when the sun is approaching sunset (between solar angles around 5° and 0°). An example of the increase in solar tracking errors typically experienced at these solar altitudes will be shown in a later chapter of this book (Figure 16.8). Such low solar altitude angle scattering is known as sunset/sunrise diffuse scattering or diffuse sky radiation, and occurs as a result of solar beams being scattered by suspensoids or molecules in the atmosphere close to the earth surface. In terms of

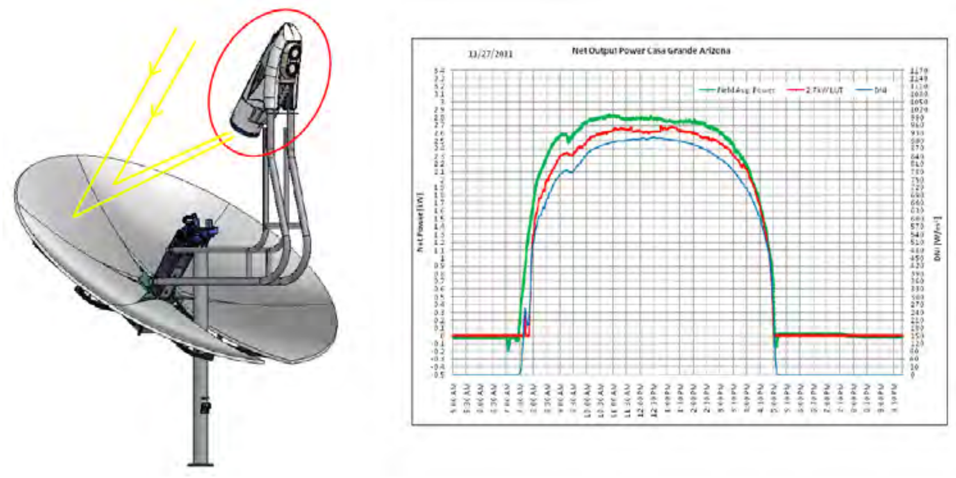


Figure 13.23 Parabolic solar reflector solar power generator device (left) and typical daylight energy output curve on a clear day (right) (Greyvenstein, 2011).

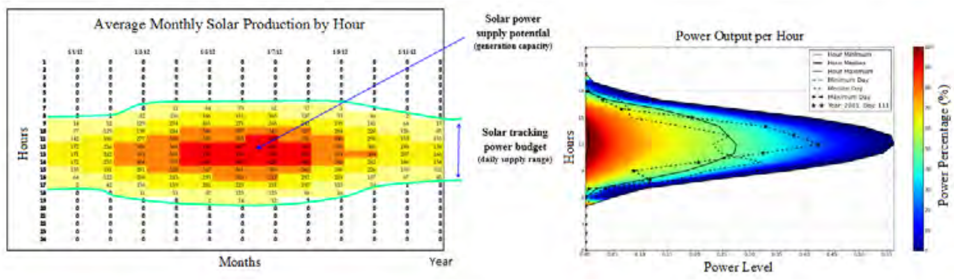


Figure 13.24 Display of temporal power budget over four seasons (left) and over 24 hours of a single day (right) (Krymsky, 2013)(Schroder, 2014).

power budget calculations, it may be important to take any associated losses in efficiency (reduced direct light and potential solar tracking errors) near sunset or sunrise into consideration. Alternatively one use compensation mechanisms to adjust the solar tracking angles that compensate for low altitude solar radiation scattering (Griffin and Burke, 2003).

Solar tracking is important as it aims to eliminate the so-called "cosine factor" by ensuring pinpointing of the optic reflector means onto the moving solar disk. This is referred to as *h*igh-precision solar tracking. Solar tracking is a generic term used to describe devices that orientate various payloads toward the sun on a continuous and real-time basis. In general, payloads can be photovoltaic panels, reflectors, lenses or other optical devices. A typical parabolic type solar reflector power generating system is shown in Figure 13.23. This device includes a parabolic optic reflector means to focus the electromagnetic energy onto a power conversion unit, which essentially converts thermal energy into electrical energy. This mechanisms further includes an electronic control with associated mechanical drives in order to direct the parabolic towards the sun and to automatically follow the course of the sun throughout the daytime.

A solar tracking accuracy is thus an important factor in concentrated solar power system design, since concentrated solar systems convert solar energy directly from thermal into electrical energy in proportion to the amount of directly captured solar energy. High precision solar tracking is thus required to ensure that the solar collector harvest the maximum amount of energy. Figure 13.25, shows and example of the sensitivity of the intercepted solar energy with respect to the solar tracking optical pointing error for a particular solar receiver. Although this relationship is strictly a function of the shape and size of the solar receiver, guidance in terms of setting a solar tracking accuracy specification for your concentrating solar tracking design can be taken from technical reports for existing concentrating solar dish systems (Bendt *et al.*, 1980)(Kinoshita, 1985)(Le Roux *et al.*, 2012)(Hughes, 1980).

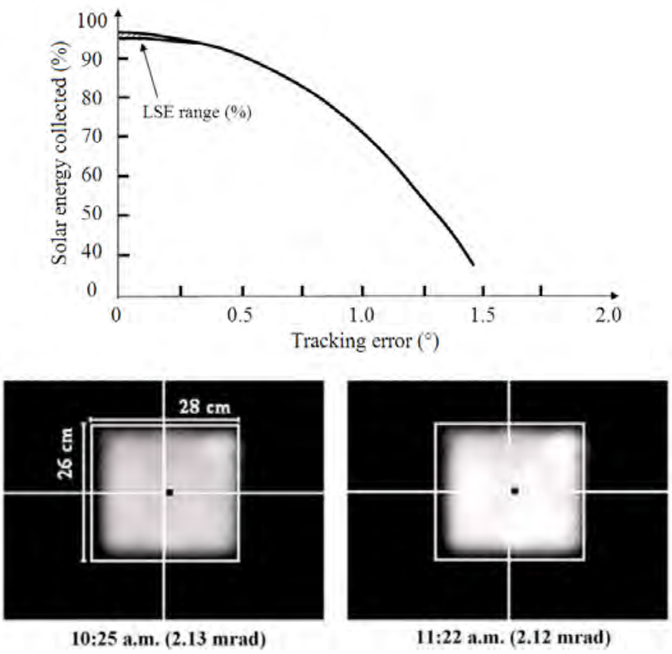


Figure 13.25 An example of the sensitivity of solar energy collected in a CSP system as a function of tracking error (Kinoshita, 1985)(Xinhong *et al.*, 2007)

In the example of Figure 13.25, the solar energy intercept factor remains above 90% for angular accuracies (allowable solar tracking misalignment/errors) between 0.25° (∼4 mrad) and 1.0° (∼17 mrad). Thus solar tracking errors within an error margin of ∼1.0° will translate into dish intercepted heat rate losses of less than 4%. Above this tracking error rate (i.e. 22% for ∼2.0° tracking error), the thermal losses increase exponentially as a function of solar tracking error.

In order to maintain high output power in the concentrated solar power system, a high-precision sun-tracking system with a good solar tracking resolution (i.e 0.1°) is typically required. In general a sun-tracking formula is used to provide a general mathematical solution that expresses the sequence of solar vectors throughout the day. The tracking error resolution for your solar receiver system (Stirling, flatplate, etc.) should then be used as basis to define an acceptable tracking error specifications for the solar tracking platform, control system and solar receiver.

A number of other factors further determine the effectiveness with which concentrated solar systems are able to convert solar energy into electrical energy. Figure 13.26 shows the progression of losses from the radiation of solar thermal energy, from solar radiation stage right up to the stage where solar energy is converted into electricity.

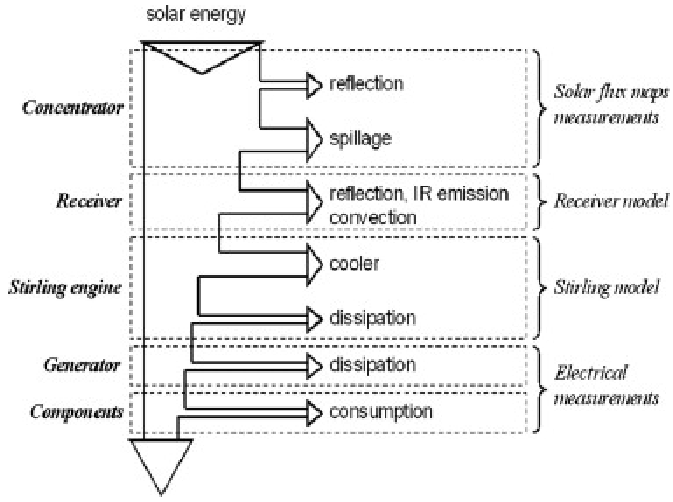


Figure 13.26 Hierarchy of solar thermal energy conversion losses in the various components of the solar harvesting means.

The hierarchy of solar thermal energy conversion losses in the various components of the solar harvesting means (Figure 13.26) helps to determine the overall solar harvesting efficiency. This overall system efficiency depicts the conversion from solar energy into electrical energy.

During 2008, Sterling Energy Systems (SES) claimed to have been maintaining the world record with parabolic solar dish system power conversion efficiency with their SunCatcher design. While illustrating a breakdown of their subsystem efficiencies, as shown in Figure 13.27, announcements during 2008 read: "The SunCatcher: Concentrating Solar Dishes Set Efficiency Record" and "New World Record for Sun to Grid Efficiency at 31.25%" (Linden, 2007).

The SunCatcher systems serves as a good reference on subsystem efficiencies and helps to understand how the efficiency of each subsystem contributes to the overall system solar-to-power conversion efficiency.

The NREL website (`http://www.nrel.gov/csp/`) is a good starting point for those readers interested in concentrated solar power systems and the latest developments in this field of technology. The next section details solar harvesting using photovoltaic technology.

13.8 Harvesting Solar Light Energy for Daylight Lighting

Kandilli *et.al* (Kandilli *et al.*, 2008) found that solar lighting via fibre optic bundles can be considered as a very promising option from the viewpoint of energy efficient green buildings. Figure 13.28 presents an illustration of the system in which an optical fiber bundle is connected to the dish focal point and used as optical energy transmission on transport medium.

Their report concludes that "the primary advantage of lighting systems with solar concentrators is their potential to reduce energy consumption with respect to conventional

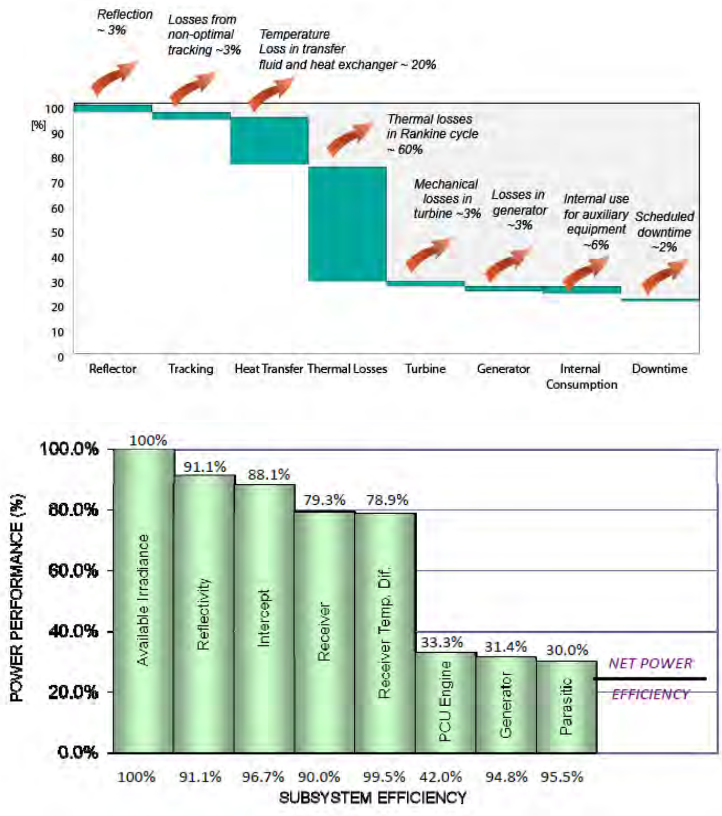


Figure 13.27 Typical parabolic dish system conversion, operational and downtime losses (top) (Green Rhino Energy, 2014), and measured SES Stirling dish system losses (bottom) (Linden, 2007).

Figure 13.28 Transmission of concentrated sunlight in a fibre-optic bundle for solar lighting (Kandilli *et al.*, 2008).

ones, while they have an important superiority about sunlight providing a perfect match with human visual response. In other words, integrated fibre optic lighting systems based on solar energy emerged an alternative, energy efficient and qualitative option for the spaces illuminating insufficiently, requiring safety and having a large lighting load" (Kandilli *et al.*, 2008).

From a solar thermal perspective, there are certain limits to the energy carrying capacity of optical fibre bundles. In this regard, Zidani *et.al* (Zidani *et al.*, 2013) coupled a paraboloidal dish with dual axes tracking component to a fibre cable to ensure direct concentration and transmission of solar irradiance. They found that solar energy at temperatures above $1600°K$ could still be transported with optical fibres for the medium to maintain good efficiencies (25 W). It was found that transported solar energy is diffused up to the point of entry, from where this solar light energy is conveyed and absorbed by the receiver. The experiment was to show that solar furnaces could be constructed with temperature gradients that may be determined experimentally.

Liang *et.al* (Liang *et al.*, 1999) studied the use of fibre optic in solar energy transmission and concentration and reported on a flexible light guide that had the capability of transmitting up to 60 W of optical solar power with efficiencies up to 60% using nineteen optical fibres (which they compared to a single fibre and a 7 core fibre). A review of modelling systems for the transmission concentrated solar energy via optical fibres by Kandilli and Ulgen also provides an interesting background to this field of research (Kandilli and Ulgen, 2009).

13.9 Linear Solar Thermal Harvesting Systems

Two main types of linear tracking reflectors are commonly used in harvesting solar thermal energy. A solar parabolic trough consists of a linear parabolic reflectors that is tilted on one axis to focus sunlight onto a heat collecting fluid in a linear tube or pipe that is located at the parabolic focal point and runs along the length of the solar trough. The fluid is typically a synthetic oil or melted salt operating at temperatures around 300°C and 400°C.

Figure 13.29(left) presents an illustration of a solar trough that comprises of a parabolic shape dish lined with a reflective coating that focuses sunlight onto a thermal absorber pipe that carries an oil (Sopogy, 2014). In this micro-CHP system the heated liquid goes through an organic Rankine cycle engine to convert it into electricity.

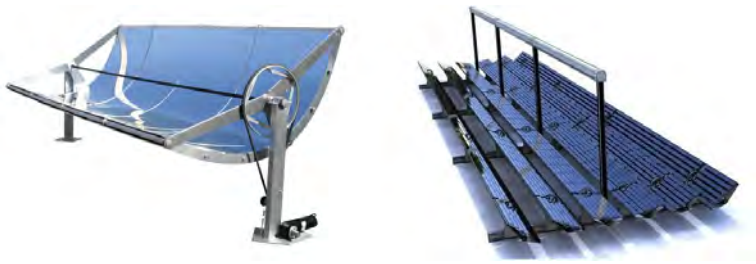


Figure 13.29 Examples of a parabolic trough (left) and linear Fresnel (right) type linear solar thermal harvesting means (Sopogy, 2014)(HelioDynamics, 2009).

A linear Fresnel reflector system on the other hand uses single axis tracking technology using long parallel lines of thin flat (or shallow curved) mirrors or reflectors. These mirrors track the sun to ensure that direct solar irradiation is reflected and concentrated onto a stationary, single linear receiver (solar tube or receiver structure) filled with fluid and located at a common focal point of the reflectors. Once again the fluid can be synthetic oil or melted salt, while these systems operate at temperatures around 250°C.

Figure 13.29(right) presents an illustration of a concentrating linear Fresnel reflector, often referred to as a compact linear Fresnel reflector if it uses multiple absorber tubes

(HelioDynamics, 2009). These reflectors use long, thin segments of mirrors to focus sunlight onto a linear (fixed) thermal absorber pipe located at the common focal point of all the linear reflectors. By steering the individual linear mirror array elements to follow the sun and focus their energy on the overhead absorber, the mirrors concentrate the sunlight onto the solar receiver/absorber. A thermal fluid inside the solar absorber pipe transfers the solar thermal energy through a heat exchanger to power a steam generator.

Linear solar systems operate at relatively low to medium high temperatures, meaning the solar heat can be used for industrial processes, for example providing warm water for industrial processes. Linear solar systems can also provide hot air for drying (i.e. food and paper industries) or it can generate steam that can be fed into steam heat distribution networks, while existing industrial machinery and distribution infrastructure remains in place.

Fieldhoff (Feldhoff, 2012) compiled a technology overview on a range of Linear Fresnel Collectors for various applications, which is available for read on this link `http://sfera.sollab.eu/downloads/Schools/Fabian_Feldhoff_Linear_Fresnel.pdf`. Amongst other interesting data, the review includes valuable data on comparisons between linear Fresnel (LF) and parabolic trough (PT) technologies. Figure 13.30 for example illustrates the differences in daily power generation and efficiencies of LF and PT systems for different seasons of the year.

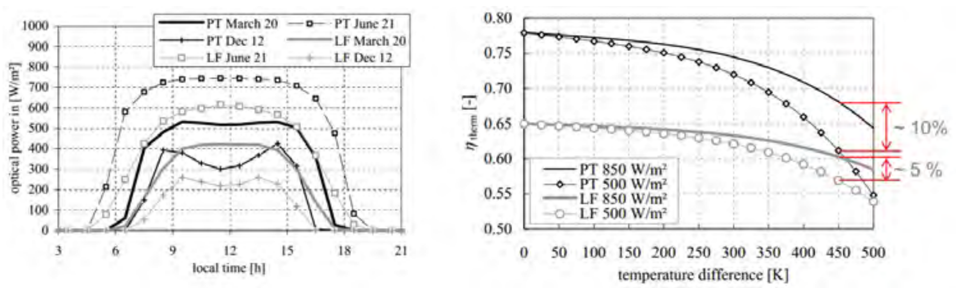


Figure 13.30 Examples of differences in daily power generation (left) and efficiencies (right) linear Fresnel and parabolic trough systems for different seasons of the year (Feldhoff, 2012).

In terms of practical examples relating to linear Fresnel and parabolic trough developments, Walker (Walker, 2013) describes the design and construction of a low-cost linear Fresnel solar concentrator to replace existing thermal sources in the generation of power and process heat. This development includes sample software code to simulate operational aspects of the solar collector. In another example, the Schneider Electric BipBop community development programme use a Microsol thermodynamic linear concentrated solar systems technology for simultaneously producing electricity, drinking water and heat for an Eco estate or rural village community (Schneider Electric, 2013).

13.10 Heliostat Central Receiver Systems

A central receiver system employ a heliostat field to focus sunlight on a solar receiver and power generation unit, typically situated on a solar tower. These systems are typically grid-connected plants that deliver power in the range around 0.515 MW (Romero *et al.*, 2002).

One lightweight mechanical design approach by Google (Google, 2014*b*) led to the development of a easily transportable heliostat frames with mirror reflectors. Brayton Energy designed and developed a purpose-built Brayton cycle engine for tower CSP applications and the concept system illustrated in Figure 13.31 (Google, 2014*a*).

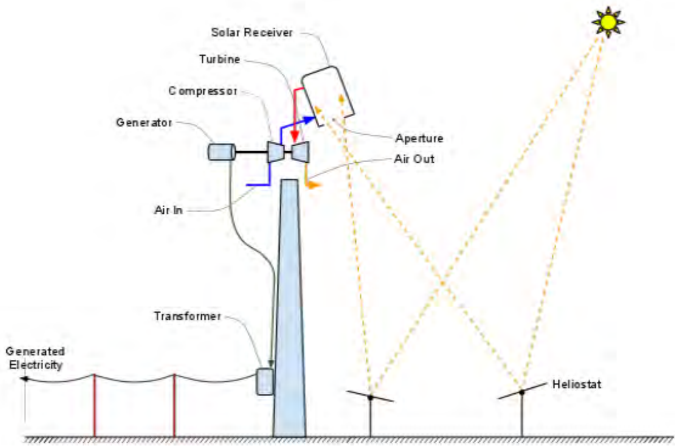


Figure 13.31 Major components of a central receiver concentrated solar power system (Google, 2014*a*).

Bode and Gauché (Bode and Gauché, 2012) published a review on algorithms for the optical design, analysis and optimisation of central receiver systems. The review includes an analysis of the functionality of software algorithms (i.e SolTrace, TieSOL, SPRAY, STRAL, etc.) in two categories, namely tools to analyse and optimise field layout and secondly tools to simulate the flux distribution at the receiver from the heliostat mirrors. This is a good resource to consult in terms of design tool functionality and feature comparisons.

13.11 Reinventing the Leaf

As a matter of interest, and to end off the discussion on weird and wonderful solar conversion systems, solar antennas and solar trigeneration systems, we feel that it is important to close-off with an image that emphasises the work of nature. Figure 13.32 shows the frequency spectrum for visible light portions of the solar radiation to which nature respond in the photosynthesis process. There is opportunities is developing a so-called "artificial leaf" to directly convert sunlight into chemical fuels that can be stored and transported (J. Marshall, 2014).

It may be important to emphasise and to consider once again the solar spectra favoured in the process of photosynthesis, wherein only the blue and red colors in the visible solar color spectrum play an important role. It seems odd that scientists, engineers and inventors place significant emphasis on harvesting the complete solar power spectrum, while some of natures most efficient mechanisms to convert sunlight into fuel is biased towards mainly using the red and blue frequency bands of the sunlight spectrum. Thanks to this, the wonderful unused green light energy is reflected back for our eyes to feast on. This redundant color green even led humanity to the development of wonderful words such as *G*reen Energy and the *G*reen Economy.

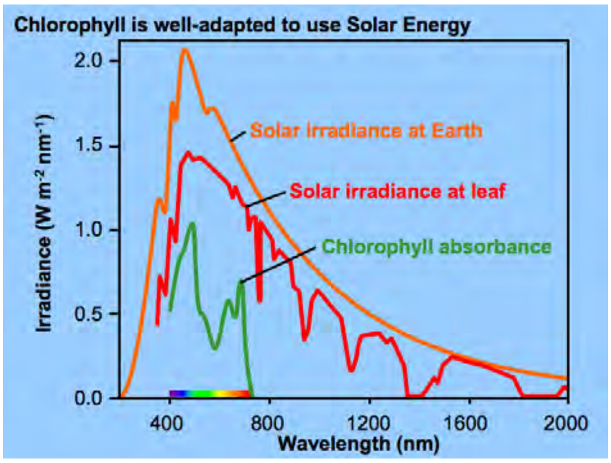


Figure 13.32 Solar cell spectrum compared to plant photosynthesis (Koning, 1994).

From a solar tracking perspective, Vandenbrink *et.al* published and article name "Turning heads: The biology of solar tracking in sunflower" (Vandenbrink *et al.*, 2014). This article provides interesting bio perspectives on mechanisms that may contribute to daytime and night-time movement and actions of plants, including light signalling, hormonal action, and circadian regulation of growth pathways and explaining to some extent the adaptive significance of heliotropism in the sunflower plant. It may just be time for more organic solar cells and organic solar tracker mechanisms that mimic nature in solar harvesting.

13.12 Summary

This chapter detailed various aspects related to the harvesting of solar energy and the importance in following the sun on its apparent movement trajectory throughout the sky. It shows the importance of solar tracking accuracy as a design parameter is solar harvesting means, as well as the energy gains tracking the sun in two dimensions and to retain the focus on the sun as solar resource for maximum energy yield. Readers interested in an overview of solar harvesting techniques can study this publication that is a field guide to renewable energy technologies, a land art generator initiative (Ferry and Monoian, 2012).

This chapter showed that a solar harvesting means, such as a parabolic dish, must be tracked in two dimensions in order to allow focussing of the sunlight and to maintain the incident beams of the sun normal to the solar receiver aperture. The next chapter describes solar tracking systems, platforms and mechanisms required for more effective solar energy harvesting.

CHAPTER 14

PARABOLIC DISH SHAPING, FORMULAS AND CURVES

14.1 Introduction

May readers are familiar with the concept and working principles of a parabolic dish or through, but when it gets to the practical implementation and shaping of the dish then the mathematics causes much difficulty. It is actually not very complicated to design and fabricate your own parabolic dish. The biggest question that most readers answered is: How do one shape the dish material so that it adheres to the seemingly complicated mathematical equations. This chapter presents a very simple and practical answer to this question by way of showing readers the practical meaning of the parameters of a parabolic curve, but more importantly, how to use these parameters "in reverse" (i.e. how to shape material in the form of a parabolic curve in practice so that it is suitable for solar harvesting).

14.2 Parabolic Dish Parameters

A parabolic dish or trough is well known for its abilities to optically focus the rays of the sun onto a specific spot. This capability has made it ideal in concentrated solar power systems and the principles behind parabolic curves have been used for many years in concentrated solar harvesting.

A parabolic dish or trough configuration can be described in terms of the parameters of a parabolic function of the same family. A parabolic family means parabolic functions with identical parameters but varying parabolic constants (f/D ratios). This parabolic constant, or so-called f/D ratio, means the ratio between the the focal point distance (f) of the dish/trough and the diameter or width of the dish/trough (D). The focal point distance (f) of the dish/trough is measured from the vertex or base of the center point of the parabolic curve to the focal point of the parabolic curve where the solar receiver will be located. The diameter or width of the dish/trough (D) is measured from the one outer edge of the upper rim of the dish/trough to the other side of the dish/trough

Figure 14.1 illustrates a set of parabolic equations for the same family of curves/functions. It shows the (a) parameters defining an individual parabolic dish (with truncated circular differential strip as an example), and (b) a set of parabolic dish shapes for the same family of parabolic shapes with varying f/D ratios.

In terms of solar harvesting and solar tracking, the f/D ratio of a parabolic curve is a crucial parameter in the parabolic curve as it determines the spot where the sunlight will focus when that shape is used in solar harvesting and solar tracking applications. The f/D ratio of a parabolic curve also has the same meaning for both parabolic trough and parabolic dish.

In an earlier discussion in this book (Section 2.5), the importance of the parabolic constant of a solar/satellite dish (Figure 2.10) was highlighted. It was shown that the focal point determines the angle at which the sunlight enters the solar receiver cavity at the point where concentrated heat is transferred to the solar receiver (dish focal point). In this discussion, it was shown that the satellite dishes in Figure 2.10 was typically very "deep" as the focal point of satellite dishes can be closer to the dish than in the case of a solar parabolic dish.

Section 2.5 also mentioned that, compared to radio and satellite dish designs, the parabolic focus plane and payload for a concentrated solar system is normally located further from the dish (higher f/D ratio) to ensure proper thermal impedance matching between the parabolic dish and the solar receiver (aperture and cavity). It was said that, in technical terms, a satellite dish has a lower f/D ratio (focal point closer), while the f/D ratios nor-

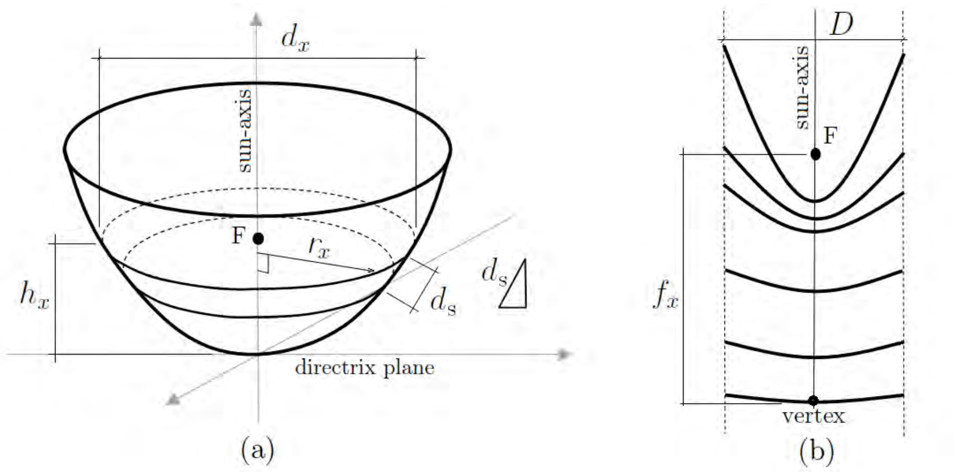


Figure 14.1 Parabolic elements with (a) parameters defining a circular differential strip and (b) flatter curves for increasing f/D (Stine and Geyer, 2001).

mally used in concentrated solar dishes are typically around 0.6, and in satellite dishes this ratio can be as low as 0.3 or lower. For parabolic troughs, the dish shapes may be deeper (lower f/D ratio) as the heat is focusses on a linear pipe and not on a semi restricted aperture cavity sunlight entry point.

In this discussion we shall assume a parabolic constant of $f/D = 0.6$ for solar parabolic dish shapes, which will be used as basis for the discussion and examples (Prinsloo, 2014*b*). For parabolic troughs, the same explanations and formulas hold, but the optimal f/D ratio may be different. Readers are referred to the book "Power From the Sun" (Stine and Geyer, 2001) on the following link to study the technical details related to the choice of the parabolic constant or f/D ratio `www.powerfromthesun.net`.

14.3 Parabolic Dish Shaping and Calculations

The main challenge for most readers is not to understand the parabolic shapes and curves (shown in the previous section), but how to use the parameters in reverse. That is, given a selected dish size and parabolic constant or f/D ratio, how does one practically shape material or a space frame for a parabolic dish in three dimensions.

It is actually not very complicated to design and fabricate your own parabolic dish. The answer lies in the graphical illustration of Figure 14.2. It shows that a parabolic dish can be constructed by way of the selective integration of imaginary differential ring-like strips/curves for the same parabolic curve into a compound structure Figure 14.2. This parabolic curve integration can either be a discrete integration (i.e. fixing separate sections on the same frame) or a continuous integration (i.e. forming or pressing material to shape a continuous dish within the height constraints of the discrete imaginary sections).

Figure 14.2 shows one way of shaping a parabolic dish for a given diameter D size and f/D ratio, by way of fabricating a dish shaping jig to define height levels above the ground plane for different radius sections of the dish component. This can be defined as shaping a parabolic curve by way of placing height restrictions on imaginary circular differential strips of the parabolic curve (Prinsloo, 2014*b*). Exactly the same method can be used in

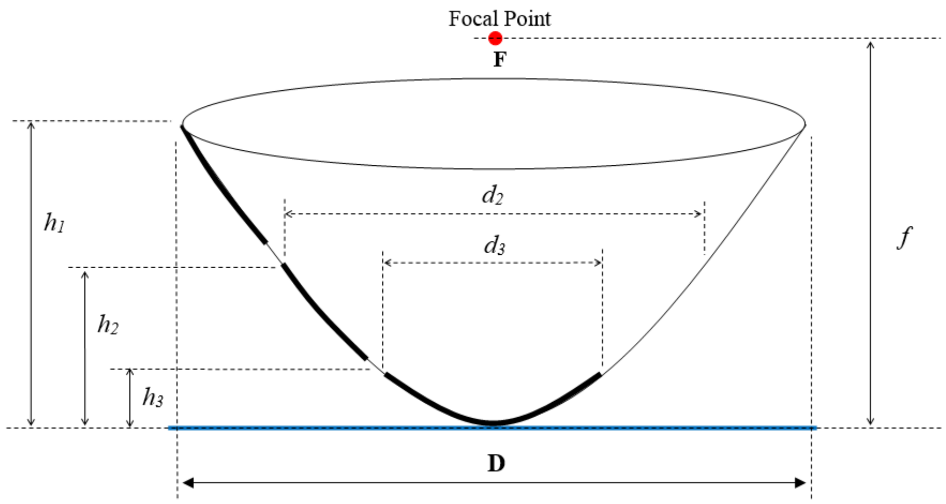


Figure 14.2 Shaping a parabolic dish for a given diameter D size and f/D ratio, in terms of defining height restrictions on imaginary circular differential strips (Prinsloo, 2014*b*).

fabrication a parabolic curve for a solar trough (for its given diameter D size and f/D ratio).

The parabolic equation in Equation 14.1 (Stine and Geyer, 2001) can now be engaged in a process to select the height for every circular subsection of the parabolic dish at certain radius elements (sub-diameter) of the dish. A summary of parabolic formulas is listed on this link `http://www.montgomerycollege.edu/Departments/cadtecgt/es100c/antenna.pdf` (Montgomery College, 2014). In the illustration of Figure 14.2, three imaginary parabolic sections jointly guarantees an optimally shaped parabolic dish geometry in a fashion that describes a perfectly shape parabolic dish or curve. The height levels for each of these sections are computed by selecting three (or more) radius sections (i.e. D, $D/2$ and $D/3$) and then using Equation 14.1 to compute the height of each section h_x as illustrated in Figure 14.2.

$$h_x = d_x^2/16f \tag{14.1}$$

With the dish facing upwards from the ground (i.e ground as parabolic directrix plane), the height parameters h_1, h_2 and h_3 are measured upwards from the base (parabolic vertex) of the parabolic dish as shown in Figure 14.2. These parameters are key in ensuring that the shape of the curve fits the parabolic curve as the parameter $h_x(x = 1, 2, 3, ..n)$ represents the height of the upper-outer edge rim of each respective (x) parabolic segment above the vertex flat plane.

The dish/curve shaping process thus starts with a centre/inner ring as first parabolic segment with a conventional parabolic constant (say $f/D = 0.6$). The same f/D parabolic constant values should subsequently be used in the computations for the second and third circular array elements, with values such that the basis of the outer-edge of each subsequent parabolic ring can be shaped relative to its height (h_x) from the ground plane (parabolic directrix plane).

Remember that the size of the dish (in particular the parameter D) determines the total amount of energy that can be harvested by the dish. Roughly, one square meter of parabolic dish area is required for every kW of solar energy to be harvested (Stine and Geyer, 2001). Knowing that the area of a parabolic dish is calculated as $A = \pi \times (D/2)^2$, and knowing that the solar thermal energy levels is around 1 kW/m^2 when it reaches the surface of the earth (Duffie and Beckman, 2006), the diameter D size of the dish can roughly be calculated from the required kW_t thermal energy as follows:

$$D_{min} = 2 \times \sqrt{\frac{kW_t}{\pi}} \tag{14.2}$$

The fabrication trick is basically to understand the the shape of the parabolic dish of diameter size D begins in the centre (parabolic vertex or eye), working outwards towards the outer edges. If the centre of the dish sits on the ground plane, then all one actually needs to know is what is the height of the outer edge of the cylindrical elements of the dish from this ground plane upwards. Figure 14.3 shows fabrication jig devices for shaping a parabolic dish (green) with a given diameter D size and f/D ratio. The jig pillars (blue) to shape the parabolic curve (green) is defined in accordance to Equation 14.1.

Figure 14.3 thus shows two parabolic dish shape fabrication options. In the first, the shaping jig pillars may stand upright to embed the to-be-shaped material (reflective material or its mould or structural support) on the inside of the pillars Figure 14.3(top) (use Equation 14.1 to determine h_1, h_2 and h_3). In the second, the shaping jig pillars may stand upright to embed the to-be-shaped material on the outside over the pillars Figure 14.3(bottom) (in this case use Equation 14.3 to determine h'_1, h'_2 and h'_3).

$$h'_x = \frac{D^2}{16f} - \frac{d_x^2}{16f} \tag{14.3}$$

For a parabolic dish shaping, the jig pillars stands upright in circles at selected radius $(d_x/2)$ measured from the centre of the parabolic dish (vertex point) outwards. For parabolic trough shaping, the pillars would be lined up in rows, once again measured from the centre portion of the parabolic through vertex, measured outwards at radius distance $(d_x/2)$.

Although the examples in Figure 14.3 above demonstrate only three rows of pillars for parabolic dish shaping, the reader can imagine that a larger number of pillar rows may be defined (smaller $d_x/2$ increments used in Equation 14.1 $f(d_x/2, h_x)(x = 1, 2, 3, ..n)$) to ensure greater accuracy. In high accuracy applications, a router may be used to cut the parabolic dish shape or mould thereof out of wood or metal, in which case the parabolic dish shape may be programmed into the routing device through CAD programs such as Solidworks (Solidworks, 2014), AutoCAD (AutoCAD, 2014) or similar design software.

For those who need a more practical example, lets consider the blue jig device in Figure 14.3(bottom) to demonstrate (see also this reference (Zhu, 2002)). Imagine cutting a flat circular piece of paper or sheet of resilient reflective material, and laying it over the top of the jig device (blue pillars) in Figure 14.3(bottom). The centre of this circular disk is then fixed to the top the centre (longest) pillar of the circle. A parabolic shape can now be realised by embedding circular or concentric sections of the sheeting downwards, to embed the material cover wards the ground, each time with the correct distance (h_x) from the ground to adhere to the parabolic shape (Equation 14.1).

The illustration in Figure 14.4 shows examples of the manufacturing of the mould for the composite dish for the South African Square Kilometre Array SKA project (SKA, 2007). This is an example of a system for shaping a parabolic dish for a given diameter D size and f/D ratio in terms of upright jig pillars to shape the parabolic curve. In this

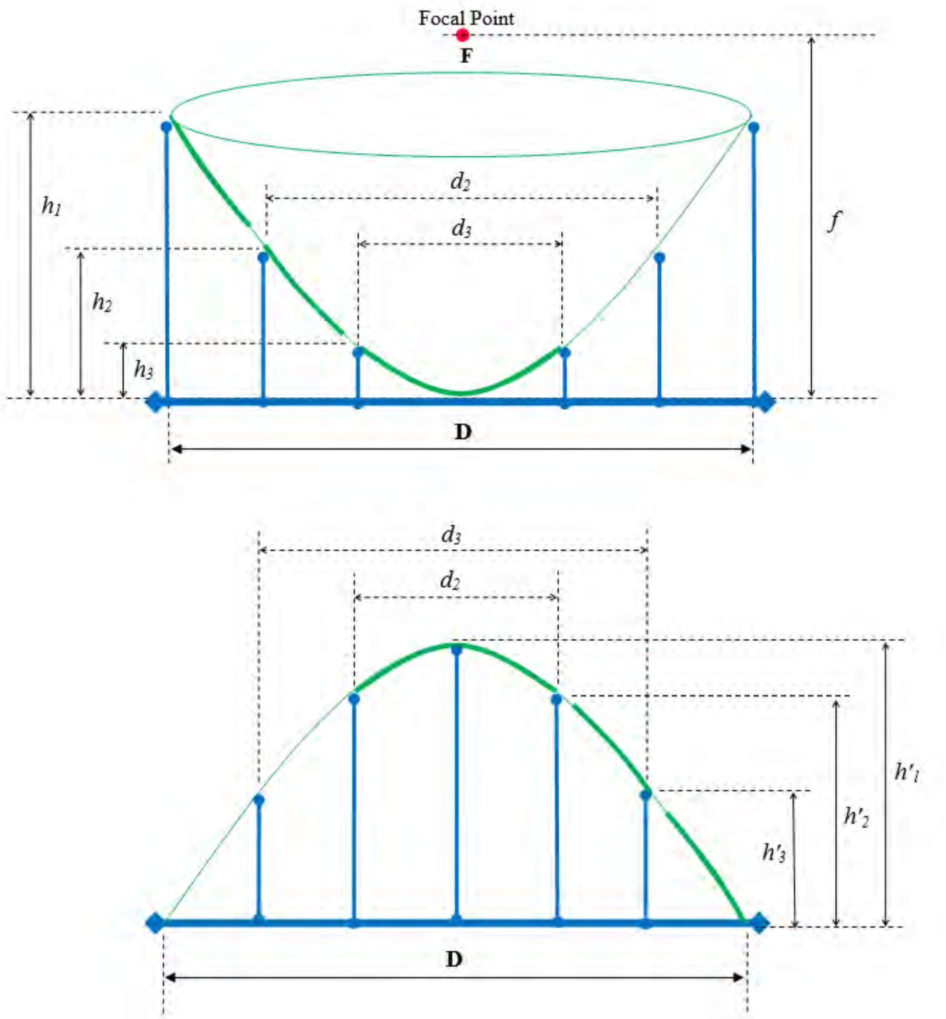


Figure 14.3 Shaping a parabolic dish (green) for a given diameter D size and f/D ratio, in terms of defining jig pillars (blue) to shape the parabolic curve. The shaping jig pillars may be fabricated to embed the to-be-shaped material over the pillars (bottom) or inside the pillars (top).

example a mould is also shape to place over the pillars since the dish has a very large diameter.

14.4 Choice of Parabolic Shapes for Solar Harvesting

The parabolic dish is not only the largest component of the concentrated solar power system but it is also the most sensitive and mathematically complex component. In conceptualising a concentrated solar power system, the parabolic dish design should cater for the fabrication of the dish as modular units which can be packaged into a number of smaller more easily handled boxes for transport to a delivery area. At the same time, the dish de-

Figure 14.4 Example of a system for shaping a parabolic dish for a given diameter D size and f/D ratio in terms of upright jig pillars to shape the parabolic curve. In this example a mould is also shape to place over the pillars (image right) (SKA, 2007).

sign needs to cater for ease of assembly and installation at an installation site, without the use of complex optical alignment instruments.

Prinsloo (Prinsloo, 2014*b*) discussed the faceted or segmented ring-shaped solar reflector design developed by the IITM (Reddy and Veershetty, 2013) as well as the improvement (to flatten the mirror elements) designed by the Infinia Corporation (Infinia, 2012*a*) (see Figure 14.5(a,b) respectively). Some of these designs (Figure 14.5(a,b)) offer structural benefits as it includes an air gap between the multi-segment parabolic faceted rings (elements forming the inner and outer dish sections) which inherently helps to reduce the windload on the dish structure and mechanical actuator systems.

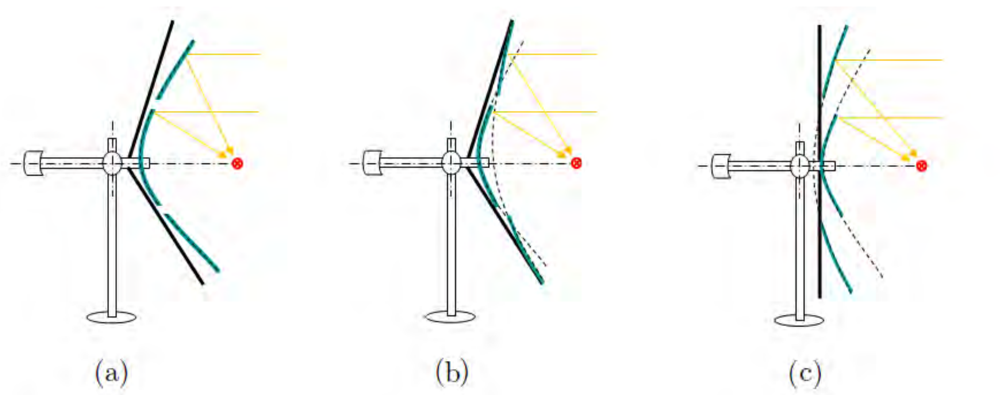


Figure 14.5 Circular cone-shaped load bearing structure to support (a) conventional parabolic dish, (b) staggered parabolic dish, and (c) flat load bearing structure with compact staggered parabolic dish (Reddy and Veershetty, 2013)(Infinia, 2012*a*)(Prinsloo, 2014*b*).

Such type of parabolic dishes offer the opportunity for modular fabricated with individual segments which could be packable in boxes for transportation and assembly at a remote installation sites. It is also known that Fresnel-type dishes are ideal for deployment where compact, lightweight and flatter structures are required. The opportunity exists to start with the same cone-shaped load bearing structure of a continuous parabolic dish, but to stagger Fresnel-type parabolic reflector elements onto the cone in order to flatten the cone structure (Figure 14.5(b)).

The Fresnel type design, such as the rotating parabolic curve on a circular flat-plane load-bearing structure (Figure 14.5(c)), would greatly simplify the remote installation. The design presents non-complex procedures to simply assemble a circular support frame from triangular-shaped supporting ribs supplied in a kit form (flat load bearing structure kit), followed by the fitting of reflective panels (individual rugged reflective metallic elements) in differential parabolic ring patterns.

To expedite and simplify the installation of the parabolic dish at remote rural sites, the Fresnel type parabolic dish configuration further comprises of modular parts, including a flat (lightweight) load-bearing structure fitted with an array of multiple parabolic reflector ring surfaces. The reflecting surfaces can be shaped/moulded as composite panels, or individual mirror petals can serve as optical reflecting surfaces (Figure 14.6).

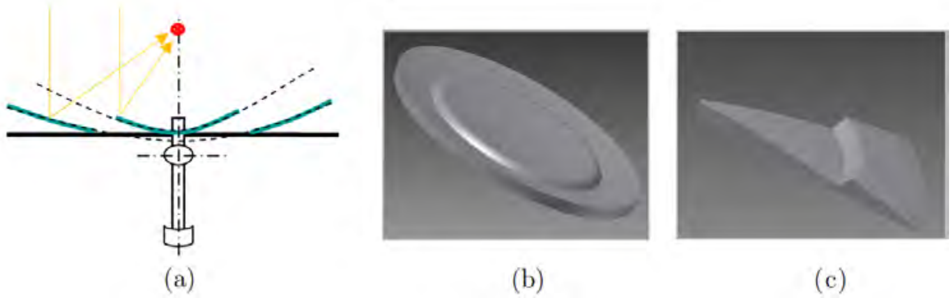


Figure 14.6 Parabolic design configuration, including (a) flat basis fitted with (b) curved composite material panels or (c) moulded reflective elements.

The support structure of the dish would be mounted onto the balancing boom of the mechantronic platform (Figure 14.6(a)) and has utility as a carrier structure for the concentrating (flat or slightly-curved) mirror facets. Multiple mirrors or a thin film of reflective material reflects and focus the solar energy onto the solar receiver. Alternatively, the flat frame can be fitted with reflective material in the form of one or more segments of moulded composite material panels, aiming to further reduce the extent of field work assembly.

14.5 Fresnel Type Parabolic Dish Shaping

In large diameter point-focussing solar concentrator reflectors, a continuous parabolic dish is not ideal. The slope angle of the parabolic curve gets very large further away from the parabolic vertex, meaning that a large volume of dish material and weight hangs over onto the sun-axis of the balancing boom, causing an uneven weight distribution and strain on the actuators drives. A continuous parabolic dish further complicates dish installation at remote sites, since great precision and competency is required to perfectly assemble a large continuous parabolic dish.

To meet the challenge of producing a simple, modular, easy-to-assemble and relatively flat parabolic dish structure suitable for rural applications was proposed by Prinsloo (Prinsloo, 2014*b*). This study proposed a compact multi-layered (Fresnel-type) dish configuration of the geometry illustrated in Figure 14.7. It comprises of an array of differential parabolic sections (1.inner, 2.middle and 3.outer ring sections) embedded onto a flat plane located at the vertex of main parabolic curve. This plane is orientated perpendicular to the parabolic sun-axis, intersects with the parabolic curve at the vertex, and is known as the parabolic *"directrix"* plane.

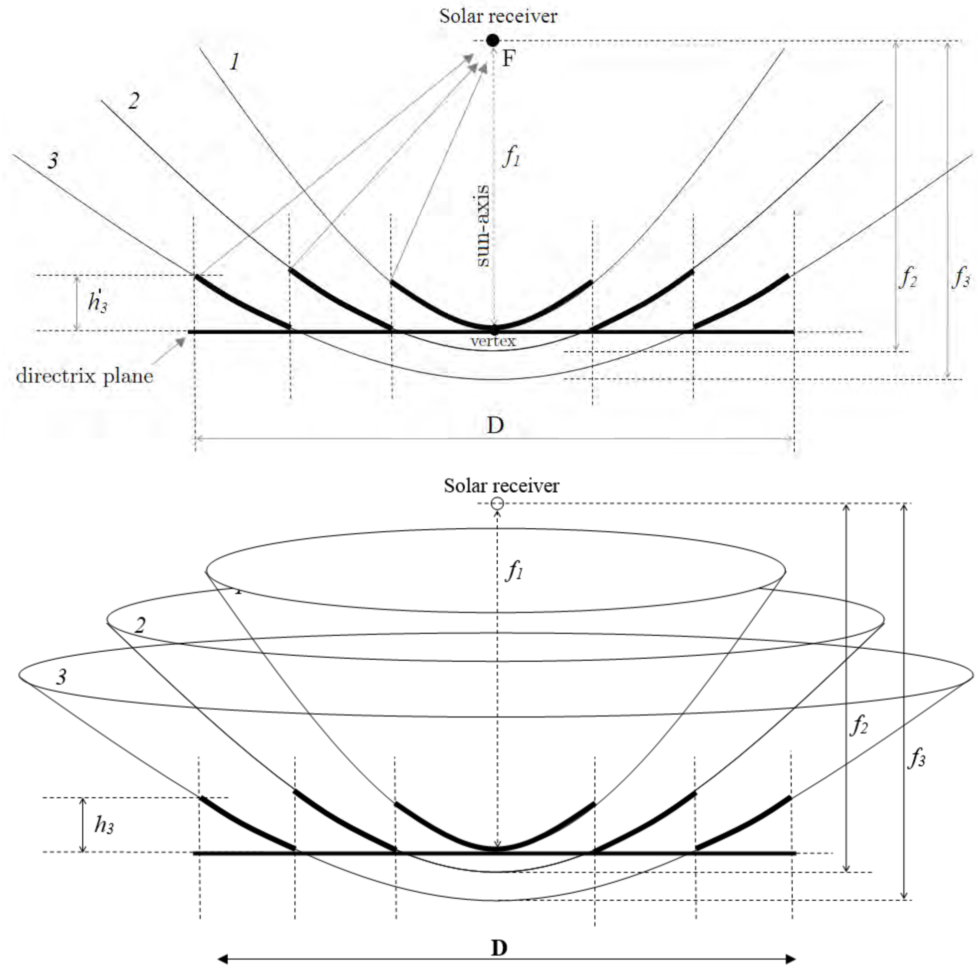


Figure 14.7 Orthographic view of a family of parabolic curves with identical parameters and focal point F, but with increasing f/D ratios, axially embedded onto the main parabolic directrix plane, serving as flat load bearing structure.

A simplified way to help visualise the geometric shape of this parabolic dish configuration (Figure 14.7), is to consider the surface of a conventional continuous parabolic dish being axially sliced into an series of circular differential strips/rings (Figure 14.1). These truncated differential ring sections are then collapsed and embedded onto the directrix plane of the main parabolic curve (Figure 14.7), which now serves as the "load bearing structure" for the proposed dish configuration.

Mathematically, this dish configuration can be described in terms of the parameters of an array of truncated sections of parabolic functions of the same family, parabolic functions with identical parameters but varying parabolic constants (f/D ratios). Parabolic equations can thus be used in the selective integration of differential ring-like strips/curves from members of the same parabolic family into a compound structure Figure 14.7, while retaining a common focal point (F) through selected parabolic ratios (f/D).

Parabolic equations can now be engaged in a mathematical iteration process to select a set of three parabolic family members, which jointly guarantees an optimally flat parabolic dish geometry in a fashion that describes three reflective circular parabolic arrays embedded onto a flat load bearing structure (Figure 14.7). This process starts with a centre/inner ring as first parabolic segment with a conventional parabolic constant of $f/D = 0.6$ (Stine and Geyer, 2001). Increased f/D parabolic ratio values should subsequently be computed for the middle and outer circular array elements, with values such that the basis of the inner-edge of each subsequent parabolic ring can be mounted flush onto the flat load bearing structure (Figure 14.7), while at the same time ensuring optimal physical separation from one array element to the next (ring-like air gap divisions between the three parabolic ring elements) to help minimize the effect of inter-element shadowing. Moreover, the selected set of three parabolic family members should at the same time guarantee an overall dish reflective surface area of A=12 m^2, for the system to deliver a solar collection capacity of 12 kW_t (also taking into consideration Stirling module optical shadowing losses). The complexity in optimally selecting three parabolic member sets to balance all of the requirements calls for an iterative process that involves the use of differential parabolic equations ((Stine and Geyer, 2001)):

$$h_x = d_x^2/16f_x \tag{14.4}$$

$$A_x = \pi d_x/12h_x^2 \times \left[(d_x^2/4 + 4h_x^2)^{3/2} - d_x^3/8\right] = 12\ m^2 \tag{14.5}$$

The parameters (d_x, f_x, h_x, h'_x) for the inner ($x = 1$), middle ($x = 2$) and outer ($x = 3$) parabolic dish elements was calculated iteratively through Equation 14.4 and Equation 14.5. The parameters h'_1, h'_2 and h'_3 are key in ensuring the flattest possible dish structure, as it represents the height of the upper-outer edge rim of each respective parabolic segment above the load bearing plane (see Figure 14.7). Table 14.1 lists the parameters for the selected set of parabolic family members. Interesting to note is that inter element- and Stirling unit- optical shadowing losses increased the overall diameter of the compound dish from $D = 3908\ mm$ (conventional parabolic) to $D = 4274\ mm$, allowing for the system to maintain the specified collector capacity of 12 kW_t.

For example, a parabolic dish for a solar collector with a capacity to collect 12 kWt thermal energy during MSA requires a calculated parabolic solar reflector area of around $A = 12\ m^2$ (1000 W/m^2) (Duffie and Beckman, 2006). In a conventional continuous parabolic dish, this would would have equated to an outer diameter of $D = 3908\ mm$. The resulting optical shadowing losses caused by the Stirling module and collapsed inter-ring element edges on one another, increases the diameter of the proposed compound dish from $D = 3908\ mm$ to $D = 4274\ mm$, allowing for the system to maintain the solar collection capacity of 12 kW_t.

Table 14.1 Parabolic ring element parameters (Figure 14.8).

Parameter	**Inner ring** ($x = 1$)	**Middle ring** ($x = 2$)	**Outer ring** ($x = 3$)
d_x	2063.46 mm	3655.27 mm	4274.00 mm
f_x	2400.00 mm	2520.00 mm	2600.00 mm
h'_x	58.96 mm	176.87 mm	184.61 mm

Figure 14.8 presents a two-dimensional CAD drawing, illustrating the multi-segment dish structure with selected dimensions (d_x, f_x, h'_x) computed above. This drawing shows how the three segments in the three element dish structure ensures a relatively flat compact parabolic dish configuration with uniform flux profile on the target plane. In order to simplify manufacturing and on-site installation, the inner, middle and outer parabolic ring elements can be fabricated as flat reflective surface panels that mounts onto the flat ribbed frame (load bearing structure), providing a slightly broader flux profile (533 mm x 533 mm) at the solar receiver area (Figure 14.8).

By fabricating each tile in such manner that it represents a linear approximation of each parabolic segment, multiple tiles can be packed and mounted in a circular fashion in order to approximate each of the three parabolic ring elements.

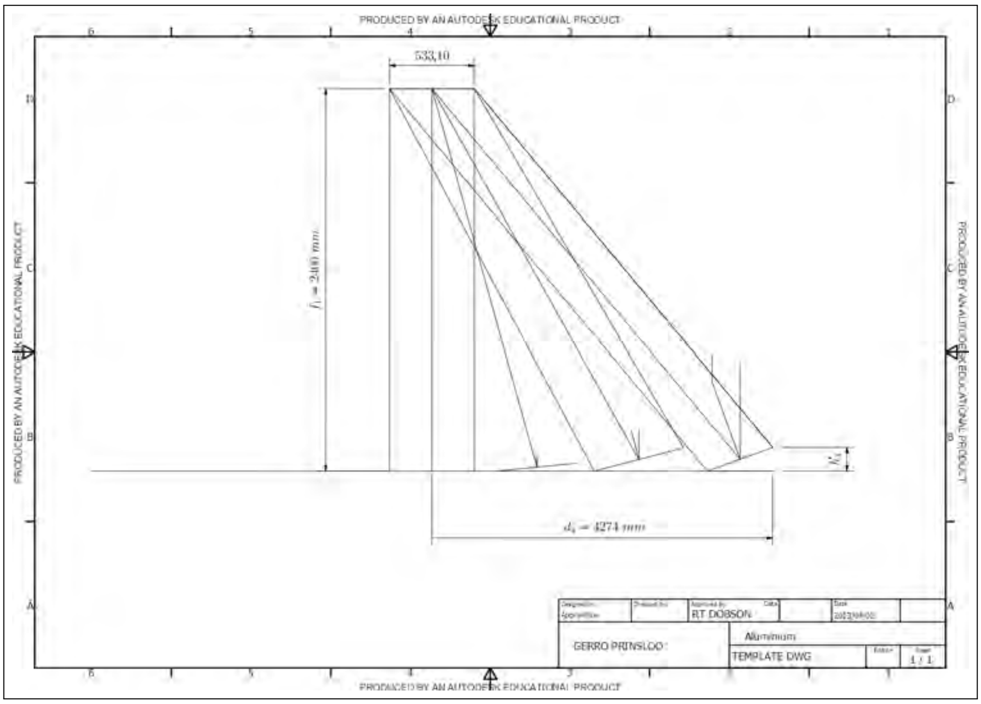


Figure 14.8 Parabolic dish elements and calculated segments at different f/D ratios to concentrate on the same focal area.

It should be noted that, in the CAD designs, the designer chose higher f/D parabolic ratios for the outer parabolic elements or circular arrays, with values such that the light reflection from each (collapsed) dish element converges on the same optical focal point (solar receiver). The values for the parabolic f/D ratios of the outer arrays are computed such as to ensure that the basis of the inner-edge of the outer parabolic rim is mounted flush onto the flat load bearing structure (ensuring an optimally flat dish structure.

Figure 14.9 shows the engineering prototype of the physically assembled dish arrangement in terms of the dimensions detailed in the CAD drawings, with (a) the construction of the prototype dish fully assembled; (b) the assembly of one of the modular parabolic dish rib segments; and (c) the hub or inner flange of the load bearing structure through which the dish structure will be mounted onto the actuator means. The resulting less-curved outer sections of the dish structure would potentially assist in ensuring a lower probability of dust fixation on the mirrors on the overall dish, helping to overcome a problem that is typically experienced with parabolic systems in agricultural and rural areas. This design configuration aims to simplify assembly, installation and reduce field maintenance in remote sites.

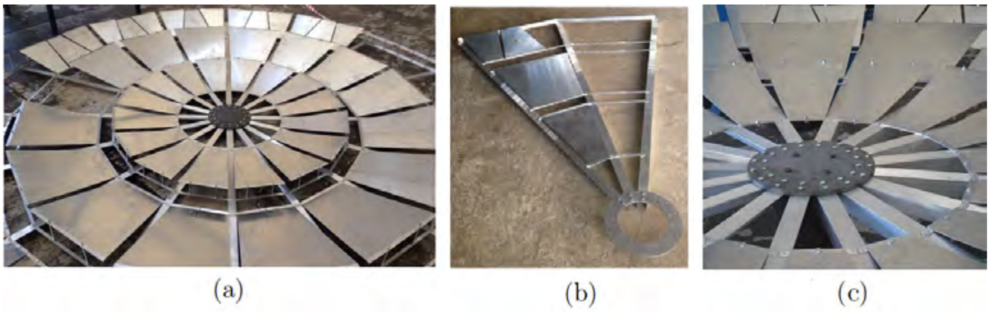


Figure 14.9 Physical construction of proposed parabolic dish, showing (a) the reflector array ring elements, (b) modular dish segment, and (c) dish inner hub/flange.

To compensate for the optical shadowing losses caused by the physical orientation in the collapsing of the parabolic ring elements onto the same plane, and the resulting ring-like air gaps between the parabolic ring elements in the dish face (Figure 14.9), the dish diameter needs to increase from 4 m to 4.2 m (D=$\sim$4.2 m) to allow for the system to maintain the same solar collection capacity of 12 kW$_t$. However, thanks to these ring-like air passages dividing or breaking the continuous surface of the parabolic dish face, the dish structure and mechanical actuator systems may be experiencing less load strain from head-on winds and wind gusts.

14.6 Fabricating Solar Reflector Solar Parabolic Dish from Flexible Material

A solar parabolic dish or parabolic trough is normally expensive to fabricate and difficult to transport since the concentrator mirrors needs to be relatively precise and remain intact during transportation. Li and Dubowsky (Li and Dubowsky, 2012) developed a new concept for the design and fabrication of large parabolic dish mirrors in which the dish mirrors are formed from several optimal-shaped thin flat metal petals with highly reflective surfaces. The rear surface of the mirror petals hold thin layers shaped as reflective petals to form into a parabola when their ends are pulled toward each other by cables or rods. A Finite Element Analysis analytical model was used to optimize the shape and thickness of the petals, permitting for the flat mirror elements to be easily fabricated and efficiently packaged for shipping to field sites where they can be assembled into the parabolic dish concentrators (Li and Dubowsky, 2012).

Any parabolic dish concept should have the potential to provide precision solar parabolic solar collector at a sustainable cost. In general, the shaping or fabrication of a parabolic dish or parabolic trough depends on the type of design. In this section we will deal only with the simplest version, namely to shape a parabola as they are easy to formulate and to fabricate through proper shaping. These dishes remain popular because they provide a sharp focus compared to other types of reflectors, but at the same time it was very sensitive to even a slight change in the position of the sun and hence the use of such reflectors means constant tracking.

With many of the CAD programs (Autocad, Solidworks) the designer can specify any appropriate combination of parameters to define the parabola such that the parabola is not constrained by relations. With these platforms, the designer have the advantage that if one or more parameters are changed, the other parameters update automatically. Instead of discussing each design, it will be simpler to provide the user with some links to CAD designs for parabolic dish shapes, starting for example with the question on How to create a parabola with Solidworks http://help.solidworks.com/2013/English/SolidWorks/sldworks/t_Sketching_Parabolas.htm and http://help.solidworks.com/2012/English/SolidWorks/sldworks/Sketched_Parabola.htm?id=e7fe059bbd084d549bde00491d1b2d4b (Solidworks, 2014).

The are also models for designing a cost-effective carbon composite reflector dish and modular manufacturing method forms different dish sizes with near mirror-perfect reflective surfaces, without resort to one-off tools. Examples are presented on these links http://www.madehow.com/Volume-1/Satellite-Dish.html and http://www.compositesworld.com/articles/cost-effective-carbon-composite-reflector-dish(2). Other mate-rial that may be used in concentrating solar tracker systems are carbon fiber matrix and resin systems as well as glass fiber composites (Mouzouris and Brooks, 2010).

A discussion on this AutoCAD forum http://forums.autodesk.com/t5/inventor-general-discussion/parabolic-reflector/td-p/2976844 (AutoCAD, 2014) and a 3D Printer design on this link http://sustainabilityworkshop.autodesk.com/products/fea-lightweighting-uss-solar-tracker and design steps on this link http://www.instructables.com/id/How-to-build-a-strikeheliostatstrike-paraboli/.

Once a dish configuration and shape have been defined, the designer can analyse the optical performance of the reflector using simulation tools such as SolTrace (NREL, 2014*f*) or Schetchup plugins (Miller, 2014). Soltrace utilizes the Monte Carlo ray-tracing methodology to trace sunrays through various optical interactions it encounters. The code is written in C++for Windows and Mac based operating systems, while a plug-in is available for the free solid modelling tool Trimble SketchUp for designers who wish to graphically design and save optical geometries for SolTrace analysis.

Another plugin for Sketchup, the Light Ray Reflection Simulator Plugin (Miller, 2014), also allow a dish designer to graphically design and simulate the reflection on sun rays from a solar concentrator surface. Experiments can be made with different types of solar collector designs simply by drawing their surfaces as well as lines to represent sunrays and run the plugin. Figure 14.10 presents examples of sunlight ray tracing analysis and simulations for a Fresnel dish (left), parabolic dish (center), and linear parabolic dishes (right) (Miller, 2014).

The ray tracing simulation in Figure 14.10(left) is for the Fresnel solar cooker on this site http://www.sunspot.org.uk/ed/. The plugin also allows to focus the sunlight as angled sunrays through the hours of the day, and the illustration (bottom left) shows the rays for a Fresnel parabolic dish that is not being aligned to face the sun.

A solar mirror is typically used to gather and reflect solar energy in solar thermal systems and concentrating solar power dish systems for renewable green energy. A solar mirror can be made from a glass substrate wherein the mirror surface is coated with highly reflective layer such as silver or aluminum. Such metal reflective coating is very thin super sensitive layer protected with layers of paint including anti-UV resistant lacquer to ensure highly reflective Solar Parabolic Mirrors for concentrating solar power or thermal plants (Xinilogy, 2014). The process of glass bending and coating are cardinal determinants of the quality, performance and durability of parabolic mirrors (ThermoSolGlass, 2014).

Mooney expressed the opinion that rhodium plating (extremely expensive) is one of the best reflector coating materials (Mooney, 2009). Silver and aluminium are more economi-

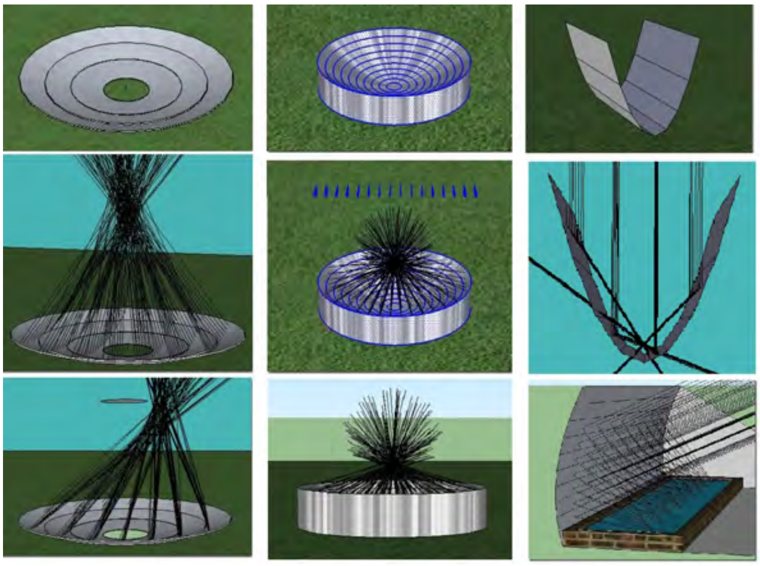


Figure 14.10 Examples of sunlight ray tracing analysis and simulations for a Fresnel dish (left), parabolic dish (center), and linear parabolic dishes (right) (Miller, 2014).

cal options, but may be subject to deterioration and tarnishing and it would need some kind of highly transparent and heat and UV-resistant organic coating. For metal coating, the designer can consider aluminum vacuum metallizing on polycarbonate sheets. "Aluminum vacuum metallizing is a good decorative finish, but the usual organic topcoats might not be as optically transparent and UV resistant" (Mooney, 2009). Lavagna also describes a process for improving the reflectivity of reflective surfaces of antennas and parabolic dishes (Lavagna, 2013).

The other option available for parabolic dish solar concentrator systems is to use a highly reflective polymer coating. One such film available is ReflecTech-Plus, a mirror film has high reflectance in the wavelength range for sunlight (Reflectech, 2014). This film is durable against ultraviolet UV radiation and the material have been tested to outdoor exposure in conditions where natural sunlight was concentrated 50 X while sample exposure temperatures were maintained at 30°C and 60°C to accelerate degradation mechanisms. A range of other film coatings for parabolic dishes are discussed on these references (SolarMir, 2013)(ReynardCorp, 2014).

Other than designing and fabricating your own parabolic dish from fibreglass composite materials or metallic mesh, commercial do-it-yourself (solar) tracker kits and dish assemblies are also available that may be suitable for solar tracking applications. See discussion in Section 2.5 on the use of satellite dishes for solar harvesting. For example, self assembly prime focus parabolic dishes are available as a DIY kit with a variety of F/D ratios (0.35, 0.40, 0.45 and 0.5), while parabolic mesh dish kits are available for a range of diameter dimensions (1 Meter, 1.2 Meter, 1.5 Meter, 1.9 Meter, 2.4 Meter, 3 Meter (F/D 0.40 and 0.45) and 4.5 Meter (F/D 0.45)) (RFHamdesign, 2014). More details are available on this link `http://www.rfhamdesign.com/products/parabolicdishkit/index.php` (RFHamdesign, 2014).

There are various other resources available on the internet to create a parabola and the reader can consult Section 24.21 of this book for a list of more resource links.

14.7 Summary

This chapter discussed solutions on how to shape the material so that it adheres to the seemingly complicated mathematical equations. The discussion was aimed at answering questions with practical answers by way of showing readers the practical meaning of the parameters of a parabolic curve and, more importantly, how to use these parameters ”in reverse” to shape material in the form of a parabolic curve in practice so that it is suitable for solar harvesting.

CHAPTER 15

COMPARING RENEWABLE TECHNOLOGY OPTIONS

15.1 Introduction

We are living in the age of the so called new ”energy vectors”, where a variety of man-made forms of energy (solar, hydrogen, biofuels, heat exchange fluids, electricity, etc.) allow for different forms of energy to be converted back into other forms of energy before, during or after transportation (Orecchini). The modern challenge in energy research is to focus on so called ”closed cycle” energy systems that aim to consume marginal resources with limited waste. By structurally integrating energy vectors into the same energy system (i.e. to re-use residual heat), and by exploiting renewable resources in the energy mix, these systems are often able to operate at zero net energy (ZNE) (Stadler, Michael, Gonçalo Cardoso, Nicholas DeForest, Jon Donadee, Tomás Gómez, Judy Lai, Chris Marnay, Olivier Mégel, Gonçalo Mendes and Siddiqui, 2011)(Makundi and Rajan, 1999).

This trend already led to the development of so-called cogeneration systems that go by the names of trigeneration, quadgeneration, and polygeneration, described in limited detail in this chapter. Other popular terms commonly used for cogeneration systems are micro Combined Heat and Power (CHP or mCHP) or micro Combined Cooling Heating and Power (CCHP or mCCHP) systems. Micro systems are commonly associated with small packaged co-generation units that often distribute energy in networks such as a microgrid or smartgrid.

Because of the interaction between thermodynamic and electrical systems, these systems by nature are often complex to control and require integrated and intelligent control strategies. Modern stand-alone off-grid renewable energy systems further include smart-grid demand side control, that also require an intelligent digital electronic control approach. This opens up opportunities for novel research work in which different technologies can be brought together.

15.2 Cogeneration in Trigeneration, Polygeneration and Quadgeneration

Solar cogeneration systems refers to those systems that not only generates electricity or electrical power from solar energy, but also other forms of energy such as steam, cooling, heating and power any any combination depending on the system configuration. A cogeneration system works with a wider spectrum of energy (i.e. added cooling, heating, steam capacity), allowing for novel and alternative integrations amongst the solar energy storage, solar power generation and energy/power management subsystems.

Combining thermal heat and storage in a single cogeneration system offers interesting power generation, solar cooking and cold storage options that substantially increases the efficiency of the solar tracking or solar power system (Badea and Voncila, 2012)(Bracco *et al.*, 2014)(Chen, 2013)(Friesth, 2014). Badea's book Design for Micro-Combined Cooling, Heating and Power Systems presents a preview or current technologies and projects on micro-Combined Cooling, Heat and Power systems (mCCHP systems) and will help to understand the difference between centralized and decentralised cogeneration systems within the context of Stirling engine based mCCHP designs (Badea, 2015).

Figure 15.1 shows the Sankey energy flow and energy balance diagram in a typical trigeneration system, in certain contexts also known as a triple generation system or a polygeneration system (Trigeneration, 2014). In the trigeneration configuration, the system automation control solution manages the production of electricity while recovering heat generated by the thermal plant to produce cooling energy for chilling water for air conditioning or cooling units (Trigeneration, 2014).

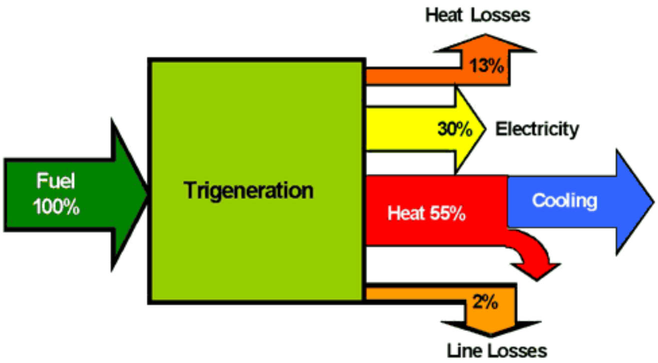


Figure 15.1 Energy balance diagram in a typical trigeneration system with balanced energy control (Trigeneration, 2014).

The values in the energy balance diagram in Figure 15.1 illustrates that trigeneration plants have the ability to conserve natural resources, which makes them very attractive in a variety of applications since they are extremely energy efficient. If its control system are optimized, then trigeneration power plants can be around 90% efficient, approximately 300% more efficient than centralized power plants (which on average is only around 27-40% efficient) (Trigeneration, 2014).

Solar cogeneration systems operate by way of recovering most of the energy contained in the thermodynamic streams of the system (Neuhaeuser, 2009). By utilising solar heat or thermodynamic streams in such configurations (in conjunction or to replace diesel/biogas engine heat), electricity co-generation can integrate steam cycles or an ORC cycles or any other thermodynamic or thermochemical conversion process.

Consider the simple example of a cogeneration system in terms of the heat generated by a diesel/biogas power generation plant, as illustrated in Figure 15.2, wherein the waste heat (exhaust heat and radiator cooling) can be utilised to drive a Stirling engine, microturbine or an organic-rankine cycle (ORC) engine to generate more electricity, while the waste heat from this process is in turn used to generate a refrigeration cycle for producing cold water, while the last bit of waste heat from this cycle in turn heats water for household consumption (Invernizzi *et al.*, 2007).

The example of the trigeneration system for which the energy flow diagram is illustrated in Figure 15.2, shows a very compact and integrated cogeneration system known as the G-box 50 module and is developed by 2G Energy (Grotholt, 2014). This example illustrates that power generation by-products can be an equally valuable source of fuel.

Many literature sources refer to a trigeneration system as a triple generation system or as a micro combined, cooling, heat and power (mCCHP) system. The term changes to mCHP if the micro cogeneration system configuration can only generate combined heat and power (CHP). mCCHP trigeneration is an effective and pragmatic solution capable of meeting the energy supply needs in a rural household, small village, islanded or environmentally conscious eco-estate environments. In such systems, thermodynamic and electrical subsystems should be properly modelled and intelligently controlled for optimal thermal exchange and heat transfer efficiency.

Whereas trigeneration describes the process of simultaneously generating of three forms of energy, namely cooling, heating and electrical energy from at least one energy resource.

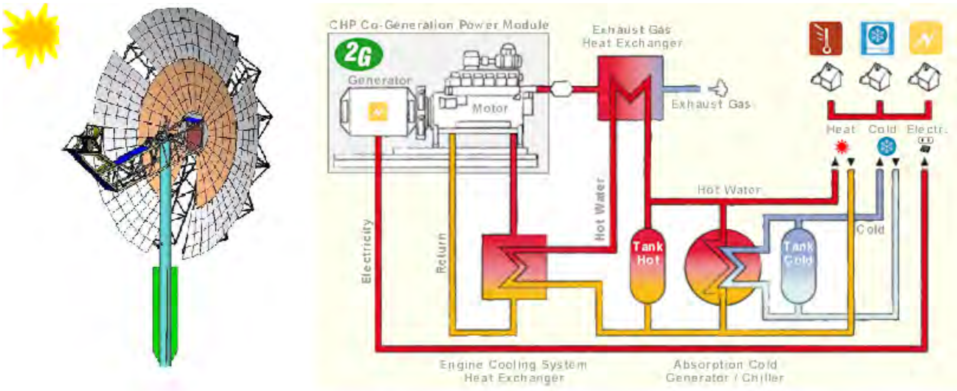


Figure 15.2 Example of a trigeneration system that simultaneously produces cooling water, hot water and electricity from diesel, biogas or biofuel heat (right), further illustrating that a concentrated solar tracker can serve as further fuel in this trigeneration process (left) (Grotholt, 2014).

Polygeneration systems involve a combination of conventional and new technologies for heating cooling and electricity production, but also other fuel sources such as for example biogas, biofuels and so forth (Bracco *et al.*, 2014).

In concepts associated with polygeneration, energy and power systems become more integrated, meaning that the polygeneration system configuration should be modelled as an integrated combination of the components and substructures, building a system level unit by connecting substructure models. This concept is a good platform for the integration of a variety of generally intermittent renewable energy resources (Blarke and Jenkins, 2013).

Examples of trigeneration and poly generations can be viewed on this link for Innova `http://www.innova.co.it/eng/catalog/products/trinum.html` and on this link for Qnergy `http://www.qnergy.com/products_overview`.

All of these integrated energy systems are known to offer significant improvements in overall energy delivery efficiency. This is because cogeneration systems offer the ability to achieve maximum energy utilization through multiple layers of waste/redundant heat recovery and subsystem integration.

When further fuelled from renewable energy resources, mCHP, mCCHP, and trigeneration micro power plants have the potential to be carbon neutral (operate at ZNE) and suitable for off-grid energy applications (Rosen, 2008)(Qnergy, 2013). This further means that such systems has the potential to produce energy with zero greenhouse gas emissions, which in turn makes it valuable to applications that seek to reduce energy cost and greenhouse gas emissions i.e. Eco-Estates (Sawubona, 2014).

Quadgeneration systems typically adds a fourth form of energy as output, such as for example delivering process heat or steam. Other quadgeneration system reduce the carbon footprint of the integrated system (up to 25% of the yield of a powerplant can be CO_2) by converting CO_2 into oxygen (Blarke, 2014). Certain quadgeneration plants are designed to produce food-grade CO_2 from certain bio-combustion processes. Such quad generated CO_2 can then be used in fizzy softdrinks or by the plants as a photosynthesis nutrient in recovering oxygen from CO_2. In this respect, the Village Farm concept is a good example `http://www.villagefarms.com/images/pdf/investorPressReleases/pressRelease032314.pdf`.

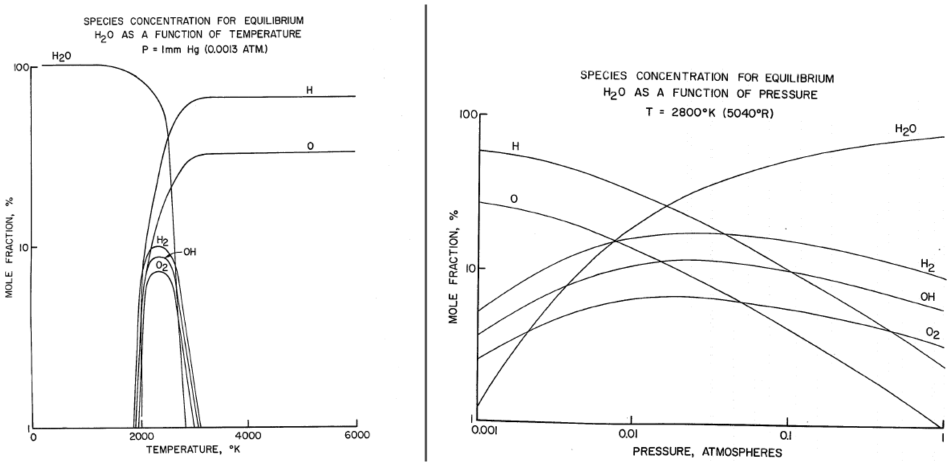


Figure 15.3 A system for the thermal dissociation of gaseous matter into its component parts using solar energy in a molecular beam skimmer (Pyle, 1983).

In terms of concentrated solar quadgeneration systems, thera may also be interesting applications for whihc solar thermal power are used. Solar photochemical detoxification technologies can provide environmental waste management solutions to destroy waste and ensure clean solar photochemical technology solutions (PSA, 2014*b*). The module devised of Pyle (Pyle, 1983) for thermal electrolysis of water into hydrogen and oxygen is also of interest. It uses concentrated solar energy for the thermal dissociation of molecules into their constituent parts, in accordance with the principles in Figure 15.3. For example, the module can be incorporated into a quadgeneration system and used as component in hydrogen production from methane or hydrogen and oxygen production from water using solar thermal energy at selected temperatures and pressures (Pyle, 1983). Such and other modules may in future prove to be valuable elements of concentrated solar quadgeneration systems still to be developed.

Bazmi and Zahedi presents an extensive review of the role of optimization modelling techniques in cogeneration and supply in sustainable energy systems (Bazmi and Zahedi, 2011). This article reviews existing literature as part of an analysis on the role of modelling and optimization as well as the future prospects of optimization as a tool towards sustainability. The study concludes that a holistic system engineering level approach provides a sound scientific framework to improve efficiency in integrated microgrid solutions. It is shown that control solution modelling and optimization have widespread application that can benefit user demand, system operations planning and resource allocation.

15.3 Microgrid and Smartgrid Distribution

Microgrids comprise low and medium voltage distribution systems with distributed energy sources, storage devices and flexible loads, operated connected to the main power network or islanded, in a controlled and coordinated way.

Figure 15.4 shows an application analysis for electrical power systems in terms of the size of the distribution network and the energy services associated with particular power generation systems and distribution capacity (EEP, 2014)(Schnitzer *et al.*, 2014). This illustration shows that when microgrids are combined with efficient generation and end-uses applications, they typically ensure lower price services. For example, microgrid size distribution would typically accommodate applications from the level of cellphone/mobile phone charging up to comfort and productivity energy services/application.

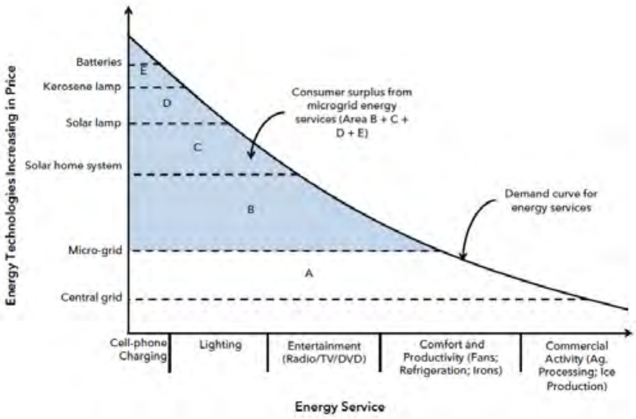


Figure 15.4 Price of energy services provided by energy fuels and technologies in relation to user requirements (Schnitzer *et al.*, 2014).

Co-generation and associated smartgrid distribution are also gaining confidence in the race for energy savings at many university campuses throughout the world (NREL, 2013)(Adene Energy, 2013)(Powell, 2011). One such initiative is in Europe, and illustrates the competitive advantages of trigeneration in reducing energy demand for tertiary sector buildings (Adene Energy, 2013). In this European Union (EU) initiative, the European Commission (EC) subsidises trigeneration systems in the tertiary sector for EU member states simply because of the excellent energy efficiency of such systems. The initiative proves to be especially successful in the tertiary sector at (hot) Mediterranean countries (Greece, Italy, Spain, Portugal), a project commonly known in the Mediterranean as TriGeMed, under the EU SAVE Energy Programme (Adene Energy, 2013).

At the heart of any smart microgrid is an energy management and control system. The performance of the complete infrastructure is influenced by this element, which function is to manage and schedule energy generated from microturbines, photovoltaics, and energy storage as an integrated system. An intelligent energy management and control system typically uses forecast data to optimize smart microgrid operation in terms of day-ahead scheduling. One example is the University of Genoa implementation that employs a Siemens microgrid module in a technology configuration that includes the Trinum trigeneration system (Delfino, F. Barillari, L. ; Pampararo, F. ; Rossi, M. ; Zakariazadeh, A. ; Molfino, P. ; Podesta, A. ; Venturin, A. ; Robertelli, 2014).

Throughout the world there is a need for continued research to improve the operations and efficiency in smartgrid technology, especially for smart microgrids. A company like Siemens considered the smartgrid problem complicated enough to put out an open call to challenge academic institutions, researchers and innovators from around the world to participate in its global smartgrid idea contest (Siemens, 2011*b*). Real Time Simulations, Demand Response and Control Monitoring featured prominently as research topic clusters in this contest, and highlights the prominence and importance of the present real time intelligent control simulation/synthesis research.

15.4 Cogeneration Equipment and Technology Picking

The first challenge in cogeneration and smart microgrid systems, especially in distributed renewable and solar energy generation configurations, is to pick the technology most suitable to the application and the environment. The intermittent nature of renewable energy resources availability makes this step crucial in planning system integration between solar thermal or electrical power and other systems, especially since power generation cycles and costs needs to be matched to dynamically varying user demand side requirements (Connolly *et al.*, 2010*a*).

This calls for mathematical optimization to find the best combination of technologies that would provide an optimum in terms of a selected criteria, for example the ability to deliver energy at a certain capacity, the optimum cost of electricity, the cost of heat, optimum system-level energy efficiency, ensuring a low carbon footprint, or any other chosen criteria.

In this respect, Blarke (Blarke, 2013) developed a software model named Compare Options for Sustainable Energy (COMPOSE). This is a very valuable energy-project assessment tool and allows for techno-economic evaluation of user-defined sustainable energy-systems allowing in which the user can compare selected energy technology options. COMPOSE includes an optimization algorithm that can identify the optimal operational strategy for a combination of energy cogeneration systems by minimizing the economic cost of heat and cooling production for each year of operation under constraint of annual and hourly deterministic projections for energy requirements, system capacities, carbon credits and cost of electricity and and gas (Rudra, 2013).

Figure 15.5 shows an example of the overall EnergyPLAN model that allows for the selection and simulation configuration for an overall energy system in terms of components. The user manual developed by Lund (Lund, 2007) gives step-by-step instructions on how to "input data into the EnergyPLAN model, perform exercises that give step-by-step training, and documentation containing the code and theoretical background of the EnergyPLAN model".

This model enables the user to analyse a user-defined energy system while simulating financial aspects in conjunction with renewable energy generation, thermal storage, energy conversion and mobile energy technologies. More details are available on the ENERGYPlan website (advanced energy system analysis computer model) `http://www.energyplan.eu/compose/`, where the model is described as a tool to "combine energy-project operational simulation models with the strength of energy-system scenario models in order to arrive at a modelling framework that supports an increasingly realistic and qualified comparative assessment of sustainable-energy options. The aim of COMPOSE is to assess to which degree energy projects may support intermittency, while generally offering a realistic evaluation of the distribution of costs and benefits under uncertainty" (Lund, 2007).

15.5 Cogeneration Control Optimization

A range of parameters can be recorded for optimization during an energy analysis process for a specific site, including the solar flux DNI, Air Mass, Energy Use Intensity, Life Cycle Energy Use and Cost, Renewable Energy Potential, Annual Carbon Emissions, Annual Energy Use/Cost, Energy Use: Electricity, Potential Energy Savings, Monthly Heating Load, Monthly Cooling Load, Monthly Fuel Consumption, Monthly Electricity Consump-

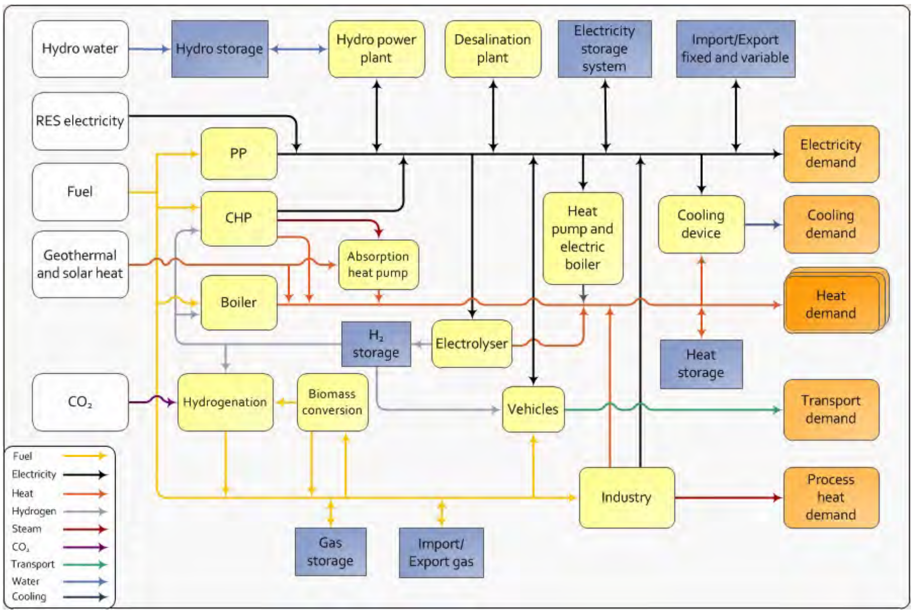


Figure 15.5 EnergyPLAN model allows for the selection and simulation configuration for an overall energy system consisting of components as illustrated (Lund, 2007).

tion, Monthly Peak Demand, Annual Wind Rose, Monthly Design Data, Annual Temperature Bins, Diurnal Weather Averages, Humidity, and so forth `http://help.autodesk.com/view/RVT/2015/ENU/?guid=GUID-51F923AF-836B-4B64-B9FA-BB8288A06004` (Autodesk, 2014*a*).

The DER-CAM model (Distributed Energy Resources Customer Adoption Model) is an integrated techno-economic and environmental simulation model that model aimed at optimization of technology integration and optimization (Stadler *et al.*, 2013). It runs on an online platform called WebOpt that allows the user to set up a system configuration for a particular site and set of technology. A schematic of the high-level information flow in the DER-CAM algorithm is illustrated in Figure 15.6.

Whilst the DER-CAM model can also advise the system developer on picking the optimal technology configuration mix for a certain user demand profile, the model is very popular for its ability to optimize the operational schedule for a particular technology mix and user demand profile. One of the outputs is a week-ahead schedule that advises any control system how the energy technology configuration should be operated based on specific site load and price information (Stadler *et al.*, 2008). This website presents more details on the DER-CAM model, its parameters, interfacing and operations `http://der.lbl.gov/der-cam`.

Whilst the focus of this book is biased towards solar and solar tracking systems, the user is referred to the literature for further information on cogeneration and optimization of cogeneration information `http://www.energyplan.eu/othertools/` and `http://www.osti.gov/estsc/catalog.jsp?Go=Search&pf=true&All=Y` as well as (Baños *et al.*, 2011)(Connolly, 2012)(Corbin, 2014)(ESTSC, 2014).

Finally, Connolly *et.al* (Connolly *et al.*, 2010*b*) published a review of computer tools for analysing the integration of renewable energy into various energy systems. It described

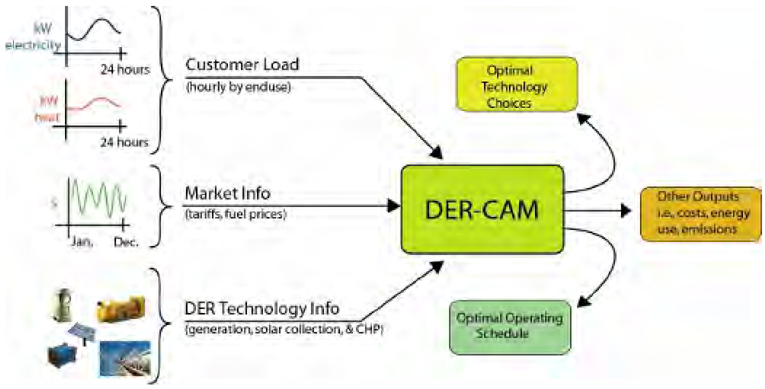


Figure 15.6 Schematic of the high-level information flow in the DER-CAM control optimization algorithm (Stadler *et al.*, 2008).

a variety of computer tools available for the analysis of renewable energy integrated system. A total of 37 software tools is discussed and compared. The review is very help in identifying suitable energy tools for the analysis renewable energy systems and objectives.

15.6 Summary

In this chapter, it was shown that cogeneration describes the process of simultaneously generating more than one form of energy, such as for example cooling, heating and electrical energy from at least one energy resource. When fuelled from renewable energy resources, cogeneration power plants have the potential to be extremely efficient and even carbon neutral. This chapter also presented a brief background around the development of efficient and economic cogeneration systems and introduced certain tools and models available for picking an appropriate set of technologies as well as for choosing optimal week-ahead operational schedules.

PART VI

SOLAR TRACKING EVALUATION AND VERIFICATION

CHAPTER 16

TRACKER PERFORMANCE EVALUATION PRINCIPLES

16.1 Performance Evaluations

The solar tracking platform and control system for a solar harvesting means should be able to control and manage the physical movements of the solar collector with great tracking accuracy. The question is, what is a "great tracking accuracy" and what is the ideal efficiency in terms of pointing accuracies and tracking errors.

Solar tracking accuracy in a self-tracking CSP platform is the topic of this chapter. It will discuss criteria for evaluation of positioning system performance, present practical examples of solar tracking error displays and give an indication of factors to evaluate the impact of optical focus errors and solar energy spillage. The discussion is presented in a generic context with references to certain literature on solar tracking system performance evaluation.

16.2 Planning a Solar Tracking Experiment

Davis and Williams published a very interesting report on Understanding Tracker Accuracy and its Effects on CPV (Davis and Williams, 2008). This is an extremely valuable report for those planning to conduct experiments towards the verification and validation of solar tracking performance as the report ventures into a broad range of aspects normally not considered in the initial stages of evaluation. The article by Ghosal *et.al* on the On-sun Performance of a Novel Microcell based HCPV system and Comparison with conventional systems and solar tracker results also includes very interesting presentations that depicts solar tracker performance graphically (Ghosal *et al.*, 2011). Some of the important aspects of these report are highlighted in this chapter and in this section.

The Davis report presents details of a variety of methods to measure pointing accuracy, including optical methods, and describe factors to be considered in the acquisition and logging of data related to solar tracking accuracy. They also emphasize the importance of using diagnostic instruments that is properly calibrated for measuring the performance of a solar tracking system.

Another important recommendation is that time-series solar tracking error graphs should be included in the results report. Preferably these graphs should be accompanied by associated time-series data that maps related solar vector elements such as astronomically computed sun elevation and azimuth (computed by time of day and location), solar tracker position (real on local tracker orientation), ambient temperature, wind speed and direction, solar DNI and GNI onto the solar tracking performance graphs. The associated data is important as such data sets can be potentially used in combination with site assessment data collected at different sites (or from existing databases), to built models for sites where the solar trackers may be installed in future.

Measuring solar tracking accuracy measurements in real time in the field can be a challenge, but it is important as the operational context of the system can influence system performance. It is best to examine and analyse detailed data sets of measurement data as this may provide valuable insight into the performance and efficiency of the solar tracking system, within the context of the operating environment. Solar tracking accuracy is thus more than just a number, it also involves correlation with power generation and wind/heat disturbances as these also impact on the economic analysis and viability of the solar harvesting system.

Some researchers have proposed alternatives to the measurement of solar tracking errors in order to eliminate the counting of solar tracking errors on the horizons (where there is a thicker atmospheric depth between the sun and tracker). These studies use a mean pointing accuracy measure, for example to express only pointing errors for times when the sun elevation is above a certain angle (say 10°) over the subset of a day. This avoids penalizing a tracker for not being able to point directly at the sun on the horizons. At the same time, the choice of horizon angle is arbitrary and may artificially enhance the performance of certain solar tracking systems.

Another alternative solar tracking error measurement is to use the 95% accuracy rule. This rule simply reports only the best pointing accuracy for the tracker over 95% of the sunrise-to-sunset hours. This is another way to remove outliers from a tracking error data set, but it has the advantage of being fairly simple to compute and explain. The measure is somewhat arbitrary and also not necessarily best coupled to energy production.

It is for these reasons that Davis and Williams emphasise that tracking accuracy should assess the full tracking system performance (mechanical, controller, algorithms, calibration) and should preferably be measured on-site and in real-time at the installation. Time varying solar tracking error graphs should preferably be used to show the temporal variations during the time of day, and preferably results should be brought in context in terms of solar DNI and solar power generation (Davis and Williams, 2008).

The handbook Power From the Sun (Stine and Geyer, 2001) is another valuable reference manual when dealing with solar tracker performance experiments. This book include sections that deals with solar tracking error experiments and also describes relationships between factors cross-linking the effects of solar tracking components, for example optical mirror alignment errors relative to solar tracking errors, etc.

16.3 Practical Experimental Setup and Instrumentation

During the development of our own concentrated solar harvesting system we experienced practical challenges and situations during the experimentation phase that are not uncommon in the research and development environment (Prinsloo, 2014*b*). We thought to share this experience within this section as part of the discussions, as our practical experiences may be of value to other solar system developers. It may be especially helpful in terms of the planning time horizons and in the preparation of the experiments and selection of equipment.

Firstly, how do we choose the value for a good solar tracking accuracy for concentrated solar systems. Controllers based on a solar ephemeral equation typically calculate the solar position to $0.01°$, but during early morning and late afternoon, some solar beam deviation will exist due to the atmospheric water vapour deflection, amounting to as much as $1 - 2°$ (Lauritzen, 2014). For most applications the concise solar tracking accuracy setting and accuracy code of $0.02°$ works well, although most Sun Position Algorithms presents a precision algorithm accurate to within $0.00003°$ (Craig, 2011). In Section 8.3.3 of this book, it was shown that solar tracking accuracy should be chosen as a function of the solar receiver design, as the solar receiver sensitivity function determines the amount of solar energy spillage.

Secondly, how can the researcher disconnect the interdependency between the work of different research teams during the evaluation phase. At the time when the components for our solar tracker prototype design was workshop built and ready for evaluation, we started preparations to conduct evaluation experiments on the rooftop of one of the university faculty buildings. Our planning schedule arranged well ahead of time with our university workshops, who prepared beforehand for the installation on the rooftop. The workshop developed an innovative footpiece concept to prevent drilling holes in the water sealed rooftop of the building and they arranged the required civil engineering approvals for the footpiece installation well ahead of the experiments.

At the same time, the structural aspects of the parabolic dish structure was the responsibility of another group. This part of the project was delayed as a result of finite element analysis and further structural optimization meant to improve the wind loading and resistance effects of this dish configuration. The construction phase of the parabolic dish prototype development was still to follow the completion of this design phase and would still also have taken considerable time.

It was realised that there may be serious delays in our evaluation experiments if we do not separate the dish development from the solar tracking evaluation experiments. The structural analysis also led to the realization that a parabolic dish part may call for safety and insurance approvals. These processes had the potential to further delay the experiments as it may require legal approval from the authorities, with insurance declarations. With such potential requirements before the prototype parabolic dish model can be fitted onto the positioning system on the rooftop (i.e. liability requirements for rooftop installations at a public facility), solar tracking experiments had to proceed independently.

Thus, with the dish reflector components still under development at the time of the solar tracking platform evaluation and validation, the solar positioning tracking system accuracies were to be evaluated without the parabolic dish component. On-axis azimuth and elevation tracking accuracy measurements were therefore taken on the sun-axis of the parabolic dish hub on the sun-pointing cantilever boom of the solar tracking platform.

A purpose-built experimental test instrument housing shown in Figure 16.1) was then specially designed and fabricated to serve as physical platform for the installation of the solar tracking accuracy sensors. This instrumentation housing was fitted securely to the hub of the parabolic dish mounting located on the sun-axis of the tracking platform boom, to face precisely into the sun on the sun axis.

Figure 16.1 Test experiments were conducted with a test instrument and sun sensor/camera mounted onto the sun-axis of the solar concentrator boom.

The instrument platform and orientation means(Figure 16.1) was designed and precision fabricated to fit directly onto the sun-pointing hub of the cantilever boom, instead of the parabolic dish. One sun-facing end of this instrumentation platform includes a "telescopic sun-vector reticle means" comprising cross-hair sun-target patterns (laser cut onto the platform footplate) for illumination by sunbeams directed from a small aperture (laser cut through a circular mask plate mounted above the target).

This mechanical "aiming means" serving a valuable purpose as it helped to simplify the mechanical system alignment, setup configuration and calibration stages. At the same time, the telescopic sun-vector reticle means was also extremely helpful to understand the system performances as it provided a real and direct visual representation of the solar vector on the cross-hard sun target during the solar tracking process.

The centre portion of the instrumentation platform served as a housing for the optical sensors (sun sensor, camera). A welding visor was mounted over the camera lens to help enhance the web camera image contrast. The visor also helped to prevent camera CMOS saturation when the solar tracking system faced the sun directly. These optical sensor devices would monitor and communicate exact digital representations of the sun vector $S_Q(\gamma_s, \theta_s)$, the physical orientation of solar concentrator, and the solar tracking axes errors to the data acquisition system.

16.4 Instrumentation and Data Acquisition

In terms of data acquisition and data logging, the ideal approach is to log solar tracking performance and errors by way of a commercial solar tracking datalogger, such as the Trac Stat SL1 (Davis and Williams, 2008). We used a much simpler and lower cost option, namely the open-source online Labview Arduino Driver (LArVa) software that incorporates pre-compiled Labview modules to conduct datalogging with an Arduino processor board.

This open source Labview Arduino Driver (LArVa) datalogger gathers data on 6 channels from any Arduino microcontroller and is able to display the data on graphs on a PC screen (Angstrom Designs, 2014). The program allows the user to save raw data at variable acquisition rates, and includes on-board firmware averaging. It further includes a simple graph application for the PC and allows for more complex data acquisition using Labview.

With the help of a sun-sensor or imaging camera, the Labview LArVa data acquisition system, shown in Figure 16.2, can be used to log the optically measured azimuth and elevation tracking error sequences in real-time on a personal computer. During experimentation, this data acquisition system networks with an Arduino microcontroller, which acts as hardware interface through six 12-bit analog to digital converters and 14-digital input/output pins (6 PWM outputs). It communicates through USB with a personal computer for data transfer and storage. It can be downloaded from this link: `http://www.angstromdesigns.com/software/faq/58-labview-arduino-driver-larva` thanks to Angstrom Designs (Angstrom Designs, 2014).

Figure 16.2 shows a typical screen display of the LArVa data acquisition system during experimental setup configuration. During the solar tracking operation, the data collected from the sun sensor was recorded on a laptop through the normal Arduino USB interface. In our case, this automatically logged continuous data was used to calculate the solar tracking error, to measure the performance of a tracker over the course of the days of experimentation and to validate the performance of the solar tracking system in terms of pre-defined tracking error margin limits (Prinsloo, 2014*b*).

Each performance experiment was conducted after on-sun calibration procedures at the site of installation, while the performance of the solar tracking platform and control au-

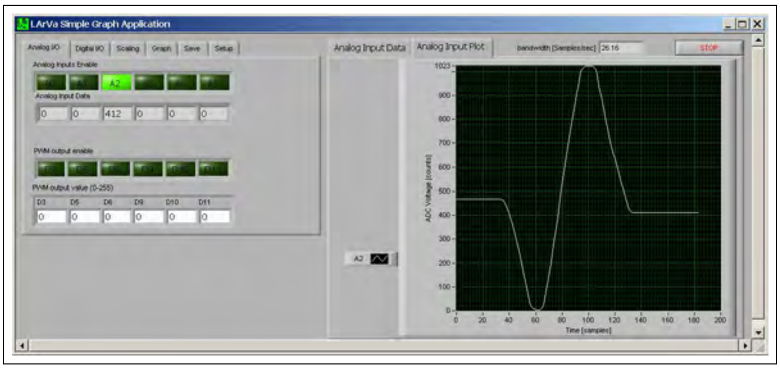


Figure 16.2 Multichannel Labview (LArVa) digital data acquisition system display (Angstrom Designs, 2014).

tomation was evaluated on the basis of the on-axis optical sun pointing azimuth/elevation errors (off-target errors). Tracking errors were measured optically through the SolarMEMS sun sensor, while data is recorded on the Labview (LArVa) digital data acquisition system and displayed through the Microsoft Excel software package.

In hindsight, it was realised that we could also have mapped the performance of the solar tracking platform to the solar irradiance and changing weather conditions, measured with other external sensors. The remaining unused channels on the LArVa was available and open to automatically log this type of data in the same results spreadsheet.

The more professional approach would have been to log solar tracking performance and errors by way of a commercial solar tracking datalogger such as the Trac Stat SL1 seen in Figure 16.3 (Davis and Williams, 2008). This Tract Stat SL1 instrument delivers an accuracy of 0.02° and has real time datalogging capabilities.

Figure 16.3 Trac-Stat SL1 a diagnostic instrument for measuring tracker accuracy (Davis and Williams, 2008).

This diagnostic instrument is often used in solar tracking experiments as it is robust enough to measure and log the pointing accuracy performance of solar trackers in the field and in real-time (which is practically more difficult than a laptop and Arduino board interface). If this instrument is not installed directly in the sun vector line, then the Stat SL1 instrument sensors reference/installation frame is not the same as the trackers axes of motion or on earth reference frame. In such cases, sun vector transformations can be performed based on current tracker angle or alternatively on the time of day or location data (via sun position calculations) (Davis and Williams, 2008).

16.4.1 Solar Tracking Performance Example Set A

This section brings us to the most interesting part of the discussion on solar tracking platform system performance. Here we will display examples of potential ways to display solar tracking performances. This is intended to provide the novel experimenter with an insight into the how to report and illustrate solar tracking performance in a more-or-less scientifically acceptable way.

Figure 16.4 shows a first example of a display type for a solar tracking platform error sequence. This exemplary display shows the the tracking errors between -4% and +10% for a clear sunny and clear day, showing the largest errors within the -3% and +4% band. It also shows that most of the errors were in the -1.5% to 0.5% band, with the highest frequency of occurrence at 0% errors (Sabry and Raichle, 2014).

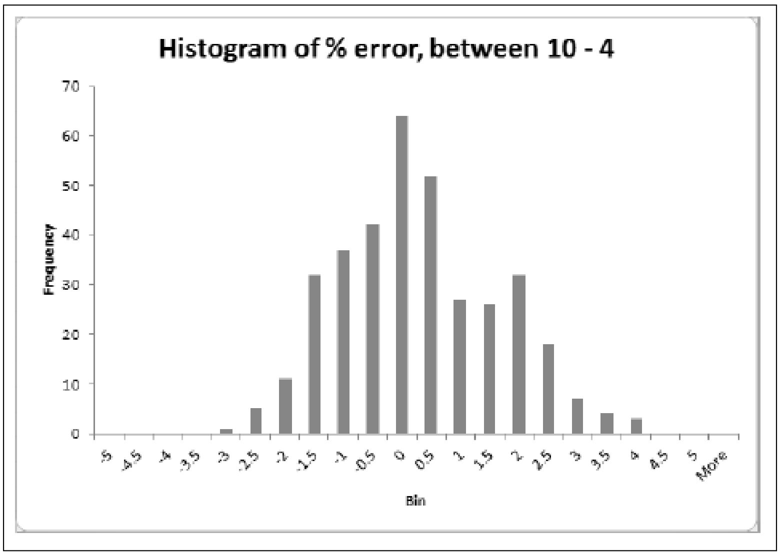


Figure 16.4 Example of a Histogram showing the tracking error percentage for one axis solar tracker (Sabry and Raichle, 2014).

The illustration is presented from a perspective of interpreting a solar tracking error display type. Looking at ease-of-interpretation of the data in terms of improving solar tracking errors, a histogram type display appears not to be very useful.

Figure 16.5 shows the second example of a display type for a solar tracking platform error sequence. This data is for an arbitrary solar tracking system and the data is displayed in polar coordinates on a type of cross-hair display. This display clearly shows biasing in tracking error towards a certain azimuth and elevation. Although this type of display helps to get an idea of the levels in which the error is contained, it helps very little in understanding the time-of-day or temporal significance in the solar tracking error sequence.

In a sense, Figure 16.5 display data in a two dimensional histogram type presentation. It offers a little more insight into the distribution of the solar tracking error rate, and also

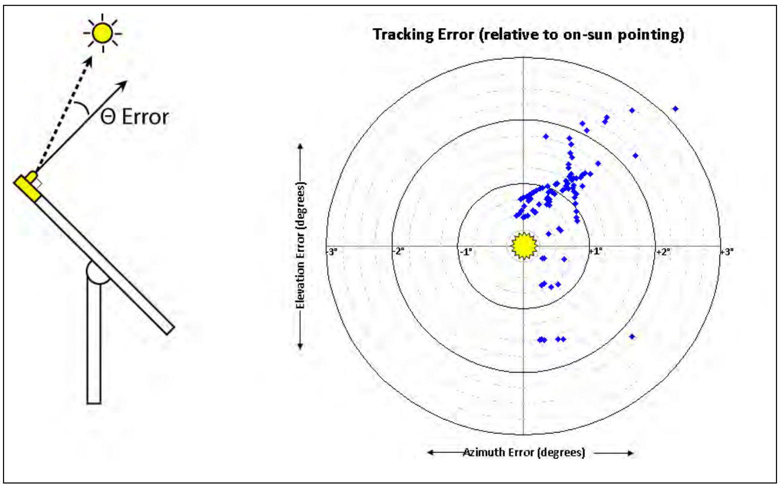


Figure 16.5 Solar tracking error display generated from Trac-Stat SL1 optically measured data (Davis and Williams, 2008).

offers some insight into the cross-linking or correlation between azimuth and elevation axes solar tracking errors (better tan two separate histograms).

Figure 16.6 shows a third example of a display type for a solar tracking platform error sequence. To a certain degree, the temporal solar tracking error sequence display in Figure 16.6 is a little more helpful. Displaying the same arbitrary solar tracking data shown in Figure 16.6, it is clear that the average tracking error largely increase as a result of the poor performance of this particular tracking system when it operates at sun angles closer to the horizon. This is basically because there is a thicker atmospheric depth between the sun and tracker (detailed explanation on this link `http://kippzonen-blog.nl/solar-energy/measuring-global-solar-irradiance/` by Lee (Lee, 2014*a*)).

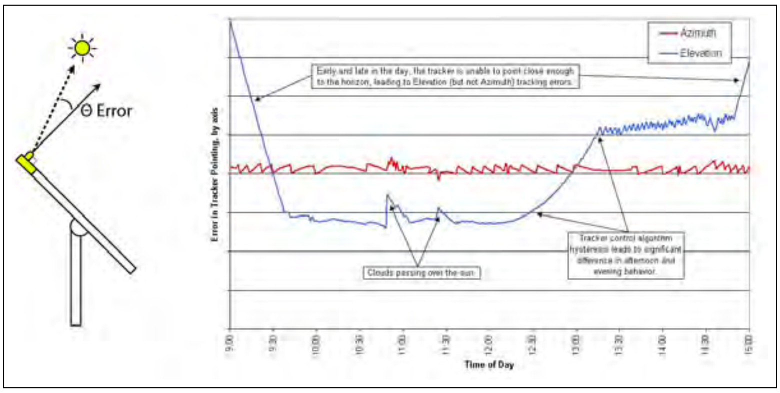


Figure 16.6 Solar tracking error display generated from Trac-Stat SL1 optically measured data (Davis and Williams, 2008).

Thus, in comparing the type of tracking error display in Figure 16.6 with that of Figure 16.5, one is able to understand and appreciate the value in the type of display being used to express solar tracking error sequences. Furthermore, in terms of off-hand interpreting the data for this particular tracking system, it appears as if the overall system on-axis tracking capabilities of this system is limited around the horizons. It gives an indication on where to experiment with improvements on the system.

Also the type of solar tracking error display in Figure 16.6 makes it easier to interpret the data than when compared to the histogram type display of Figure 16.4.

The interpretation of this particular data sets in the latter two examples is discussed in depth by Davis *et.al* (Davis *et al.*, 2008), for those readers interested in this particular error set and case data. The link to the article is this `http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4922522&tag=1`.

16.4.2 Solar Tracking Performance Example Set B

In line with the time series graph of Figure 16.6, one can also find it the results difficult to interpret the data if the graph is too congested as there is too much information on the same graph. For example, Figure 16.7 shows the simulated azimuth and elevation *movement patterns* (tracker orientation relative to the sun-vector) for the control concept detailed earlier in this book (illustrated before in Figure 8.9 and Figure 8.10). The graph shows the movement patterns (error sequences) for both the azimuth and elevation errors on the same axis set, and on a particular scale that was meant to also indicate the allowable error ($\epsilon_{az/el}$) band on the same axis set.

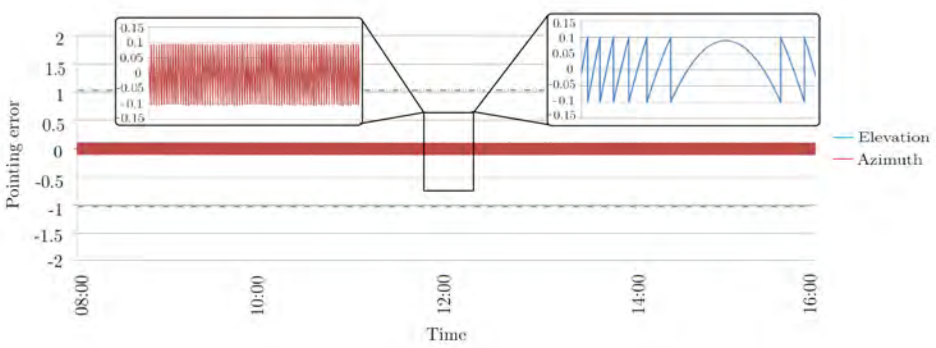


Figure 16.7 Mathematical simulation of the dish tracking movement patterns on the azimuth and elevation axes, computed using SPA solar vectors.

The fact that the graph shows azimuth, elevation and error band data on a scale sufficient to view all the trends all at once, just caused the data to become difficult to interpret for the reader. In this case it would have been better to show two separate graphs and use different scales to show the same results on different graphs with different scales to emphasise certain trends or features (Prinsloo, 2014*b*).

Figure 16.7 also illustrates another interesting point. Simulated *movement patterns* is an important tool that can be used to display anticipated data for a particular control concept. The simulation in Figure 16.7, for example, was computed from the chosen control concept formulas by way of input SPA solar vectors calculated by the SPA algorithm over the period of one full day. Such simulations help explain the ideal operating environment and is helpful in terms of comparisons with real-time measured data in the field, while the differences may help to interpret and explain certain tracking error trends. This simulation shows the best performance of the system that can be expected from the system.

16.4.3 Solar Tracking Performance Example Set C

This brings us to the point made by Davis and Williams (Davis and Williams, 2008), namely that that time-series solar tracking error graphs should be accompanied by associated time-series data that maps related solar vector elements. These could include one or a combination of astronomically computed sun elevation and azimuth (computed by time of day and location as illustrated in Figure 16.7), solar tracker position (real on local tracker orientation), ambient temperature, wind speed and direction, solar DNI and GNI onto the solar tracking performance graphs. Such associated data is important as it can potentially be used in combination with site assessment data (discussed later in this book in the chapter *Solar Resource and Resource Distribution*).

Figure 16.8 shows the a typical solar tracker performance on a cloudless day. This data reveals information about the tracker being tested that could be applied to tracker improvements. In particular, the change in elevation tracking error between noon and 2 pm indicates tracker controller hysteresis as the sun passes through its apex (Davis *et al.*, 2008).

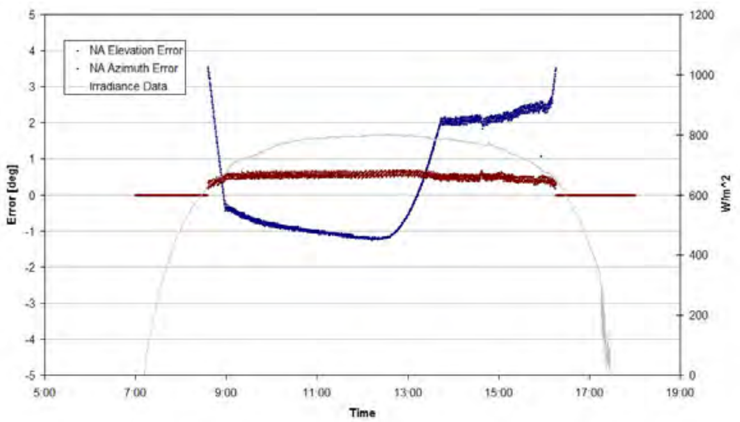


Figure 16.8 Tracker performance as measured on a clear day (Davis *et al.*, 2008)

Figure 16.9 presents the tracker error graph for another solar tracking system measured over the course of a day in combination with the power generated by the solar power conversion unit. Such display is of importance as it also gives an indication of the correlation between the solar power conversion efficiency and the solar tracking error pattern.

The cumulative DNI versus tracking error type representation (Davis and Williams, 2008) also presents interesting perspectives in terms of data interpretation. It shows the direct correlation of the solar tracking error in terms of solar energy spillages, as shown in Figure 16.10.

In addition, the characterization of the incident solar flux distribution on solar receivers is also of value in the monitoring and evaluation of concentrating solar power systems performance. It will be appreciated that the illustration of the flux distribution in Figure 16.11 may be very helpful from a solar tracking perspective, as it not only helps visualise the erros but also the final impact on thermal energy collection.

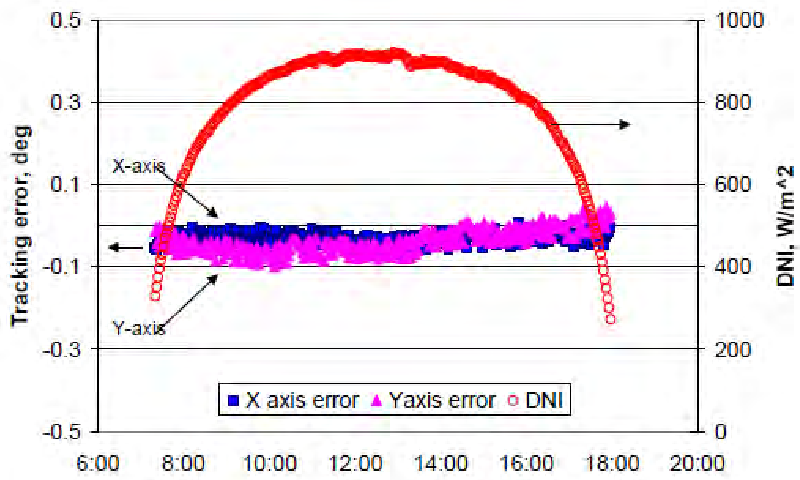


Figure 16.9 Display of tracker error over the course of a day combined with solar power generated (Ghosal *et al.*, 2011)

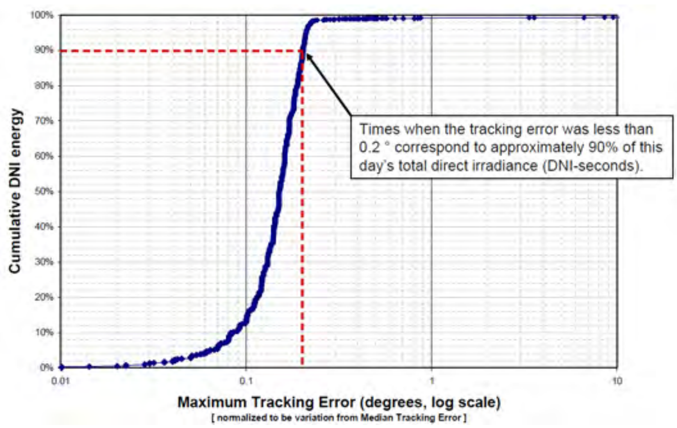


Figure 16.10 Cumulative DNI versus tracking error (Davis and Williams, 2008)

A flux map can be taken from thermal imaging devices. NREL has developed a website with tools to evaluate receiver irradiance as part of solar receiver glare studies (Ho and Khalsa, 2010).

In general, time varying and offset solar tracking errors could emanate as a result of one or more of a variety of factors, factors that may typically be experienced with rural installations. The range of known inter-dependent factors that could cause such time-varying errors include: pedestal tilt errors, reference biases, linear azimuth and elevation errors (gear drive ratios and configuration settings), non-orthogonality in the slew drive axis mountings or bore-sight errors (optical axis misalignments). These factors would often be too complex to isolate as it may vary throughout the day, season or year, typically showing a non-linear dependence on the intended sun pointing angles.

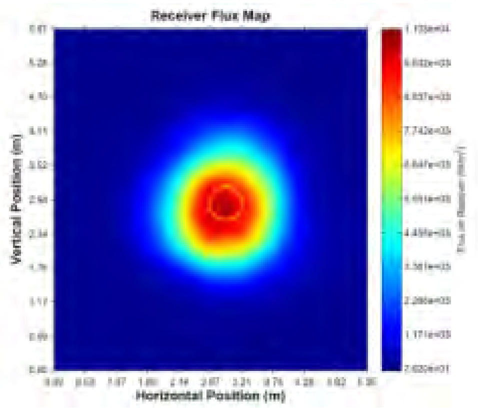


Figure 16.11 Characterization of the incident solar flux distribution on the solar receiver as part of solar tracker performance analysis (Ho and Khalsa, 2010).

Sandia National Laboratories's engineers (Khalsa *et al.*, 2011) found that it is rarely feasible to isolate the cause and repair minor installation errors or fabrication defects on any installed concentrated solar power system, because the complexity caused by the interdependency between the range of potential defects would require prolonged analyses and precise (laser) measurements stretching over several seasons.

Furthermore, complex mathematical modelling would still be required to quantify each contributing factor, while any attempt to mitigate any one factor on its own would require the prolonged analysis process to start all over again. Their attempts towards a control solution that includes mathematical models to overcome subtle disturbances showed limited success (Khalsa *et al.*, 2011).

A more viable solution to circumvent the effect of minor defects on solar tracking inaccuracies with stand-alone rural power systems would be to include an optical feedback means in the solar tracking control solution.

16.5 Summary

This chapter detailed various aspects related to the evaluation of the performance of a solar tracking systems. The discussion covered a number of performance evaluation measures and presented some examples on how to measure, datalog and display solar tracker performances using different coordinate systems. It also demonstrated some examples on how to correlate the performance of a solar power generating system with solar tracking error performance.

CHAPTER 17

HEALTH AND SAFETY ISSUES IN SOLAR TRACKING

17.1 Introduction

Before any experiments with a solar tracking system can proceed, the evaluation team should be made fully aware of certain safety and risk considerations. This chapter briefly describes some of the hazards common to concentrated solar power systems and describe some health and safety procedures on how to alleviate the associated risks and to prevent injury during experimentation.

17.2 Thermal Protection

Remember solar tracking systems would in many cases operate on the principles of concentrating solar energy. If the reflector is large enough, the collected heat from sunlight at the focal point of the dish would easily melt metals, and even in smaller solar reflector systems is enough to cause serious heat burning injuries. Thermal protection is thus one of the first important items to keep in mind when conducting experiments on any concentrated solar power system.

It is advisable to always wear gloves and use caution when working with solar concentrator parts during the daytime. Most of the solar concentrator parts and elements become very hot when exposed to bright sunlight. Extreme caution should thus be taken before handling any parts that have been exposed to sunlight. Figure 17.1 shows the safety signs that needs to be fixed onto the pedestal pole of each solar tracking system.

Figure 17.1 Safety signs to be set up at the site of installation and experiment (Prinsloo, 2014*b*).

When conducting experimental tests, it its advisable to partially tile the dish with reflective elements for safety reasons. Alternatively, some reflecting surfaces should be covered to prevent heat concentration or build up when working on the system or when the system is maintained.

17.3 Glint and Glare Hazards

It is known that solar concentrators present glint and glare hazards to passing aircraft and pilots. Addressing these safety aspects during experimentation is an important requirement towards ensuring public safety. A glint is defined as a momentary flash of light reflected from the parabolic reflective elements, while a glare is defined as a more continuous source of excessive brightness relative to the ambient lighting, usually radiated from the area of the solar receiver. The site of installation and experimentation on the university's rooftop is in close proximity to airports and aircraft flying routes, hence special care should be taken during test experiments. Partially tiling the dish with reflective elements will assist in limiting glint and glare hazards to passing aircraft and pilots.

With the deployment of a concentrating solar tracking system, it should thus be kept in mind that glint and glare from concentrating solar collectors and receivers creates a potential hazard or distraction for motorists, pilots and pedestrians. Figure 17.2 illustrates examples of the hazards of Glint and Glare from concentrating solar power plants shows from a study at NREL (Khalsa *et al.*, 2011).

Figure 17.2 Examples to illustrate the hazards of Glint and Glare from concentrating solar power plants (Ho *et al.*, 2009)

Hazards as a result of solar concentrator glint or glare further poses a potential risk for permanent eye injury (retinal burn) and temporary disability or distractions (flash blindness). This may impact people working nearby, pilots flying overhead, or motorists driving alongside the site. Partial tiling of the dish during experimentation would once-again help reduce such risks in the initial tests, especially when testing the concentrator without a solar receiver mechanism (Stirling device) installed at the focal point.

The NREL study thus provides a summary of the analyses and evaluation of glint and glare and presents guidelines on safety metrics and standards to evaluate the potential hazards of calculated irradiances from glint and glare. A WebTool was also developed to evaluate glint and glare hazards from solar collector systems (Ho and Khalsa, 2010). This is because conventional safety metrics focused only on the prevention of permanent eye damage (e.g., retinal burn), while new metrics have been introduced to counter temporary flash blindness that occurs at irradiance values several orders of magnitude lower than the irradiance values required for irreversible eye damage (Khalsa *et al.*, 2011)(Ho *et al.*, 2011).

17.4 Solar Walk-off

In parabolic dish systems, significant temperatures are generated at the focal point of the solar receiver. Consequently, damage is often caused to the solar power conversion device if the designers or the controller procedures do not sufficiently provide for this. For example, when the solar tracking system fails, the sun at the focal point of the dish would continue to walk-off the solar receiver as a result of the continued movement of the sun. This has been the cause of damage to many power conversion units, since the walking beam of high intensity heat can damage or burn any parts on the sides of the solar receiver or power conversion system that is not adequately protected.

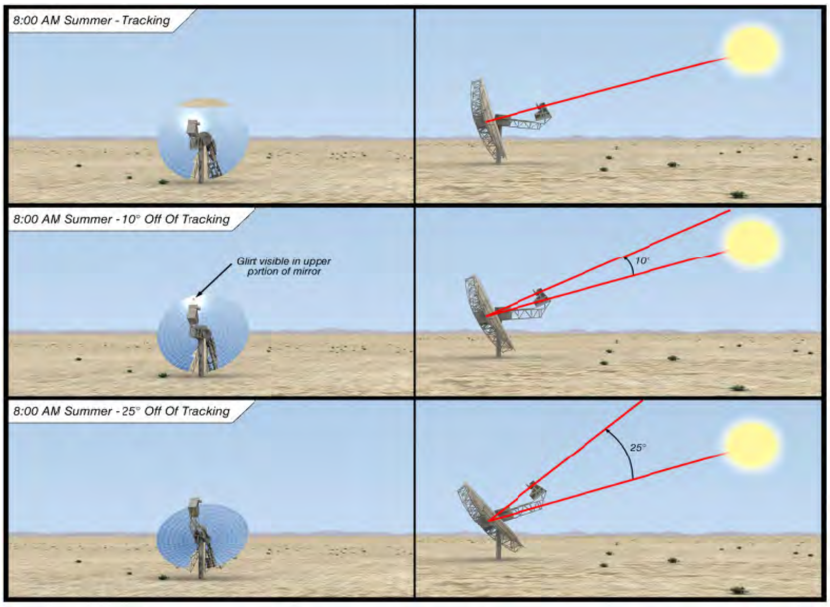


Figure 17.3 Procedures for off-axis tracking and solar walk-off to prevent damage to the solar receiver (Awaya and Bedard, 1985).

With some cause and intelligent programming in the controller system, some of this damage can be prevented. Figure 17.3 for example illustrates some procedures that may be useful in preventing hazards and damage to the concentrating solar power system as a result of system failure or stoppages in solar tracking system operation for maintenance.

17.5 Electric Shock and Lightning

It is important to emphasize that a solar concentrator system produces electricity when exposed to sunlight. Even overcast days can present enough sunlight for the concentrator to generate electrical energy. The soundest method of completely turning-off the power generation/electricity is to move the face of the concentrator away from the sun.

During experimentation, caution should also be taken when handling the electric system components of the concentrated solar power system, as backup power systems presents dangers that can still cause electrical shocks. Before touching any of the electrical parts or power connections on the concentrated solar power system, wait for a few minutes to give the bus capacitors time to discharge, as these can still cause electrical shocks after the system have been switched off.

It is important to ground the solar collector structure, including each module frame, control electronics, dish structure, the drive head assembly and the pedestal pole in order to make the solar collector and tracking system safer and less susceptible to lightning damage.

17.6 Emergency Procedures

A STOP function can be activated through a hardware emergency abort switch wired to the PLC digital input, providing for any emergency situations during experimentation. Irrespective of the mode of operation, activation of the STOP function will instantly halt all motion of the concentrator positioning system and power generation (i.e. Stirling device). Emergency soft(ware)-trip limits on the PLC configuration further allow for protection against cable windup. These soft trips limit the boundary movement positions of the solar concentrator to prevent overrun on pre-set safety angles for the mechanical actuator parts. Future implementation of alarm signals will help to alert an operator in case of safety, especially when prompt reaction such as immediate disabling of the slewing drive motors is required.

17.7 Economic Impact

Access to sustainable energy supply is widely acknowledged as a key foundation for sustainable development (Lloyd *et al.*, 2004)(Mottiar and George, 2003). It is therefore important to developed solar harvesting systems around the load profile for a typical rural villages(Lloyd *et al.*, 2004) and with sufficient capacity to help alleviate the problems presently experienced. Furthermore the impact of renewable energy solar structures on tourism and eco-tourisms is also an important factor for consideration, and attention should be placed on the artistic and aesthetic aspects of the design so that the final system blends in with the environment (Prinsloo, 2013).

PART VII

SOLAR RESOURCE DISTRIBUTION AND MODELLING

CHAPTER 18

THE SUN AS ENERGY RESOURCE

18.1 Introduction

This chapter presents a review on literature that describe the sun as energy resource. It will help you to understand the orientation of your solar tracker with respect to the sun at any location on the earth and on any given time of the day. Grasping this concept will help any hobbiest, technician, engineer or system developer to understand the formulas that one need to use in programming of micro-controllers, programmable logic controllers or to write a simple PC program that could automatically steer your solar tracking system.

18.2 Solar Energy as a Natural Resource

Solar energy is a valuable renewable source that can be utilized to provide electrical and thermal power. It offers the greatest energy potential compared with other currently known renewable resources. Harnessing the use of solar energy requires more research and development to improve the efficiency of solar applications but the efficiency of present systems already make solar harvesting a viable commercial option.

The solar energy received by any surface on earth as component of beam and diffuse radiation and the total amount of daily insulation varies according to location, season and time. Understanding of these factors is important for the design of any solar application because it can affect its performance. Optimizing the mounting of the solar systems can ultimately improve the energy capture and ultimately increase the performance of the system.

The sun radiates energy in the form of electromagnetic energy. The frequency content and the amount of electromagnetic radiation that reaches the earth from the sun in referred to as solar radiation. The term *irradiance* is normally used to define the amount of solar energy per unit area received over a given time. It was shown earlier that as the solar electromagnetic energy passes through the atmosphere of the earth, the solar energy levels reaches around 1366 W/m^2 on the surface of the earth (Duffie and Beckman, 2006). This simply means that for every square meter of surface area on your solar collecting platform that faces the sun, the system will at most be able to collect around 1 kW of solar energy (if it is 100% efficient).

The spectral or frequency content of the electromagnetic energy radiated by the sun as well as the spectral content which eventually reached the earth's surface is depicted in Figure 18.1. The solar radiation spectrum includes a small share of ultraviolet radiation and visible light, while around 49% of the electromagnetic energy falls within the long wavelength infra-red (thermal heat) spectral band.

The spectral energy distribution given in Figure 18.1 is documented by the American Society for Testing and Materials (ASTM) in terms of the ASTM Standard G-173-03 (ASTM, 1999). The electromagnetic spectrum is displayed in term of the wavelength in nanometers (nm) and shows both the extraterrestrial spectral irradiance and the Direct Normal Spectral Irradiance (DNSI) in W/sm/nm. From Figure 18.1 (top), it can be observed that the solar radiation spectrum reflects a distribution similar to that of a $5250\,^{\circ}C$ blackbody, the sun's approximate temperature.

It was noted that, as the solar electromagnetic solar energy passes through the atmosphere of the earth, the electromagnetic energy level reduces to around 1366 W/m^2 (around 1 kW/m^2). This is because part of the electromagnetic energy is absorbed by gases with specific absorption bands as the electromagnetic energy enters the earth's atmosphere. Certain frequency bands of the solar radiation is filtered by the gases present in the earth's at-

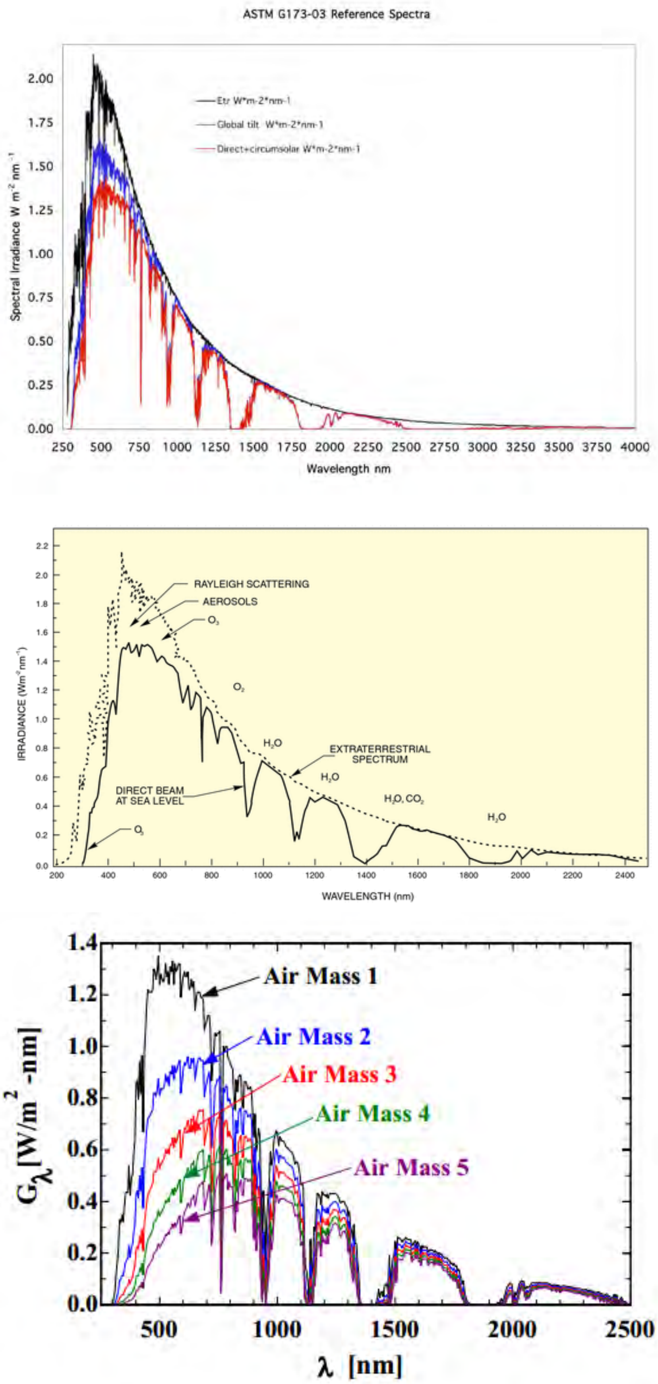


Figure 18.1 Normally incident solar spectrum at sea level on a clear day. The dotted curve shows the extraterrestrial spectrum (ASTM, 1999)(Schlegel, 2003).

mosphere like H_2O, CO_2, O_3 and O_2, and reflected by the clouds. The spectral components of the solar energy most influenced by particular gasses in atmosphere can be observed in Figure 18.1(middle).

The radiation received on the earth's surface is impacted directly by the atmosphere that solar radiation passes through. Figure 18.1(bottom) shows the variation in direct solar irradiance relative to airmass, and illustrates that radiation on the earth is a function the air mass of the atmosphere (Schlegel, 2003). The higher the airmass, the the more scattered the radiation.

Absorption of solar radiation in the atmosphere and solar energy spectrum (Figure 18.1) is largely due to ozone in the ultraviolet and to water vapour and carbon dioxide in bands in the infrared spectrum. Large absorption of short-wave radiation by ozone in the upper atmosphere at wavelengths below 290 nm and water vapour absorbs strongly in bands in the infra-red part of the solar spectrum, with strong absorption bands centred at 1000 nm, 1400 nm and 1800 nm. Beyond 2500 nm, the transmission of the atmosphere is very low due to absorption by H_2O and CO_2. The remaining unabsorbed and unscattered photons, constitute the direct beam radiation.

The diagram in Figure 18.2 shows the spectra of the main molecules that participate in the emission spectra between the sun and the earth. An idealized solar spectrum is also shown with a description of the details of the carbon dioxide spectrum and a spectrum of water vapour that shows the region described as the infrared window (Bellamy, 2014). The radiation emitted by the earth, are absorbed by clouds and other atmospheric gases. "The two primary gases that absorb long-wave radiation in the lower atmosphere are water vapor and carbon dioxide. Methane, ozone, and chlorofluorocarbons can also absorb some of the long-wave radiation. The gases can then re-emit the energy again and send the energy back down towards the Earth's surface. The emitting long-wave radiation from the earth and gases heats our planet from the surface up into the atmosphere. The sun's short-wave energy does not directly heat up the atmosphere. If that were the case, then outer space would be very warm and not extremely cold. Albedo is calculated as the amount of energy reflected from a surface divided by the total amount of incoming energy to the surface, multiplied by 100 to get a percentage" (ICC, 2014).

Bellamy published notes on the Greenhouse Gas Spectra and is very interesting to read from the perspective of the warming effect of greenhouse gases on the earth `http://www.barrettbellamyclimate.com/page15.htm`. To quote from this publication: "The red area of the Sun's spectrum is absorbed by the atmosphere and the Earth's surface. The warmed surface emits infrared radiation as indicated by the white areas on the individual molecule's spectrum. The grey bits are the parts of the spectra that are absorbed by the atmosphere. The blue area on the Earth's emission spectrum is known as the infrared window through which most of the Earth's radiation passes to space unhindered by being absorbed by any of the greenhouse gases. The last row of the spectra shows the extent of what is known as Rayleigh scattering. This is what happens to high energy quanta and applies to the UV/blue end of the solar radiation coming into the atmosphere. It is this scattering of 'blue' photons by the molecules of the atmosphere which causes the clear sky to be blue. To be precise about this, the sky should really be violet as 'violet' photons are scattered even more than blue ones. Because the human eye is very much less sensitive to violet light than it is to blue light we perceive the sky to be blue" (Bellamy, 2014).

Scattering of radiation as sunlight passes through the atmosphere is thus caused by interaction of the radiation with air molecules, water as vapour and droplets, and dust. Scattered photons (mostly at short wavelengths, such as ultraviolet colors) produce the diffuse sky radiation. The degree to which scattering occurs is a function of the number

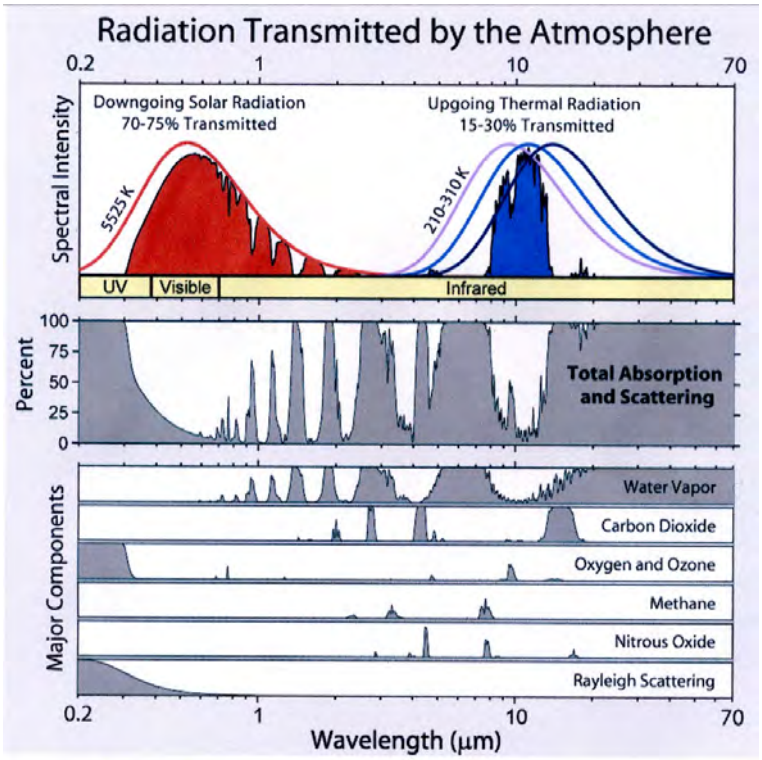


Figure 18.2 Spectra of the solar radiation, earth re-radiation and spectra of the main molecules that effect the emission spectra between the sun and the earth (Bellamy, 2014).

of particles through which the radiation must pass and the size of the particles relative to the wavelength of the radiation. The path length of the radiation through air molecules is described by the air mass.

The amount of direct and indirect radiation depends on the sky condition and therefore the portion of these radiation varies. On average, diffuse radiation constitute around 10% of global radiation as a result of the effect of the particles and molecules radiation's absorption in the atmosphere (ISEC, 2001). Jointly the direct and indirect radiation constitute the global radiation.

Figure 18.3 shows that the incoming radiant energy may be scattered and reflected by clouds and aerosols, or absorbed in the atmosphere. The transmitted radiation is then either absorbed or reflected at the earth surface. Radiant solar (shortwave) energy is transformed into sensible heat, latent energy (involving different water states), potential energy (involving gravity and height above the surface (or in the oceans, depth below)) and kinetic energy (involving motions) before being emitted back to space as longwave radiant energy.

It was noted before in this book that the effect of cloud cover on the solar spectrum is an important consideration for which the effects will be discussed in mode detail in Section 13.2. The spectrum of solar radiation received on top of a mountain in a remote region can differ markedly from the spectrum received in an industrial or urban area near sea level. Furthermore, the amount and type of radiation on the parabolic dish or photovoltaic panel

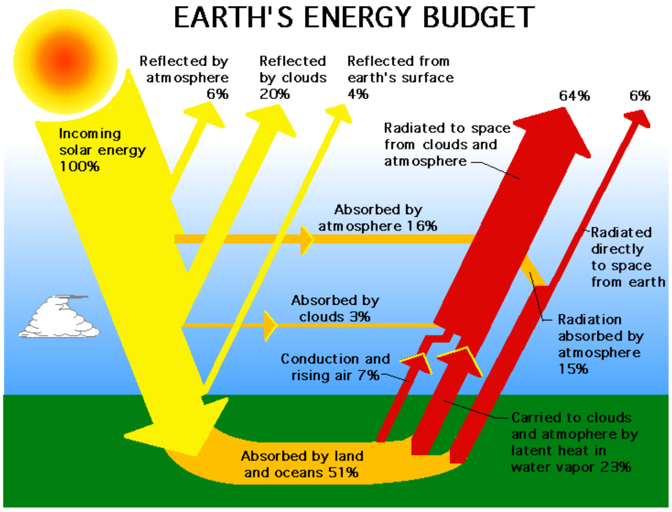


Figure 18.3 Global annual mean earth energy budget, arrows indicating the schematic flow of energy in proportion to their importance (NASA, 2014).

for a solar tracking system on the earth also depends upon the changing characteristics of the atmosphere.

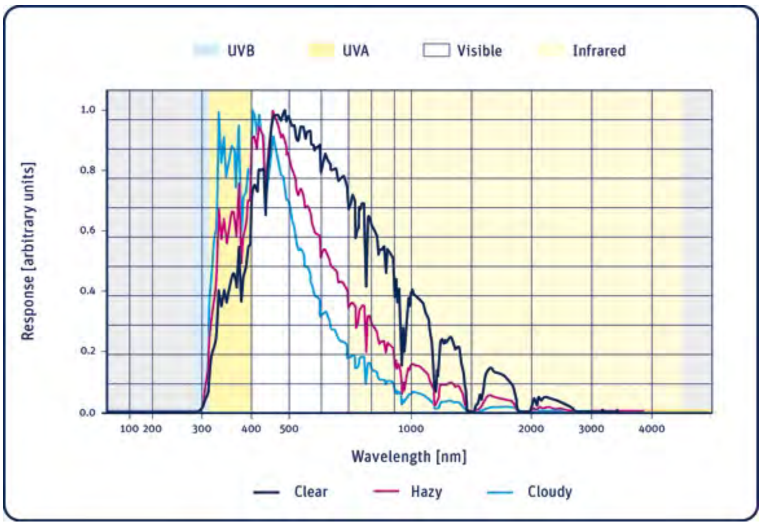


Figure 18.4 Graphic illustration of spectral shift in solar irradiance on the earth as a function of sky conditions (Lee, 2014*a*).

We showed the example in Figure 18.4 where it was highlighted that cloud cover causes a spectral shift in solar irradiance on the earth. This emphasises the fact that the solar spectrum at the solar tracker location is function of sky conditions and that the solar spectrum of sunrays that pass through the atmosphere are impacted by cloud scattering and absorption caused by air molecules, aerosol particles, water droplets and ice crystals in the clouds (Lee, 2014*a*). This spectral shift may be an important consideration in the type of material used in solar power systems, and to ensure that the technology bandpass spectrum match the solar spectrum for those systems that operate in cloudy conditions.

Given the spectral distribution of the solar energy reaching the concentrated solar energy conversion devices (Figure 19.6), technicians and engineers became interested to know the amount of solar energy available during a daily cycle at a specific geographic location. For this the unit Peak Sun Hours (PSH) was defined. The term peak sun hours (PSH) reflects the equivalent number of hours in a full day solar cycle when solar irradiance averages more than 1 kW/m^2 (1366 Watt/m^2) at that location (Duffie and Beckman, 2006). These figures now allow the energy yield of a solar collector system to be determined, typically, by multiplying the irradiation value Gsc with both the collector area power rating with other loss factors such as reflection efficiency and tracking inaccuracies to the movement of the position of the sun. When designing a solar reflector system, the exposure of the sun at the point of installation can be calculated from or in terms of calculated PSH.

In terms of the Solar Constant Gsc and PSH, it was shown earlier that solar radiation reaches the earth atmosphere at an average intensity at a solar constant of 1366 W/m^2 (Duffie and Beckman, 2006). However, this number varies with the variation of the earth-sun distance and therefore it is dependant on the time of the year. Figure 18.5 shows that it shows the variation of these radiation during different seasons in one year. For those readers interested in the time-series of solar radiation variations, the time series of solar radiation data for any location on the earth is available from the online source SODA (Solar Energy Services for Professionals) (SODA, 2014).

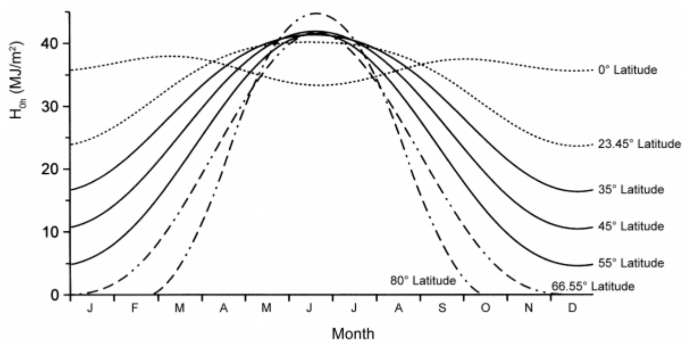


Figure 18.5 Seasonal variations in the solar radiation levels measured at an arbitrary location on the earth over a one year period showing total daily amount of extraterrestrial irradiation on a plane horizontal to the Earth's surface for different latitudes (ITACA, 2014)(SODA, 2014).

Figure 18.5 shows the total daily amount of extraterrestrial irradiation on a plane horizontal to the Earth's surface for different latitudes http://www.itacanet.org/the-sun-as-a-source-of-energy/part-2-solar-energy-reaching-the-earths-surface/ (ITACA, 2014). It shows that, for any given day the irradiation changes from latitude to latitude despite the value of the extraterrestrial (outside the atmosphere) irradiance being constant for all latitudes. This occurs because the length of the days changes and the effects is most obvious inside the Arctic circle where much of the year is either 24 hours of darkness or 24 hours of daylight.

In summary, the solar energy that it is emitted from the sun is in form of electromagnetic radiation with a specific spectrum given by the temperature of the sun. The radiation that arrives to the external layer of the earth where it is been filtered by the earth's atmosphere. Certain frequency bands of the solar radiation is filtered by the gases present in the earth's atmosfere, for example H_2O, CO_2, O_3 and O_2, and certain light reflected by the clouds

(Figure 18.1 and Figure 19.6). The solar radiation that finally arrives on the surface of the earth varies in terms of location and season of year, while it is in part being absorbed by the earth and in part being reflected (Figure 19.6). The solar radiation absorbed by the earth is eventually transformed into heat and also emitted back into space as infrared radiation (during the day and during the night).

18.3 Solar Resource Distribution

Throughout the world, there are many regions that are rich in terms of the solar resource. The solar resource map in Figure 18.6 shows on color scale those parts of the world where there is a very high potential for solar energy harvesting. Especially countries and regions around the equator shows good potential for solar energy project development.

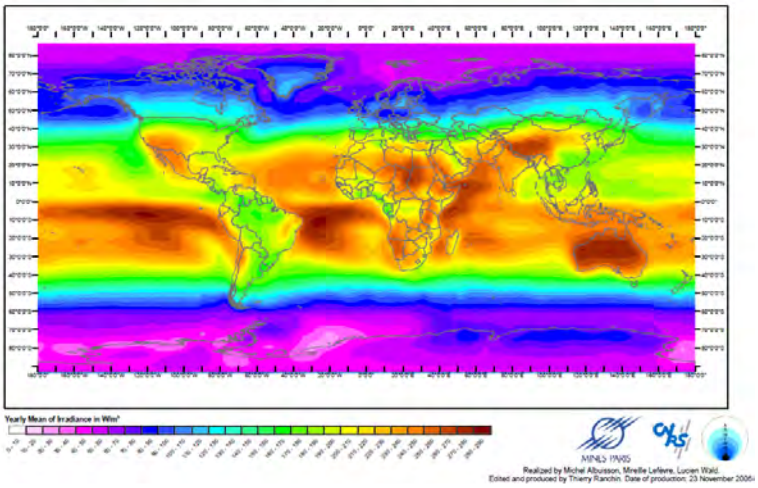


Figure 18.6 Yearly mean irradiation in the world (1990-2004) (ParisTech, 2006).

In particular, Figure 18.6 displays the mean irradiance on the surface of the earth for the world for the year as expressed in W/m^2. This map is computed from observations made by meteorological satellites from 1990 to 2004 and shows the average of daily irradiation is obtained by multiplying this quantity by 24 (in Wh/m^2) or 86.4 (in kJ/m^2) (ParisTech, 2006). This means that the most favourable belt for solar development projects in the world lies between latitudes 35°S and 35°N. This includes large parts of Africa, South America, Australia, India and China, regions that are naturally endowed with the most favourable conditions for solar energy applications. Many of these areas are also semi-arid regions, receiving direct radiation because of limited cloud coverage and rainfall.

Another interesting map is the global ultraviolet (UV) radiation map, shown in Figure 18.7. This map displays the radiation in UV (280 - 400 nm) reaching the ground in different parts of the world. The irradiation daytime quantities displayed on the map are averaged over fifteen years (1990-2004) and are expressed in the scale unit J/cm^2. The approximative assessment displayed in this graph was also obtained from observations made by meteorological satellites (ParisTech, 2008).

From a community upliftment and regional economic development perspective, it is important to note that the majority of developing countries fall within favourable infrared

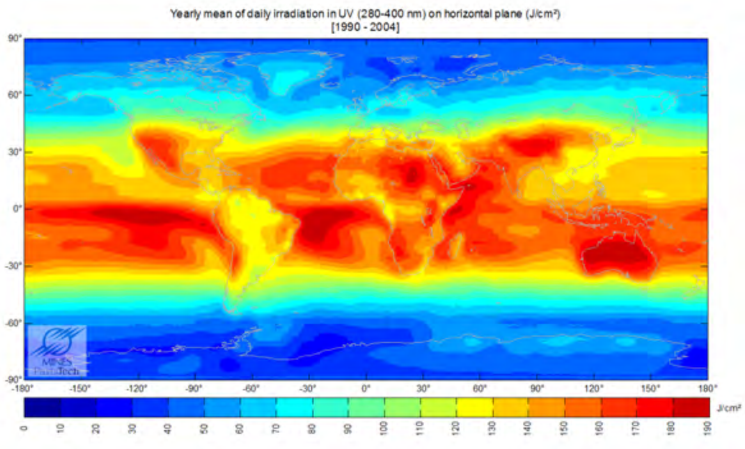


Figure 18.7 Yearly mean of daily irradiation in UV in the world (1990-2004) (ParisTech, 2008).

and ultraviolet solar radiation regions, namely between latitudes 35°N and 35°S. For this reason these countries and regions can count on solar radiation as a steadfast source of energy that can be readily exploited cheaply by both rural and urban households for a multitude of purposes, including for example solar water pumping, solar power generation and solar disinfection of drinking water.

It is well known that one of the continents of the world that lies within the most favourable solar belt Africa, is a solar rich continent. Yet many of the rural villages and communities in this continent have long been deprived as a result of a lack of electrical power.

The solar resource map in Figure 18.8 reveals that parts of Africa have a very high potential for solar energy harvesting and shows good potential for solar energy project development. Comparative studies have shown that places on the African continent measures annual global irradiation levels of approximately double that of a region such as southern Germany (SolarGIS, 2014), a region which invests heavily in renewable energy projects. It supports the view that solar energy is an ideal natural resource for driving economic development and that novel solar thermal power generating designs are called for to utilize the rich sunlight resource in Africa for the betterment of especially the disadvantaged community.

Another regional map, shown in Figure 18.9, displays the average annual solar distribution for China (SolarGIS, 2014). Solar system manufacturers in China have traditionally exported PV modules and solar cells to the rest of the world. These manufacturers are now keen to develop their own domestic and rapidly growing market, a drive that is supported by China's latest five-year plan (2011 to 2015). In this plan, renewable energy was singled out as a key strategic economic sector (Solidiance, 2013).

Even for a country like India, for which the map in Figure 18.10 displays the average annual solar distribution, the potential for the utilization of solar energy is quite good (SolarGIS, 2014). However, it should be kept in mind that India is known for its complex climate and geography and factors, such as the influence of monsoon rains on solar radiation during certain parts of the year. Their complex climate complicates solar power generation prediction, since radiation and other meteo parameters can change very rapidly and has a large impact on solar energy production. SolarGIS satellite-based solar database

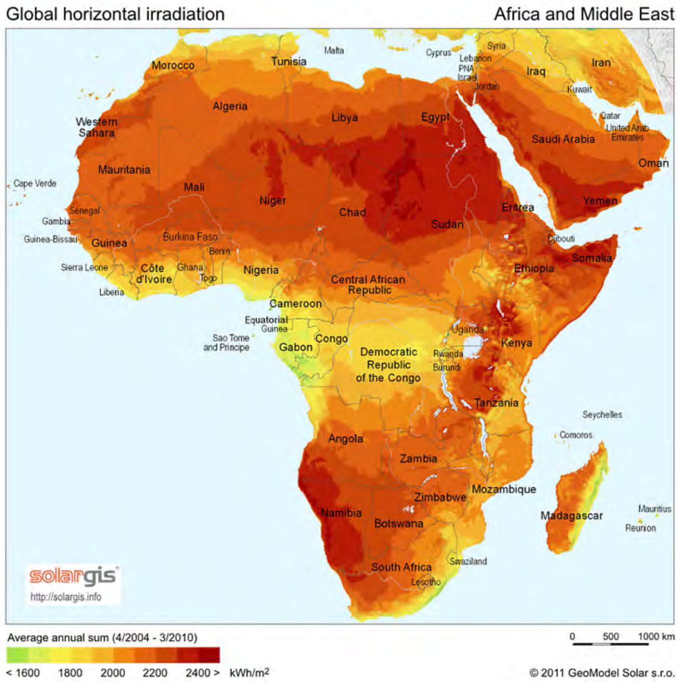


Figure 18.8 Average annual solar distribution for Africa (SolarGIS, 2014).

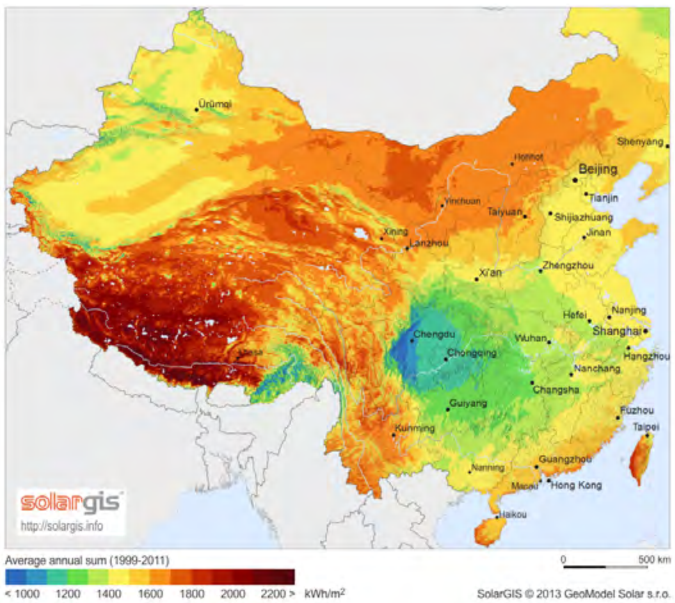


Figure 18.9 Average annual solar distribution for China (SolarGIS, 2014).

for India covers historic data from last 12 years and is updated live every 15 minutes and can be consulted for any specific region of interest in India (India Carbon Outlook, 2014).

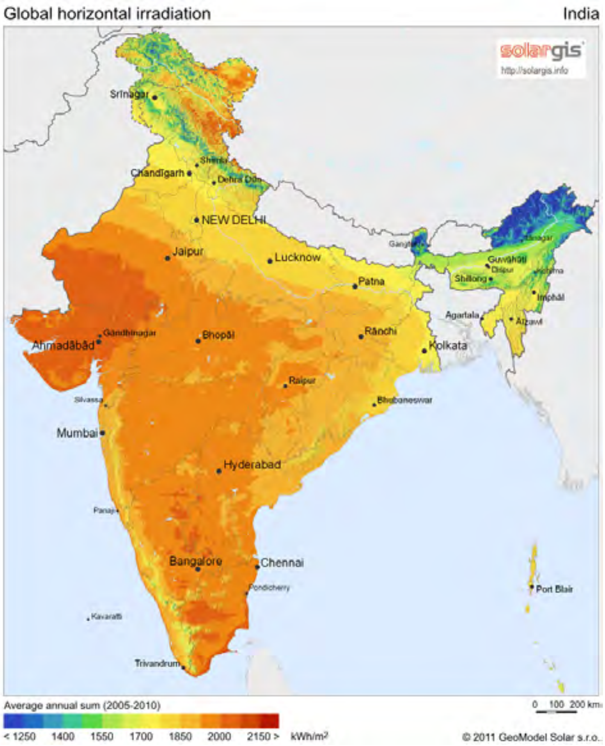


Figure 18.10 Average annual solar distribution for India (India Carbon Outlook, 2014).

Thanks to India's online Carbon Outlook resource database, that shows interactive maps and solar power estimators (India Carbon Outlook, 2014), solar power system design in India has been greatly simplified. This solar information service, built on the SolarGIS platform, includes a number of helpful high-resolution solar resource distribution tools. One of these tools, SolarGIS pvPlanner is a solar power generation simulation tool that can be used to plan photovoltaic installations based on climate and geographic data. Such tools are helpful in identifying the potential of particular installation sites in India and enables the calculation of potential solar power production. The site further offers a range of other applications for potential site prospecting as well as solar power generation potential based on predicted data.

Another interesting case in point is the developing countries of South America, including Brasilia, Argentina, Chile, Panama, Peru, Paraguay, Uruguay, Bolivia, Colombia, Venezuela, Ecuador, and its islands. Figure 18.11 displays an image of direct normal solar radiation in South America measured by NREL under the SWERA project (NREL, 2014*g*). These maps were compiled for solar PV systems and provide monthly average and annual average daily total mainly for PV solar resources, averaged over surface cells of 0.1° in both latitude and longitude (10 km rectangle).

The maps in Figure 18.8 to Figure 18.11 once again illustrates the value and importance of solar energy in developing countries. It again supports the view that solar energy is an ideal natural resource for driving economic development and that novel solar thermal power generating designs are called for to utilize the rich sunlight resource in South Amer-

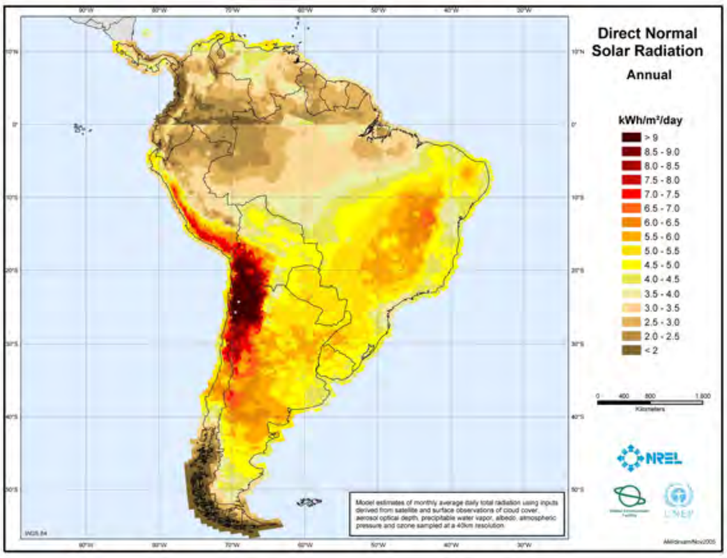


Figure 18.11 Average annual solar distribution for Brazil, Argentina and South America (NREL, 2014*g*).

ica where a number of disadvantaged communities are also deprived certain qualities of life.

Climate change is likely to have a more severe impact on communities in Africa, India, China and South America because of adverse direct effects, like floods and droughts, and a high dependence on agricultural success for large parts of the continent (Collier *et al.*, 2008). This puts additional pressure on governments to provide technology, incentives and economic environments to help facilitate social adjustments to change. While many rural villages experience high levels of solar radiation, rolling out reliable solar solutions for tapping into this renewable energy resource in rural areas pose a number of challenges, for example the cost of these systems, maintenance at remote sites and the reliability and robustness of the design (Collier *et al.*, 2008).

Historically, studies like the European Photovaltaic Industry Association (EPIA) prospect analysis (EPIA, 2014) placed significant emphasis on the role and development of off-grid solar power installations and microgrid systems in developing countries. This particular study for example noted that: "Long before PV became a reliable source of power connected to the grid, it was largely used to provide electricity in remote areas that lay out of the reach of electricity grids. While off-grid systems in Europe account for less than 1% of the installed PV capacity, they represent a significant power source in other parts of the world. For this reason, off-grid systems are also taken into account in the total installed capacity. In the USA, off-grid systems represented 10% of the overall market in 2009 and declined since then. In Australia and South Korea, dozens of megawatts of off-grid capacity are installed every year and are accordingly taken into account in the total installed capacity in those countries. In countries such as India or Peru, the development of PV in the coming years could originate at least partially from hybrid systems and micro-grid applications. In that respect the notion of on-grid or off-grid installations could be more difficult to assess outside Europe" (EPIA, 2014).

The map in Figure 18.12 displays the annual quantity of energy for Europe. This yearly irradiation is expressed in kWh/m^2. This map was also computed from meteorological satellites observations.

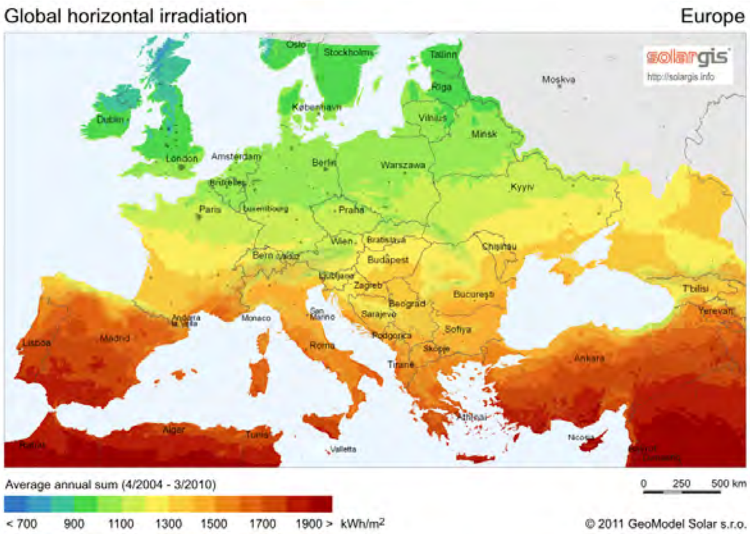


Figure 18.12 Average annual solar distribution for Europe (SolarGIS, 2014).

For Europe, one valuable resource is the book, The European Radiation Atlas (de Greif and Scharmer, 2000). This is an resource that focus on knowledge and the exploitation of solar resources for the continent. It describes the trajectories of the sun as it moves across the sky in Europe throughout the year for particular geographical locations. The content also deals with solar radiation interaction within the context of atmospheric components (haze, turbidity, clouds, etc.), as well as the scattering of radiation into the direct and diffuse parts in Europe. The book presents details on solar radiation in various domains of importance for solar power engineering, and describes the regions in which solar energy is used to provide electrical power systems, heating for houses hot water systems.

The map in Figure 18.14 shows the average annual solar distribution for the Ukraine (SolarGIS, 2014). The map shows that the souther region of the country includes solar distribution comparable with the subtropical Mediterranean.

Australia has a dry climate and the map in Figure 18.13 shows shows that the country has a high potential for solar energy production (SolarGIS, 2014) (see `http://www.victoria.ac.nz/architecture/centres/cbpr/resources` for sun path diagrams for New Zealand cities (CBPR, 2014)).

Finally, an interesting tool used in the analysis of solar power levels and potential harvesting capabilities is the NREL Solar Prospector (NREL, 2014*d*). The National Renewable Energy Laboratory of United States (NREL) has done an amazing job developing the Solar Prospector, a tool to navigate through data derived from satellite imagery with a resolution of 10$\times$10 km. This mapping tool is designed to help developers site large-scale solar plants by providing easy access to solar resource datasets and other data relevant to utility-scale solar power projects. Unfortunately the information is only for United States, but the concepts used in this tool may be valuable enough for researchers from other countries to develop similar tools.

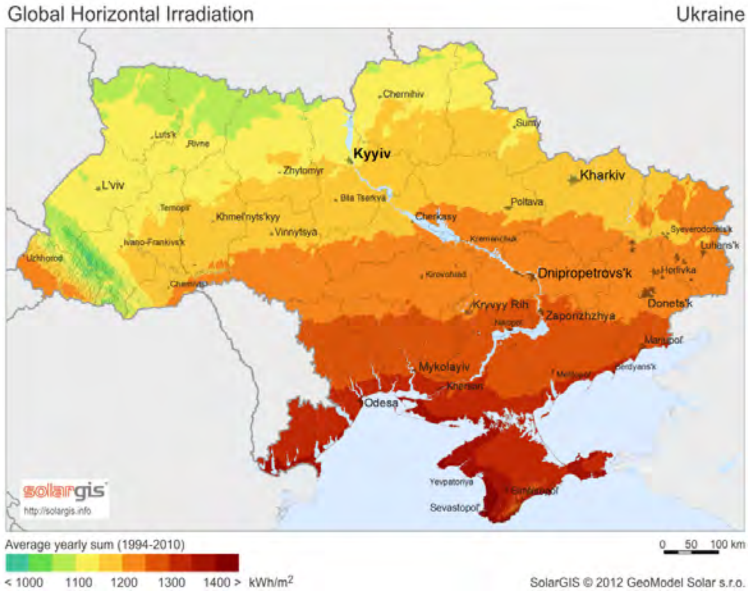


Figure 18.13 Average annual solar distribution for the Ukraine (SolarGIS, 2014).

Further maps showing the global solar irradiation for various other countries and regions not shown in this book are available on this page to download (SolarGIS, 2014). SolarGIS database is the source of solar data represented on the maps. Global horizontal irradiation is the most important parameter for evaluation of solar energy potential of a particular region and the most basic value for PV simulations.

18.4 Summary

This chapter detailed various aspects of the sun as energy source, the radiation spectrum of the sun above and below the earth's atmosphere. The discussion also showed maps of the solar resource distribution to give an idea of the amount of solar energy that is available in different parts of the world and the average solar energy available to harvest with any solar harvesting means. One important aspect with solar harvesting is that an harvesting means, such as a parabolic dish or photovoltaic panel array, must be tracked in two dimensions in order to allow focussing of the sunlight and to maintain the incident beams of the sun normal to the solar receiver means.

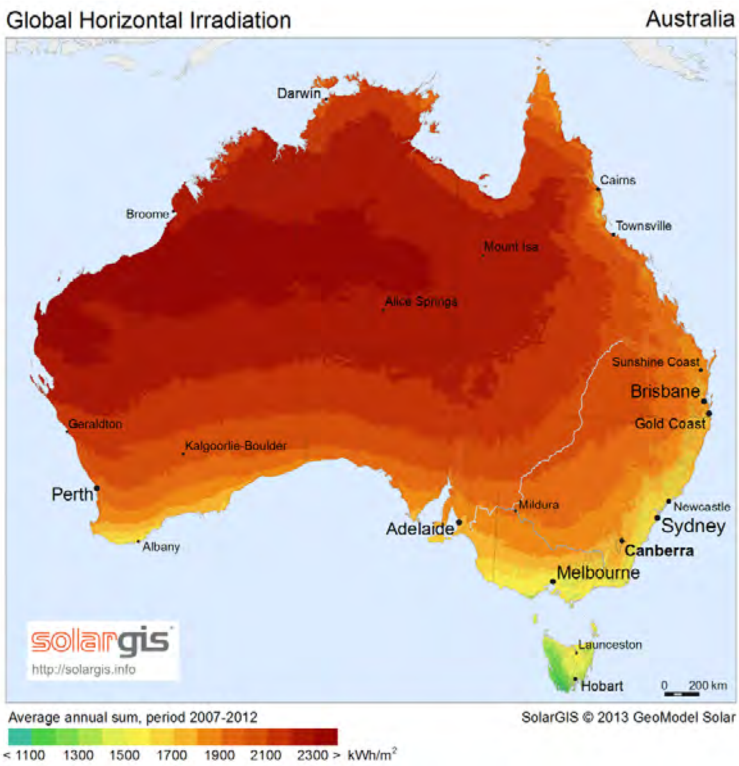


Figure 18.14 Average annual solar distribution for the Australia (SolarGIS, 2014).

CHAPTER 19

SUN SURVEYING AND SOLAR RESOURCE MODELLING

19.1 Introduction

Solar radiation and solar energy budget studies are important to be able to understand the complexity of the solar energy and spectral composition of the solar thermal energy at the tracker location. To detect long term trends regarding climate changes, accurate solar irradiance data and other atmospheric parameters are needed to feed the climate models. Therefore solar sensors and geographical information databases are used to measure and log the Direct, Global and Diffuse irradiance.

Solar tracking is also an important tool for solar resource assessment and for the analysis and modelling of solar energy for a particular city, area, location or region. This is because solar resource assessment is the first step in the process of designing solar applications for a particular area or region since it helps to determine economic viability of a solar harvesting project. This analysis process provides information about the sources characteristics and such measurements are important inputs for any simulation or feasibility study (ISEC, 2001).

19.2 Analysis and Modelling of Solar Energy for City or Region

GIS systems are ideal platforms as tools for solar prospecting, solar investment analysis and for the modelling of solar representations. The NREL SOLRMAP initiative acquires, ground-based solar data for the modelling of solar maps form satellite for example (NREL, 2014*b*). These models and maps are based on data from satellite images that is used to measure and generate hourly estimates of DNI and global horizontal irradiance (only United States), for up to 30 minute temporal and 4 km x 4 km spatial solar mapping resolution.

Figure 19.1 illustrates a typical GIS solar resource system (Hoyer-Klick *et al.*, 2009). It also illustrates the hierarchical importance of solar resource data to start a cascade of steps and decisions in preparation for solar installations and picking of solar energy technology. Measuring, assessing or predicting solar flux and solar DNI data are important steps to analyse and consider the major influences on any the application, especially since the optimizing of a solar harvesting system in terms of efficiency in over different seasons is crucial (see `http://solargis.info/doc/solar-and-pv-data`).

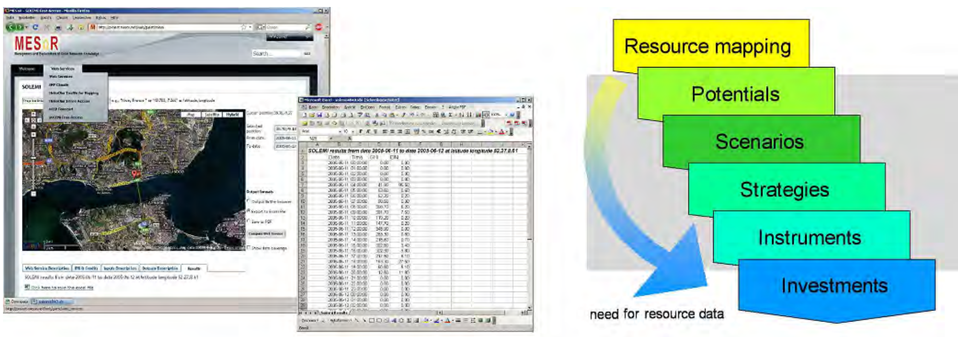


Figure 19.1 Example of solar GIS software and solar resource data required in a cascade of steps and decisions in preparation for solar installations and picking of solar energy technology (Hoyer-Klick *et al.*, 2009).

As mentioned earlier, the solar irradiance for a specific location affected by different factors including the cloudiness and the change of the sun position. Therefore understanding the solar resource at the required location can significantly influence the performance of any solar tracking system, and the best way to pre-determine the capacity performance of the system is through solar radiation analysis and modelling. While following the course of the sun in the sky, the GIS sun surveyor system should also log collect data and information associated with atmospheric conditions, climatology of solar radiation and the influence of the seasons and orography.

Many new commercial Earth-observatory platforms such as Google Earth and Microsoft Bing Maps (Virtual Earth Bing Maps API) may be of help to simplify solar geographical systems (http://www.programmableweb.com/api/bing-maps) (Bing, 2014). Microsoft Virtual Earth 3D (an extension for Internet Explorer) is another platform that lets the designer display 3D views of the main cities in the USA (Microsoft, 2014). These platforms may be an interesting feature of a solar surveyor if solar resource displays can be integrated on this platform.

The NREL website (http://www.nrel.gov/solar_radiation/), Kipp & Zonen website (http://www.kippzonen.com/) and the MeteoControl website (http://www.meteocontrol.com/en/) are good starting points for those readers interested in solar data acquisition, solar prospecting, or the analysis and modelling of solar power systems for a particular country, area, region, city, place, premises or location. Custom developed GIS solar resource data can also be used in solar energy technology planning, climate change research or in the development of solar models. An Open source solar spectrum project and Open Source Solar Spectrum Analyzer with source code (http://www.appropedia.org/Open_source_solar_spectrum_project) will also help to get the reader going with a customized sun surveyor experiment (Pearce, 2014).

19.3 Analysis and Modelling Tools in Solar Energy for City or Region

CSP systems focus sunlight onto a receiver and replies on the direct solar beam DNI. Consequently, the measuring, mapping, and modeling the DNI resource are essential. One of the NREL tools, namely the Solar Resource and Meteorological Assessment Project (SOLRMAP), has the ability to collect precise, long-term solar resource measurements for a particular location (see site http://www.nrel.gov/midc/ (NREL, 2014*a*)). Normally NREL provides expertise for station design, instrument selection, data acquisition, quality procedures, data analysis, calibrations, and data distribution, while the solar developer carry the cost of using the instruments, maintenance, and station operations(NREL, 2014*b*).

There are also many other tools available to compile a solar model for a particular location by measuring and analysing the fluctuations of the solar radiation (i.e. direct and diffuse radiation) as well as atmospheric conditions at a particular location or in a particular region (KippZonen, 2014). Tools such as those on SkyServer can be valuable to solar researchers http://cas.sdss.org/public/en/tools/.

Software tools from the University of Oregon was developed to collect solar radiation data used in predicting the performance of many different systems from heating loads on buildings to electricity produced by concentrating collectors. The argument is that it is not feasible only to measure the solar resource for all these potential uses, but models must be developed to calculate the incident solar radiation (Oregon, 2014).

The surveyor products Autodesk Vasari and Revit are solar radiation analysis tools normally used in buildings and architectural designs to iteratively test solar radiation on the faces of a conceptual mass. With Autodesk Vasari the user can visualize and quantify the amount of solar radiation a building receives when one create a conceptual structure or mass (Autodesk, 2014*c*).

Climate visualization with Matlab is further available on this link `http://www.tedngai.net/?p=571` (Ngai, 2014).

In solar power systems, it is important to understand the patterns of solar radiation that affect the solar tracking system. The same representation can be used to provide a visual display of the available solar energy at a particular solar tracking installation site (e.g. PV panel faade instead of a building faade). One can therefore use the so called Massing Strategies for Passive Heating Analysis Tool to analyse/display the solar incident radiation throughout the day and throughout the year on the five exposed faces of a cube-shaped solar receiver (for example a building). In this type of representation in Figure 19.2, the vertical axis shows times of day while the horizontal axis shows times of year, and the color shows the amount of incident heat (Autodesk, 2014*b*).

In Figure 19.3, there is shown an example of another type of display. This diurnal weather average chart illustrates the solar irradiation for a particular geographical location, with atmospheric and weather data superimposed on the solar data (Ecotect, 2014*c*). The chart shows both direct and diffuse solar radiation in association with the atmospheric and weather data.

In this example (Figure 19.3 for Copenhagen), the location is cloudy in the winter meaning the absolute value of direct radiation is lower and the diffuse radiation is higher, but keep in mind that diurnal weather charts may also show that solar radiation can also create hotter weather which in turn will affect humidity (Ecotect, 2014*c*).

The NREL SRRL BMS web site serves as a very handy reference guide for those readers interested in professional modelling of solar irradiation and meteorological datalogging. Apart from a host of data for various locations (solar calendars, wind roses, precipitable water vapor, etc), a very interesting feature of this NREL solar surveying data service is the All-Sky (180° fish eye lens) Web Cam feature (NREL, 2014*a*). It shows a SkyCam Snapshot of the current sky-conditions (updated every 5 minutes) as shown in the example of Figure 19.4. The resource website also includes SkyCam Image Gallery with historical snapshots every hour, as well as Daily SkyCam Animations will animate all the hourly historical snapshots (NREL, 2014*a*).

Photos of instrumentation and trackers at SRRL's Baseline Measurement System is shown on this link `http://www.nrel.gov/midc/srrl_bms/pictures.html` (NREL, 2014*a*). This site includes a gallery of pictures of solar tracking systems associated with solar surveying systems. The general Measurement and Instrumentation Data Center (MIDC), providing Irradiance and Meteorological Data from a number of stations on this site `http://www.nrel.gov/midc/` (NREL, 2014*a*).

Determining the amount of electricity that can be generated at a specific GPS location largely depends on the type of solar harvesting means and its rating. For example, the standard solar energy rating is around 1 kW/m^2, but most systems (depending on the technology) will only gain energy with around 15-50% efficiency at best (see Section 13.1).

There are also Solar Calculators that can calculate the amount of clean electricity that can be harvested from the sun at a particular address or geographical location. The NREL PVWatts Calculator help to estimate the energy production and cost of energy of grid-connected photovoltaic energy systems throughout the world, allowing homeowners, small building owners, installers and manufacturers to easily develop estimates of the performance of potential photovoltaic installations (NREL, 2014*c*). Other solar calculators allow the developer to enter the location address or GPS information or to find the location by

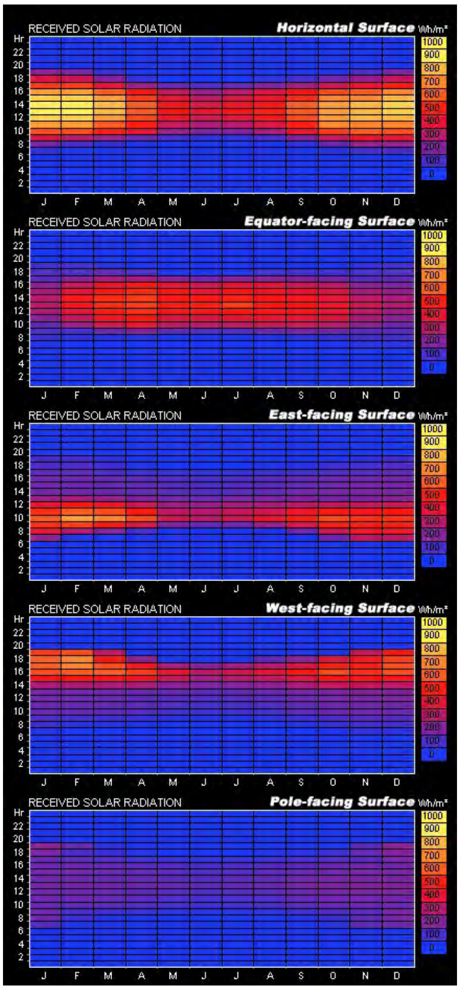


Figure 19.2 Graphic visualization uses cumulative incident solar radiation and normal radiation data to draw a type of bar graph for each face of the five faces of a cube shaped building fitted with photovoltaic panels (Krymsky, 2013).

clicking on a map `http://www.wunderground.com/calculators/solar.html`. More solar calculator links are listed in Section 26.3 of this book.

With these tools, solar DNI and irradiance information and models can be integrated into a solar map, solar atlas or geographical information systems such as GIS or ArcGIS (ESRI, 2010). Such solar mapping models allows for defining local parameters for specific regions that may be valuable in terms of the evaluation of different solar in photovoltaic of CSP systems on simulation and synthesis platforms such as Matlab or Simulink (MathWorks, 2014) or DER-CAM (Stadler *et al.*, 2013).

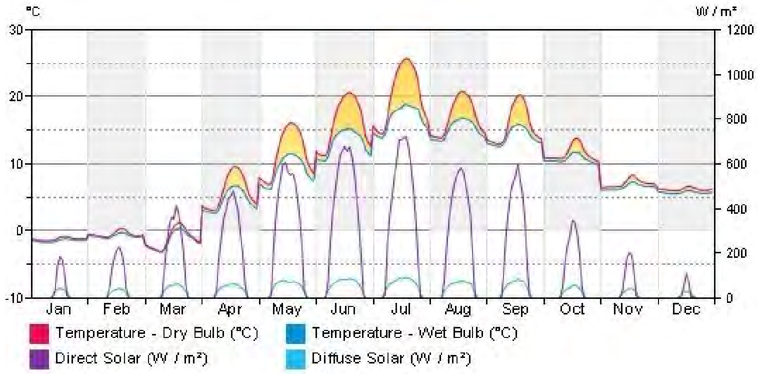


Figure 19.3 Example of diurnal weather average chart showing both direct and diffuse solar radiation for a city that is cloudy in the winter - meaning the absolute value of direct radiation is lower and the diffuse radiation is higher (Ecotect, 2014*c*).

Figure 19.4 NREL solar surveying data service includes the All-Sky 180° fish eye lens as skycam webcam feature that takes images of the sun to help model the solar irradiance for a particular location (NREL, 2014*a*).

19.4 Calculating the Solar Radiation for any Location on the Earth

For a solar module that directly faces the sun so that the incoming rays are perpendicular to the module surface has the module tilt equal to the sun's zenith angle and the module azimuth angle equal to the sun's azimuth angle. The calculations to combine the calculation of sun's position with the Airmass formula and then calculates the intensity of light incident on a module with arbitrary tilt and orientation. JavaScript example and formulas to calculate Solar Radiation on a Tilted Surface is given on this link `http://pveducation.org/pvcdrom/properties-of-sunlight/arbitrary-orientation-and-tilt` (PVEducation, 2014).

The average daily horizontal surface solar irradiation data for many locations on the earth are published. However, sometimes a more accurate indication is required of how much solar irradiation energy at a particular location (`http://www.itacanet.org/solar-panel-angles-for-various-latitudes/`) is falling on a solar receiver that is titled at an angle from the horizontal. This can be done through a series of calculations. The ATACA site includes formulas for a simplified calculation to find the total daily irradiation falling on a tilted surface that faces towards the equator, and a more complex calculation that calculates the irradiation on a titled plane hour by hour through the day. Both methods follow the same basic path and is available on this link http://www.itacanet.org/the-sun-as-a-source-of-energy/part-4-irradiation-calculations/ (ITACA, 2014).

Solar radiation for any geographical location can be calculated on the basis of solar availability using the Points Cumulative Insolation Analysis techniques. It can be used to generate Incident Solar Radiation Graphs and Maps for a given GPS location. The results for solar availability using an analysis grid can also be displayed on a map http://wiki.naturalfrequency.com/wiki/Solar_Radiation_Analysis. Ecotect tutorials are available for solar radiation analysis (http://sustainabilityworkshop.autodesk.com/buildings/ecotect-solar-radiation) is available on this page http://wiki.naturalfrequency. com/wiki/Solar_Availability_Tutorial (Ecotect, 2014*b*).

Source Code for Solar Analysis Programs and Classes tools (http://www.builditsolar.com/References/Source/sourcecode.htm) (BuiltItSolar, 2014) include programs to estimate the solar radiation that will fall on a planar solar collector surface as a function of the collector orientation, solar simulation example that shows how the Sun, TMY weather, and Collector classes can be used to build a simulation of a solar collector using actual weather and a solar collector defined by its efficiency curve, and a module to represent the position of the sun based on date, time, and location inputs, it provides sun elevation and azimuth angles, and sunny day solar direct and diffuse radiation.

19.5 Sun Surveying Spectral and Weather Instrumentation

Accurate broad-band solar radiation measurements are obtained using a suitable set of pyranometers, including an optional pyrheliometer (DNI sensor) with sun tracker, and an adequate data logger. A good broad-band pyranometer and pyrheliometer should have a flat spectral response which measure the broad-band solar radiation homogeneously. Broad-band radiation sensors are physical instruments which provide accurate measurements if they are maintained and calibrated routinely (Eco Instruments, 2014).

Sunlight spectrum content and levels are measured with a Solarimeter instrument that uses a thermopile to measure the solar radiation levels. A good thermopile must have a flat response to the whole spectrum that is measuring. An instrument that measures only energy levels as a function of infrared wavelengths is called a Pyrgeometer, but if is is designed to measure the visible spectrum, then it is referred to as a Pyranometer. Such devices measure the total electromagnetic radiation levels from various angles of incidence by way of determining the photon levels of light within selected spectral frequency bands through different masks and sensors. The Solarimeter can be configured to specifically measure the direct component of the solar radiation in which case it is referred to as a Pyrheliometer (Duffie and Beckman, 2006).

Pyranometers are radiometers designed for measuring the irradiance on a plane surface. The Pyranometer thus gives the user three key outputs, namely global radiation, diffuse radiation, and sunshine duration. A variety of models of Solarimeters can be selected to measure the full solar spectrum from infrared to ultraviolet (see Figure 19.5) (KippZonen, 2014).

In general, a differentiation is made between measurements for Direct Beam Radiation, Direct Horizontal Radiation, Diffuse Horizontal Radiation, Global Horizontal Radiation (sum of both the direct and diffuse components as measured incident on a flat hori-

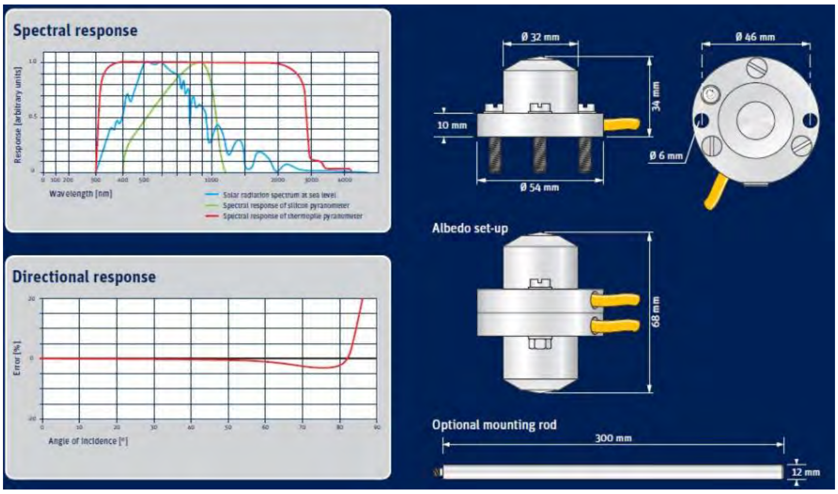


Figure 19.5 Example of the directional and spectral responses of the Kipp and Zonen Pyranometer SP Lite2 Silicon Pyranometer (Eco Instruments, 2014).

zontal plane), derived from solar radiation measurements available from weather stations equipped with instruments such as pyrheliometers, pyranometers or solar colorimeters, that include sensors that use photo-sensitive material, charge-coupled devices (CCD) or thermocouples to measure the amount of radiation coming from the sun (Ecotect, 2014*b*) - more of which can be read in this link: `http://wiki.naturalfrequency.com/wiki/SolarRadiation/Components`.

The principle of operation of a Solarimeter as it measures the radiation level of solar exposure at any location on the surface of the earth, proving the solar radiation flux density readings in W/m^2. Where a Solarimeter measures the combined direct and diffuse solar radiation, a Pyranometer measures only the direct component of solar irradiance. This meter effectively measures the total electromagnetic radiation levels from various angles of incidence by way of determining the photon levels of light within selected spectral frequency bands through different masks and sensors (KippZonen, 2014).

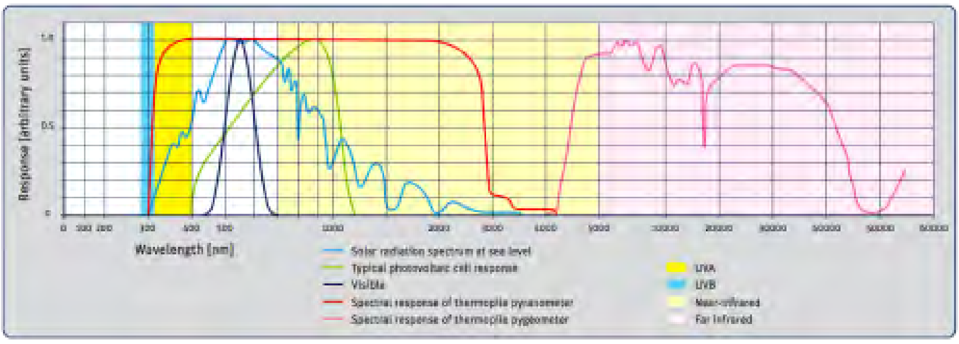


Figure 19.6 Full solar radiation spectrum measured by Kipp&Zonen instruments shown in the graph index (KippZonen, 2014).

To end off the discussion on the solar energy spectrum, Figure 19.6 is presented to show an example of the full spectrum solar radiation measured through a range of meters as (Pyrgeometer, Pyranometer) as indicated in the graph index. In terms of terminology, the fact that the earth's outer atmosphere receives on average approximately 1366 Watt/m^2 of insolation is called the Solar Constant Gsc.

The Meteocontrol weather station can be installed an monitored using the Meteocontrol online interface http://www.meteocontrol.com/en/ or the Safersun Professional (weather station) mobile app http://www.meteocontrol.com/en/industrial-line/portals/safersun-professional/ (MeteoControl, 2014).

Figure 19.7 Examples of Eko Instruments Pyranometer and Sun Tracker (Eco Instruments, 2014).

The company EKO Instruments (Eco Instruments, 2014) specialises in solar and environmental management and analysis and supply products (see Figure 19.7) from in-house development for Solar Energy Solutions, Instrumental Meteorology, Atmospheric Environment and Plant Science as well as Material Characterization and Analysis [1]http://eko-eu.com/products/solar-radiation-and-photonic-sensors/sun-trackers.

The EKO Instruments SRF-02 All-sky camera comes with new cloud analysis software (see Figure 19.8) that is capable of classifying clouds and cloud influence on solar radiation (Eco Instruments, 2014). Optical Thin and Thick layer clouds can be automatically examined trough the find clouds analysis software while cloud image parameters can be individually tuned by the user.

The All-sky camera makes full hemispheric pictures of the sky under low and full sun light conditions. With the find clouds software detection algorithms and the horizon determination tool are particularly interesting features for photovoltaic evaluation applications. The latest software version provides sophisticated algorithms to perform thin and thick layer cloud analysis http://eko-eu.com/news/new-cloud-analysis-software (Eco Instruments, 2014).

Other EKO instruments include small radiometers, pyranometers (ISO9060), spectroradiometers, Calibrated Solar Radiation Sensors, Calibrated Pyranometer (solar radiation reference meters compliant to ISO17025/ISO9847 for the solar energy market), and multi-panel IV curve tracer systems for PV performance evaluation, while information on an

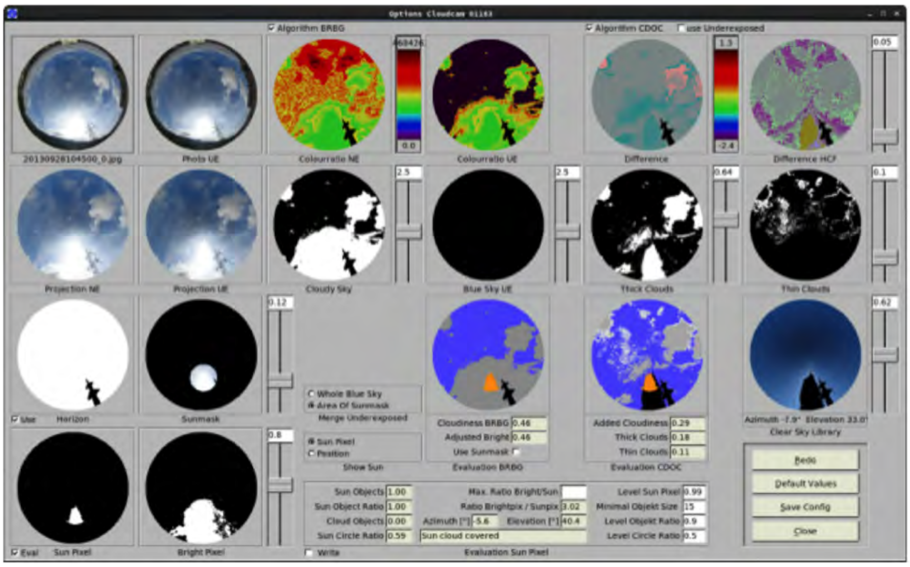


Figure 19.8 Examples of Eko Instruments Pyranometer and Sun Tracker (Eco Instruments, 2014).

associated a solar tracker system is available on this link `http://eko-eu.com/products/solar-radiation-and-photonic-sensors/sun-trackers`.

19.6 Summary

The solar and meteorological research community studies solar distribution and climate changes at various sites of interest. With modern advanced measurement equipment (satellites, remote sensing technologies) and sophisticated computer models, multiple meteorological parameters can be analyzed at a large scale. Climate system is very complex and it is difficult to give accurate predictions of our future climate, but climate models are used to predict atmospheric data from historical data.

GIS systems are ideal platforms as tools for solar prospecting, solar investment analysis and for the modelling of solar representations. It presented frameworks for calculating the solar radiation for any location on the earth and also Instrumentation for sun surveying as well as solar spectral and weather analysis. For further reading, this page `http://www.builditsolar.com/References/SunChartRS.htm` lists a number of resources is listed on Solar Site Survey, Skyview to do solar shading surveys, Solar Shading and Other Solar Tools, Bright Harvest Solar Survey, Effects of Tilt and Azimuth On Annual Incident Solar Radiation, Solar Position, Solar Radiation, Solar Design Climatic Data and more (BuiltItSolar, 2014).

PART VIII

OVERVIEW OF BEST PRACTICE DESIGNS

CHAPTER 20

SMALL SOLAR TRACKING PLATFORMS

Solar Tracking, First Edition.

20.1 Introduction

This chapter presents a literature review and introduces theoretical models for harvesting solar power by means of a concentrated solar power system. A broad overview of existing solutions from literature on commercial dish Stirling systems are presented in this review.

20.2 Small Concentrating Solar Power Systems

For the purposes of the current chapter, smaller (less than <5 kW) field tested systems, with their respective design features, tracking actuators and control benefits need to be carefully evaluated. Some of these designs and their features will be considered.

Figure 20.1 Arizona University boxed telescope concentrated solar power system and solar tracking design (Angel and Davison, 2009).

Viewing concentrated solar tracking design from a precision telescope design point of view, Arizona University researchers proposed a novel solar concentrator and tracking design concept (Figure 20.1). This solar tracking design emerged from team research in the field of astronomy and low cost high precision telescope design (Angel and Davison, 2009). Their dual-axis solar tracker includes multiple dish-shaped monolithic mirror elements, made from low cost float glass. These elements are co-axially aligned in an array supported by a large moveable lightweight box-shaped steel frame. In order to minimize gravity and wind forces on the structure, the steel frame and array is able to swing about the cantilever which is balanced on the elevation axis. The tracking actuator assembly includes independent chain drives for both azimuth and elevation angle mobility. This design provides a cost-efficient solution for capturing light from the sun and provides a platform for both Stirling and concentrated photovoltaic power generation.

The Solartron system (Figure 20.2) was designed for direct heat transfer or CPV power generation and is strictly speaking not a Stirling solar concentrator power generating system (Solartron, 2013). However, the dish and actuator presents a solution aimed at simplicity and low cost. The dual-axis solar tracking actuator system for the Solartron concentrator solar system includes a slew drive mechanism for achieving azimuth axis rotational mobility. The advantage with the slew mechanism is that a large gear ratio can be realized through a planetary gear supplemented DC drive system. Very precise positioning can thus be achieved with relatively small permanent magnet electric motors to drive the azimuth movements. Elevation mobility on the Solartron solar concentrator system is accomplished independently through a linear-drive actuator system. The advantage with this design is that the linear actuator inherently guarantees large gear-ratios with little or no backlash and require smaller motors with less torque, drawing less electrical current.

(a) (b)

Figure 20.2 Solatron hot water system produced in New Zealand showing (a) linear actuator elevation and (b) rotational azimuth drives (Solartron, 2013).

Researchers at the Department of Mechanical Engineering of the Indian Institute of Technology Madras (IITM) have developed a prototype 20 m^2 parabolic solar collectors (Figure 20.3(a)) (Reddy and Veershetty, 2013). The IITM solar concentrator dish is made of highly reflective light weight plastic mirrors placed on a rigid structure mounted on a single truss support. A circular slot midway in the dish structure diameter accommodates air flow through the dish to reduce the effect of wind on the structure. The thermal receiver is placed at the focal point, using supporting rods, while a counterweight at the back of the dish supports cantilever-type balancing of the dish over a support pedestal.

(a) (b)

Figure 20.3 Concentrated solar tracking systems developed by (a) Indian Institute of Technology Madras (Reddy and Veershetty, 2013) and (b) H-Fang dual-axis slew drive solar tracking mechanism (Juhuang, 2013).

Chinese based JuHuang New Energy Company also manufacture solar energy systems for photovoltaic and heliostat applications. One of their actuator designs include a dual-

Figure 20.4 The *Trinum* thermodynamic solar co-generating system produced by Innova in Italy (Innova, 2013).

axis slew drive tracking mechanism (Figure 20.3(b)) (Juhuang, 2013). This solar tracking mechanism was developed for mobility of photovoltaic and heliostat systems. From a rural power generation perspective, this dual slew mechanism provides an effective means of directing a parabolic solar concentrator. It incorporates a tracking system controller and supports astronomical dual-axis sun following. The actuator drive assembly integrates two slew gear drives fitted on a mounting in a perpendicular fashion. The slew drives ensures azimuth and elevation solar tracking motions using permanent magnet DC motors. The advantages of this assembly is that it provides a simple, easy-to-assemble and cost effective transmission solution built around two independent grease lubricated slew drives. The slew drives inherently ensures a self-locking mechanism which helps to prevent wind damage. Slew drives further require minimum motor inertia which ensures full motor movement control with high solar pointing precision and control reliability.

The *Trinum*, a 3 kW_t thermodynamic concentrated solar co-generating system (Figure 20.4) was developed in Italy by Innova (Innova, 2013). This co-generating system has the capability to produce 1 kW_e grid-parity AC electric energy through a Stirling unit (without an inverter) switchable to a 3 kW_t fluid flow thermal energy output, for example to dispatch hot water. The design of the Trinum system includes a dual-axis tilt-and-swing balancing beam cantilever concept similar the McDonnell Douglas solar tracking design (Mancini, 1997). In terms of actuator design, the Trinum differs from the McDonnell Douglas design in that it incorporates a perpendicular slew drive system instead of the planetary azimuth gearbox and linear elevation gear drive. The grease-lubricated slew drive design provides advantages in terms of simplicity and increased freedom of movement, while reducing the risks of soiling due to oil leaks and maintaining gearbox oils levels.

Aiming to improve the conventional McDonnell Douglas type designs, the Infinia Corporation evaluated a number of solar concentrator designs to find a design for small scale solar power generation suitable for mass-manufacturing (Infinia, 2012*a*). These designs focuses on smaller supply systems, utilizing Stirling systems developed for spacecraft, for which the company was able to develop a smaller solar concentrator/reflector and less complicated solar tracking systems. Figure 20.5 illustrate various Infinia design generations. The first model, Powerdish-I (a), was developed in 2006 and delivered 1 kW_e of electrical energy. Powerdish-II (b) was a 3 kW_e system completed in 2007, while the Powerdish-III

(c) 3 kW_e saw the light in 2008. The latest model of Infinia, the 1 kW_e Powerdish-IV (d,e), was released early in 2012 and was built around design concepts borrowed from the automotive industry. For example, the dish frame which supports the mirrors was designed on the principle of a lightweight automotive chassis.

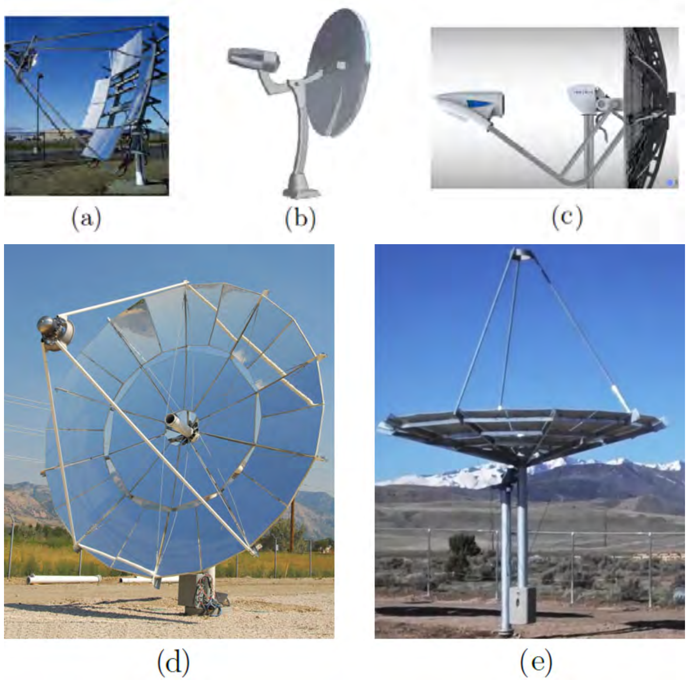


Figure 20.5 Four generations of the Powerdish I, II and III designs (a,b,c) and two photo angles of the latest Powerdish IV design (d,e) (Infinia, 2012*a*).

The Powerdish-IV solar concentrator design (Infinia, 2012*a*) resembles the structure of a spoke-wheel design of Erez *et. al.* (Shelef and Erez, 2011). This 3.5 kW_e system concentrator dish frame includes a plurality of angularly placed elongated structural members which supports the parabolic concentrator mirror facets on a lightweight automotive steel chassis, structurally stabilised using tension cables. The slewing actuator comprises two grease lubricated slew drives fitted in a perpendicular fashion. Two slew drives allows elevation and azimuth movements. An industrial standard PLC platform ensures electronically controlled solar tracking. This type of actuator design is commonly used in photovoltaic and heliostat systems, similar to the JuHuang actuator design (Figure 20.3) (Juhuang, 2013). A modification by Infinia was to place the vertical slew drive on the side of the horizontal slew in order to ensure that an overhanging cantilever beam would allow for a greater degree of freedom.

The Powerdish-III concentrated solar power system was claimed to be the worlds first industrialised, mass-manufactured Stirling-based solar power system, said to enable broad access to inexpensive solar power (Infinia, 2012*a*). Although the design concepts used in the Powerdish shows some promising features suitable for rural power generation in Africa, none of the Infinia solar power generation solutions is suitable for *stand-alone deployment* as it requires a grid-connection as backup power source.

Zenith Solar developed a scalable modular concentrated solar photovoltaic system fitted onto a dual axis actuator drive mechanism (Figure 20.6) (Tsadka *et al.*, 2008). The slewing actuators were designed to save on mechanical component costs for large solar farm installations and supports actuation of a dual-dish configuration driven by a compact dual-axis actuator. In terms of the dual-dish configuration, the Zenith Solar optical dish configuration deploys multiple mirrors onto a plastic surface casing which acts as housing for the dish elements. The 11 m^2 moulded plastic surface is divided into quadrants that are fixed onto a rigid, high precision metal frame mounted on an azimuth and elevation solar tracking system.

Figure 20.6 Zenith solar system produced in Israel (Tsadka *et al.*, 2008).

University of Western Ontario solar tracking researchers have developed a smart and cost-effective solar tracking system (shown in Figure 20.7) that can be expanded to support any load demand (WorlDiscoveries, 2014). This technology has two main components, namely a dual-axis sun tracker and a group bearing mechanism that forms a standard plug and play solar tracking system.

It is claimed that this combination is more accurate, more affordable, and can be used in a variety of different solar systems, such as concentrated photovoltaic, solar panels, parabolic dish, Fresnel lenses and other concentrating solar collectors (WorlDiscoveries, 2014).

The photovoltaic panel tracker system in Figure 20.8 is an example of a so-called Polar Tracker or Polar Tracking Actuator (Groene Energie, 2014). It increases the yield or the efficiency of a PV solar panel and optimize the use of the available surface area by using a sun-tracking system that avoids obstruction losses through shadowing from other photovoltaic systems in the same matrix/array installation (so called backtracking control).

The sun tracker model in Figure 2.32 (right) is part of a project programmed in Gambas2 and is concerned with the building and programming of a precision solar tracker. The sun tracking system includes PLC algorithm based solar positioning (not a sensor light shade) wherein an algorithm created by an astrophysicist can the predict solar position based on date and time (Sanchez, 2012).

Gross developed a system that has been dubbed in the media a Stirling Sunflower (Gross, 2014). This solar energy system tracks the sun using a genetic optimization algorithm by way of moving individual mirror facets that represents the leaves of a sunflower plant as shown in Figure 20.9. The video on this link `https://www.ted.com/talks/bill_gross_on_new_energy` explain the thinking behind the system as well as a demonstration.

An example of an integrated satellite and sun tracking-system with two axes tracking means is shown in Figure 20.10 (Aktuator, 2014). This biaxial sun tracking system is commonly used in heliostats for orientation mirrors redirecting sunlight along a given axis

Figure 20.7 Solar tracker actuator technology with two main components, namely a dual-axis sun tracker means and a group bearing mechanism (WorlDiscoveries, 2014).

for a stationary target or receiver. This actuator mechanism includes a lead screw means as well as a parallelogram jack to accomplish tracking on two-axes (Aktuator, 2014).

In Figure 20.11 there is shown a commercial do-it-yourself (solar) tracker kit and dish assemblies (RFHamdesign, 2014). Self assembly prime focus parabolic dishes are available as a DIY kit with a variety of F/D ratios (0.35, 0.40, 0.45 and 0.5), while parabolic mesh dish kits are available for a range of diameter dimensions (1 Meter, 1.2 Meter, 1.5 Meter, 1.9 Meter, 2.4 Meter, 3 Meter (F/D 0.40 and 0.45) and 4.5 Meter (F/D 0.45)). More details are available on this link `http://www.rfhamdesign.com/products/parabolicdishkit/index.php` (RFHamdesign, 2014).

An integrated slew drive mechanism for dual axis photovoltaic solar panel tracker is shown in Figure 20.12 (BizRice, 2014). In this system, rotating slewing drives are sandwiched on a fixed angle support to create a dual-axis tracking method. The integrated actuator simplifies the installation of the actuator on a pedestal pole, column or pillar and typically forms the core of a DC motor dual axis solar tracking system.

On the FormHaus internet blog (ForumHaus, 2009), in interesting discussion was started to develop a parabolic dish system that includes a tracking system built into the dish mirrors. This dish element tracking system concept is illustrated in Figure 20.13. It shows that a solar reflector may be divided into prisms (like there are billboards to change the image)

Figure 20.8 Solar tracker actuator technology working on the principle of Polar Tracking (Groene Energie, 2014).

Figure 20.9 Solar energy system tracks the sun using a genetic optimization algorithm by way of moving individual mirror facets (Gross, 2014).

that may be rotated every 10-15 degrees on the pivot. The discussion around this concept can be followed on this link `http://www.forumhouse.ru/threads/43523/page-16`.

This concludes the broad review of existing solutions from literature on customized and commercial solar trackers and dish Stirling system. The discussion serves as background in compiling quantitative design specifications for concentrating solar power systems.

20.3 Summary

This chapter detailed a literature study relating to various design options presented present-day and past commercial solar concentrator and positioning systems. This background serves to give insight into practical challenges with deploying concentrated solar and positioning systems in the field and demonstrate design concepts proposed by other researchers and designers.

Figure 20.10 Integrated commercial biaxial sun tracking system (Aktuator, 2014).

Figure 20.11 Picture gallery of a 3 meter dish kit with SPID Azimuth and Elevation rotator (RFHamdesign, 2014).

Figure 20.12 Integrated slew drive mechanism as dual axis photovoltaic solar panel tracker (BizRice, 2014).

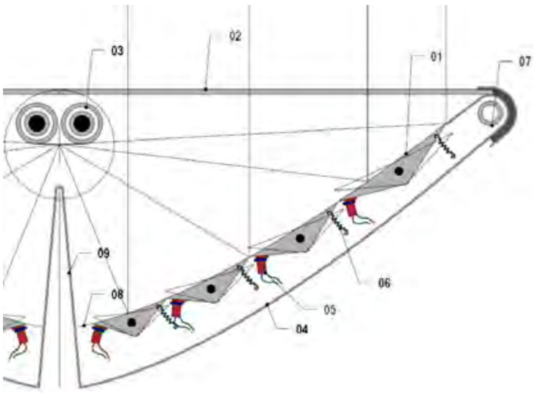


Figure 20.13 Solar tracker actuator includes moving prisms in the solar dish (ForumHaus, 2009).

CHAPTER 21

LARGE SOLAR TRACKING PLATFORMS

21.1 Introduction

This chapter presents a literature review and introduces theoretical models for harvesting solar power by means of a concentrated solar power system. A broad overview of existing solutions from literature on commercial dish Stirling systems are presented in this review.

21.2 Large Concentrating Solar Power Systems

As part of the literature study, emphasis is placed some of the most successful field-proven designs. In this section some of the design concepts found in technical- and evaluation- reports will be studied, as these reports typically provide valuable insights into best-practice designs.

The precursor to most successful utility scale industrial solar tracking systems for solar thermal electrical power generation is considered to be the Vanguard system (Figure 21.1). This 25 kW$_e$ system includes a 10.5 m diameter glass faceted dish and has set eight world records in 1984 (Mancini, 1997). Solar tracking is achieved by means of a novel design in which elevation lift is accomplished through rotational movement. The design incorporated a gimbal mechanism to attain lift through increased rotational torque (similar to a cam) and where on average 8% of the generated energy is used to drive solar tracking (92% nett gross energy generation efficiency). Whilst a solar flux to electrical conversion efficiency of 29% was achieved, problems were however experienced with noise, vibration, and excessive wear on non-hardened gears.

Figure 21.1 The Vanguard solar tracking system and drives (Mancini, 1997).

The Vanguard design was soon overshadowed by the simplicity, weight reduction and mechanical stability realised with the McDonnell Douglas tilt and swing solar tracking mechanism design (Figure 21.2; concept shown in Figure 2.5) (Mancini, 1997). In this design geometry, the weight of the reflector dish and the receiver/generator is balanced on a pivot point over the pedestal stand to achieve mechanical balance and stability.

Developed in 1984, the McDonnell Douglas Aerospace design proved to be one of the first commercially successful solar concentrator solar power generating devices (Mancini, 1997). This 25 kW$_e$ Stirling dish solar concentrator comprises of a 11 m diameter modular dish constructed as a support structure tiled with 82 mirror facets to provide 91.4 m^2 of

Figure 21.2 The McDonnell Douglas tilt-and-swing solar tracking system (Mancini, 1997).

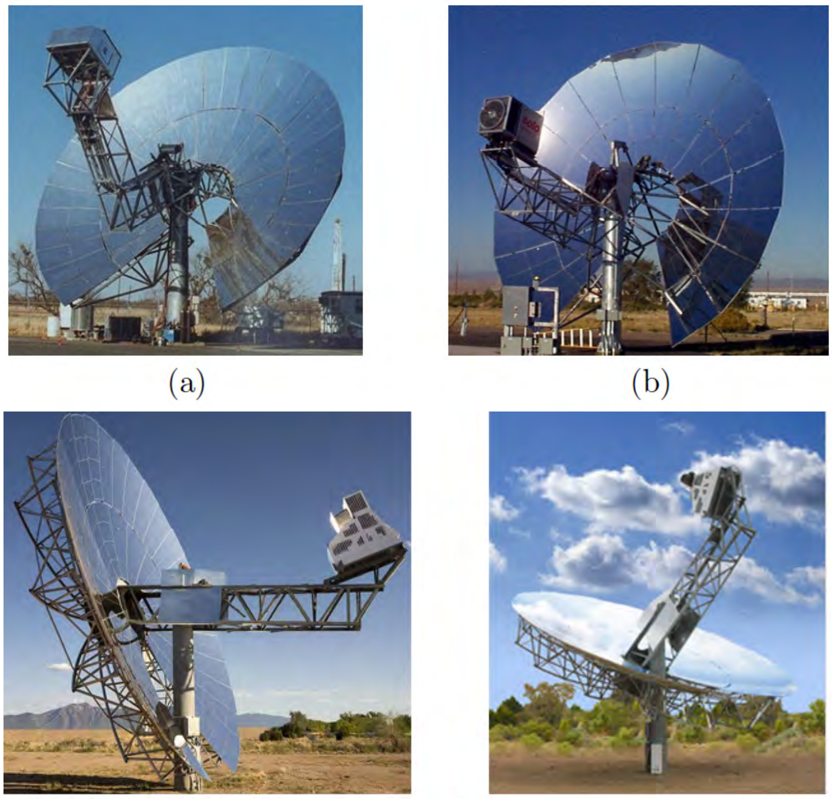
solar reflective area. The positioning system uses a balanced boom arm positioning system design to accomplish solar tracking on a dual-axis control mechanism. With the reflector dish on one end, and the receiver/generator on the other end, the boom balances on the pedestal stand on a pivot point at its centre of gravity. This solar tracking design integrates a dual drive system to electronically control the movement of the curved solar dish reflector in the altitude and the azimuth directions to ensure maximum heat to electrical power conversion through a Stirling engine.

Figure 21.3 Modifications to balanced cantilever-type design of the McDonnell Douglas modular parabolic dish (WGAssociates, 2001).

In terms of a dish structure, two alternative design changes have been made and tested, as shown in Figure 21.3. The modular dish on the left use multifaceted spherically shaped mirrors in a truss support structure, while the dish on the right is padded with shaped mirror sections to focus sun flux on the solar receiver. These ”balanced cantilever” type designs inherently guarantee near linear stability, while eliminating the need for additional counterweights to reduce the torque load on the drives. These features make this design concept ideal for solar tracking applications as it uses the structure’s own weight to balance the beam, which puts less strain on the bearings and drives. The lower torque demand requires less expensive drives and smaller electric motors to drive the concentrator dual-axis tracking motions.

Slight variations to the McDonnell Douglas design were also incorporated into the Cummins Power Generation solar tracker design, namely the 25 kW_e solar concentrator model WGA-1500 (Figure 21.4(a)), and the Sandia 10 kW_e model WGA-500 (Figure 21.4(b)). The 10 kW_e system (Figure 21.4(b)) proved to be suitable for remote off-grid applications when high gear ratio and smaller electric motors were used (WGAssociates, 2001). Field-proven commercial drives (mostly planocentric 16000:1 gear ratios) and linear actuators (off-the shelf ball screw linear actuators) were used and sized to fit weight and gravity load conditions for each concentrator.

The triangular cutaway in the bottom section of the glass-mirror surfaced section of the dish differentiates these designs from the Mcdonnell Douglas solar tracker design (which uses a narrower square cutaway section). This was done to since the reflection of light is screened by the crossbeam incorporated in this design concept. Although this cutaway reduced the weight of the moving dish, the modification moved the center of gravity upward,



(a) (b) (c) (d)

Figure 21.4 Solar tracker designs for (a) model WGA-1500 25 kW_e solar concentrator, (b) model WGA-500 10 kW_e solar collector and (c,d) the Suncatcher system (WGAssociates, 2001).

introducing potential instability. This was solved by introducing a V-shaped bend in the balancing crossbeam to lower center of gravity for stability.

(a) (b)

Figure 21.5 Concentrated solar tracker designs for (a) a test solar Stirling system by WG Associates, and (b) the Sandia stretched-membrane concentrated solar power system (WGAssociates, 2001).

Figure 21.5 shows (a) an 11 m diameter parabolic dish concentrator system built as a test system by WG Associates for Sandia in the USA, and (b) the 25 kW_e Sandia faceted *stretched membrane concentrator*. The design configuration of Southwest Solar Technologies (2013), namely the SolarCAT system (Figure 21.6), includes struts in front of the dish (similar to an umbrella structure) to support the 20 m diameter optical dish (focusing 230 kW_t of solar energy on the solar receiver). The struts were included to bring stability to the dish structure, however, it introduces a shadowing effect onto the mirrors which impacts on the efficiency of the system.

Figure 21.6 SolarCAT system of Southwest Solar, incorporating support struts for structural stability (Southwest Solar Technologies, 2013).

Figure 21.7 The HelioFocus concentrated solar dish with mirrors mounted on a flat surface (Smith and Cohn, 2010).

The Fresnel dish concept (Figure 21.7) is different from most other dish designs in that flat mirrors are individually orientated on a flat platform instead of a parabolic dish structure (Stine and Geyer, 2001). This focusing system operates similarly to the solar tower heliostat concept, but only on a limited-scale single dish frame. The mirrors are placed in a Fresnel configuration on a flat metal structure so that the composite shape of the mirrors approximates a parabolic shape, while the dish tracks on two axes. HelioFocus (Smith and Cohn, 2010) developed the *HelioBooster* system (Figure 21.7), which uses an array of small flat mirrors in order to reduce the complexity. This design resulted in lower manufacturing costs with dish efficiencies similar to conventional parabolic dish systems. This design geometry further allows for upscaling to accommodate larger dish configurations without the need for a larger footprint area. In comparison with a conventional parabolic dish, this flatter dish structure does not cause significant shifts in solar tracking balance if the dish size is increased (Smith and Cohn, 2010).

With a grant from the Swiss Commission for Technology and Innovation, IBM Research (Zurich) developed a High Concentration PhotoVoltaic Thermal (HCPVT) solar harvesting system. It includes a 40-square-meter parabolic dish made of fibre concrete and resembles a sunflower (Figure 21.8).

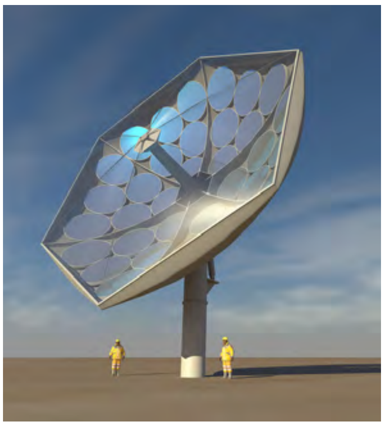


Figure 21.8 IBM economical high concentration photovoltaic thermal solar concentrator system (IBM, 2013).

This sunflower-inspired parabolic dish uses a multitude of mirror facets to concentrate sunlight onto several photovoltaic converter chips. The conversion chips form a dense array of multi-junction photovoltaic modules that operate as liquid-cooled microchannel receivers. Future work include plans to use the radiator liquid or hot water output to produce drinkable water in remote areas (IBM, 2013).

Figure 21.9 displays two similar solar tracking arrangements, namely (a) the Schlaigh Bergermann designed Eurodish design comprising of a 3.5 m diameter 10 kW_e dish (Mancini, 1997) and (b) the patented 3.2 m double diameter Titan Tracker dish designed in Spain (TitanTracker, 2013). These two designs are based on the same concept, namely a circular rail azimuth rotation path mechanism, with the Titan differing mainly in terms of the double dish system. The rail path provides some benefit in terms of azimuth stability, but problems may be experienced with accuracy due to dirt and dust on the rail-path.

(a) (b)

Figure 21.9 The (a) German Eurodish (Mancini, 1997) and (b) Spanish Titan solar tracker designs (TitanTracker, 2013).

We close of the discussion with Figure 21.10, which shows a large photovoltaic array dual axis panel tracker system. This system includes a linear drive for elevation tracking and a slew drive or rotational actuator for azimuth tracking (SolarTech, 2014).

Figure 21.10 Combined linear drive and rotation drive pan-and-tilt sun tracking system to change the angle of a solar panel array (SolarTech, 2014).

Although the systems described thus far are suitable for stand-alone operation, they also offer the possibility of interconnecting several individual systems to create a solar farm, thus meeting an electricity demand from 10 kW to several MW. Many of these solar tracking system platforms suspend larger dish reflector systems with higher capacity.

21.3 Summary

This chapter detailed a literature study relating to various design options presented present-day and past commercial solar concentrator and positioning systems. The discussion focussed on smaller capacity field tested designs, comparable to the capacity required in 3-5 kW systems.

CHAPTER 22

FIELD ROBUSTNESS AND PRACTICAL LESSONS

22.1 Introduction

In designing any practical solar tracking system, one of the most important factors to consider is the field robustness. The failure of any component in the solar tracking platform, as a result of weather or lightning for example, could result in catastrophic operational failure from which the solar concentrator system would not be able to recover.

Maintenance costs at remote or rural sites are known to escalate due to slow reaction times combined with high logistical and replacement costs. Failures will further cause the system to lose its connection with the sun, eventually leading to battery drain and automation system communication failures and the system eventually becoming non-functional.

It is very useful to learn form the experience of other solar tracking system developers that may have had experiences with certain solar tracking sytem challenges in the field that the novice developer may not think of at the commencement phases of a solar tracking project. Thanks to a range of reports in the literature as well as personal experience, this chapter is intended to share some of the most valuable practical experiences, tips and tricks in terms of solar tracking and solar energy harvesting.

22.2 Field Robustness

Apart from the mechanical structural movement and balancing challenges, the design choice for a solar tracking system that it has to live up to harsh environmental conditions. Environmental effects such as ambient temperature, temperature variations, soil dust deposits (especially on the mirrors), high winds, snow, rain/rainwater and lightning may cause operational challenges.

These effects need to be taken into account when the design robustness is considered since some of these solar generating systems might be deployed in areas that are not easily accessible to maintenance crews. Solar concentrator parts will have to be treated against rust while stainless steel components is preferred for critical subcomponents.

Control electronics need to be housed in a watertight and properly earthed enclosure for protection against wet and dusty conditions. Preferably all components should have an Ingress Protecting (IP) rating of at least IP55 in order to remain intact when used outside in adverse weather conditions. The IP number rates the degree of protection provided against the intrusion of physical elements, chemicals or water into mechanical/electrical casings/enclosures (Bisenius, 2012). IP codes are of the format IPxy, where ”x” describes the degree of protection against the entry of foreign solid objects, and the ”y” describes the degree of protection against the entry of moisture/water.

Many concentrating solar harvesting and solar tracking system designers do not consider simplicity in terms of on-site assembly to be of importance during the design phase. Concentrating solar housing structures are complicated to assemble at remote rural sites due to the mathematical precision required with the assembly of the structural members. Skilled expertise would be required to rig up and optically align most of the parabolic concentrator assemblies. In most cases an industrial crane or mechanical hoist would further be required to tension the cable trusses and optically align the system. These are not always available or transportable to remote rural or mountainous sites.

Certain mountain sites are further prone to extreme temperature variations accompanied by snowfall in winter times. The design of the solar tracking platform needs to account for the additional gravitational load bearing as a result of potential snow and ice deposits, while components with a wide operating temperature range needs to be selected.

The payload for a concentrated solar system operate with considerable energy and thermal heat with secondary added weight in terms of the Stirling engine and associated cryco cooling means. These power conversion and cooling devices not only introduces mechanical vibrations during operation, but the overhanging weight of this payload requires special consideration in terms of system stability in the design.

Some parts of the world also experience severe rainstorms sometimes followed on by long drought and dusty conditions. Solar tracking parts therefore have to be treated for rust-protection while stainless steel components needs to be used in critical subcomponents. Control electronics will need to be of at least IP55 specification and need to be housed in a water-tight and properly earthed enclosure for protection against wet and dusty conditions.

Many solar tracking and solar harvesting systems rely on the main or national electrical grid supply to accomplish solar tracking or to kick start a Stirling engine in order to realise self tracking or generate power. Such systems will simply not function or operate where a connection to the national grid is not available at the site of installation (Greyvenstein, 2011). However, if the power resource can be managed more effectively, it is possible to develop a stand-alone self tracking and off-grid solar power conversion system which is capable of operating independent from any national power grid (Prinsloo, 2014*b*).

In general, solar technology converts applied solar energy into electricity by way of focussing solar energy on the Stirling power conversion unit. The thermal focus is maintained through the solar tracking platform and (parabolic) solar concentrator which directs sunlight energy onto the Stirling receiver. In stand-alone systems, cloud transients result in intermittent power generation level changes and interruptions due to passing clouds, which introduces serious solar tracking sustainability risks.

It should be remembered that local weather conditions may further require special solar tracking considerations. Very cloudy winters coupled with very clear summers may push the ideal orientations to shallower angles, while a steeper angles may be best for photovoltaic modules to shed snow for example. Since accuracy and stability are primary design parameters for a solar tracking system, various control strategy options needs to be considered and evaluated.

Other aspects such as concentrated solar power conversion unit operation and noise, solar glaring/glinting disturbances, maintenance considerations, and remote station operational cost considerations are important factors which could have devastating effects on the technology and catastrophic consequences for the success of the project, if not catered for in the design and control processes.

22.3 Practical Solar Tracking System Challenges

This section shares some of the practical difficulties and challenges that solar tracking system developers have experienced in the field, often at remote sites, as well as the solutions improvises in order to overcome certain challenges.

Relevant reports will be individually discussed under each section heading and serves as valuable resource in the design of a stand-alone concentrated solar reflector system. These reports have help to alert the designer to give special consideration to various mission critical components, environmental effects, real-life threats and to utilize the opportunities many of these factor present to achieve an optimal solar reflector and tracker design.

22.3.1 Lightning Strikes

Lightning is an important consideration in concentrating solar power system design as the system will be operating at remote and distant sites where downtime, maintenance and repair costs are typically very high. The effect of lightning with associated protection measures must be taken into consideration during the design phase.

Lightning has potential to cause component damage which can cause system failure and eventually increase the maintenance and levelized energy cost of a system. This problem is common in systems operating in the field and at remote and distant sites where downtime, maintenance and repair costs are typically very high.

During storm conditions the solar concentrator dish would typically be directed to point 90° upward in order to reduce side wind exposure on the parabolic dish or optical reflector. Being parallel to the ground ensures that the edges of the dish can cut into the wind and also leaves the smallest area of dish exposed to the wind.

However, pointing the solar receiver towards the sky leaves the metal support structure of the solar receiver directly exposed to lightning (Lopez and Stone, 1993*b*). Some design options to further reduce potential lightning damage may include manufacturing some dish components form fibre-glass, using fibre-optic communication wires where possible while proper earthing of the support pedestal, drives and electronic housing with stainless steel is essential.

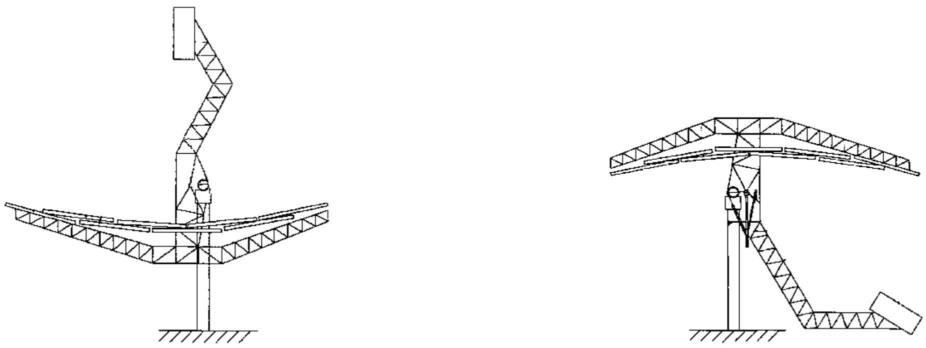


Figure 22.1 Examples of solar dish facing vertically upwards in the Windstow Position to reduce airflow (left) and facing downward to assist with power conversion unit maintenance (right) (Dietrich *et al.*, 1986).

Figure 22.1 demonstrates the positioning of the solar reflector during storms in the windstow position. It can be seen (image left) that the Stirling and PCU is positioned to be at highest point of the installation where associated electronics is vulnerable to lightning damage due to any lightning activity.

It was found that industrial grade power electronics inherently provides for lightning protection and few problems were experienced in the field with lightning damage to the controller units. However, the Stirling engine and PCU units proved to be prone to damage from lightning activity, resulting in significant downtime and maintenance costs (Lopez and Stone, 1993*a*).

Lightning damage to the Sterling and PCU could be alleviated using external earthing and provided a stainless steel stud at the base of the pedestal pole to allow for interconnection to an external grounding. This proved to serve as lightning protection system which lengthened the lifetime of many of their PCU components. The developers also repackaged the PCU electronics and grounded the enclosure, while employing different wiring techniques and shielded power and communication cabling with positive results (Lopez and Stone, 1993*b*).

One option may be to manufacture the beam connecting the PCU and the dish to be made form fibre glass and fibre-optic communication wires.

22.3.2 Ease of Access to the Stirling/PCU

One of the most important practical considerations for solar reflector and solar tracking re-designs proved to be the ability to reach the Stirling engine maintenance or repairs. The weight of Stirling engine and PCU unit makes it difficult to replace if the solar tracker design did not provide for accessibility.

Another important practical consideration for solar reflector and solar tracking re-designs proved to be the ability to reach the Stirling engine maintenance or repairs. The weight of Stirling engine and power conversion unit makes it difficult to replace if the solar tracker design did not provide for accessibility.

Lightning strikes may cause regular damage to the Striling or power conversion unit since this unit is located at highest point in windstow position. This means that the Stirling engine and power conversion unit is exposed to the highest lightning damage risk (more than any other part).

In larger solar harvesting systems, where the solar harvesting payload is extremely heavy and difficult to reach, the solar tracking system design must make mechanical provision and include electronic control states that allow maintenance staff to be able to easily reach and work on the Stirling engine or power conversion system for repairs.

It was shown earlier (see Figure 22.9) that lightning strikes may cause regular damage to the Striling/PCU when it is located at highest point in windstow position. Since the Stirling/PCU proves to be at the highest damage risk (more than any other part), the solar reflector and tracker designs must make provision for maintenance staff to be able to easily reach and work on the Stirling/PCU for repairs.

To accommodate engine maintenance convenience, the concentrator configuration in the WGE 10 kW concentrator system allows for the dish elevation to be depressed in below the horizontal plane (WGAssociates, 2001). The McDonnell solar reflector design was later modified to make special provision for the Stirling to to swing downward. This was done to simplify maintenance and to swing the PCU downwards to allow working on the Stirling PCU on the ground.

The photo pictures in Figure 22.2 provide some insight into the practical considerations (hight, weight, size) in accessing the solar receiver and Stirling Power Conversion unit for repairs and maintenance. In the system shown on the right, the designers provided for a special *maintenance mode setting* in the electronic control system whereby the PCU could be lowered to ground level with the press of a special maintenance button. This makes maintenance less costly compared to the use of scaffolding and hoists to access the PCU system for maintenance and repairs.

It is therefore proposed in the present solar tracker design, to include a control feature where the operator will be able to lower the Strirling/PCU down to a level where maintenance staff can operate on the system or remove the system, preferably on ground level. In designs where this feature was not provided for, maintenance costs increased to hire scaffolding or cranes every time the system needed repairs or an overhaul.

Figure 22.2 Accessing the solar receiver and Stirling Power Conversion unit for repairs and maintenance (WGAssociates, 2001).

22.3.3 Oil Leaking Problems

Lopez and Stone (Lopez and Stone, 1993*b*) investigated field problems of solar concentrator/dish stations, and reported that oil leaks on the concentrator and actuator drives caused oil to spill onto the solar optic reflector mirrors. This resulted in severe mirror soiling problems due to the oil attracting dust/soil particles. In such cases, expensive manual scrubbing had to be employed to remove the oil from the dish mirrors. This experience raised an alert against the use of oil lubricated tracking drives in solar concentrator design, suggesting that grease lubricated actuator drives for solar concentrators operating in extreme heat conditions might ensure fewer problems with field maintenance.

Edison Sterling Engines (ESE) proposed an improvement to the McDonnell design as shown in Figure 2.5 (right). In this design, the pivot point was changed to a lower position (top balancing) to allow a wider angle of elevation movement, from $+90,^\circ$ (facing perpendicularly upward) and $-90,^\circ$ (facing perpendicularly down to the ground).

Although this modification may introduce balance control instability problems (due to the change in the level of the pivot point above beam center of gravity), it was argued that modification was required for practical reasons. That is to simplify maintenance and to swing the PCU downwards to allow working on the Stirling PCU on the ground (as shown later on the right in Figure 22.1).

To strengthen the linear actuator and to accommodate this wide angle of movement, the linear actuator was replaced with a jack type screw. The mechanism to achieve elevation tilt of the solar reflector beam, which pivots over the pedestal, was to use mount two pivoting bars and a pivoting motor driven screw to support structure portion of the solar concentrator.

Although unproven, it is believed that the instability problem could have been overcome if a tower was used on top of the pivot pole to fix the proposed arrangement to, in order to lower the swivel point on the cross-beam and so decreasing the center of gravity of the balancing beam to be below the swivel point.

22.3.4 Power De-rating Effects

Apart from adequate provision in the drive capabilities to withstand gusty wind conditions, some steady high and medium wind conditions should also be considered from an energy loss perspective. These effects may influence the reflector's self tracking capabilities but also interferes with the thermal heat transfer processes of the solar receiver mechanism.

Energy losses due to windy conditions is an important consideration in this study as such energy losses may impact on the self tracking capabilities of the present system. This effect of power de-rating is generally caused by wind cooling in the cavity aperture of the solar receiver mechanism, resulting in thermal losses and thermal transfer losses in the solar receiver head.

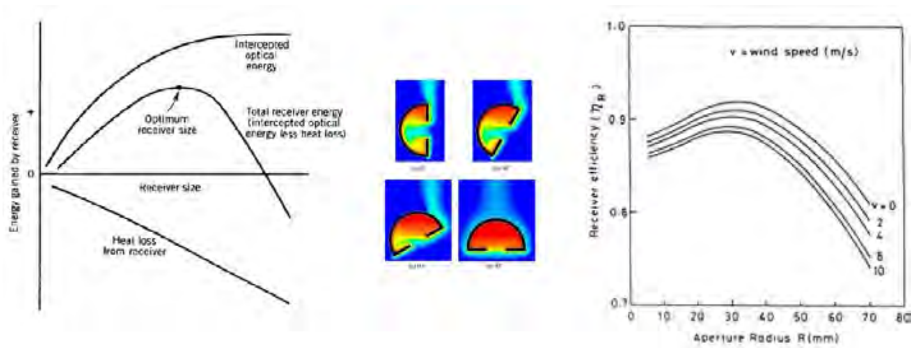


Figure 22.3 Impact of solar receiver design, orientation and wind on receiver efficiency (Hughes, 1980)(Lopez and Stone, 1993*a*)(Kinoshita, 1985).

In a report on the performance of the Edison Stirling Dish, it was shown that wind blowing across the receiver aperture results in increasing heat losses in the receiver head (Lopez and Stone, 1993*a*). Winds from certain directions had various impacts on the performance of the power generation systems receiver in terms of thermal losses but also caused movement in the optic reflector and receiver received suspended on the reflector, leading to increasing levels of solar energy spillage.

Figure 22.3 shows the solar receiver efficiency relative to the size of the aperture (left), a graphic representation of the impact of wind direction (center), and the impact of various wind speeds on solar receiver efficiency (Infinia, 2012*b*).

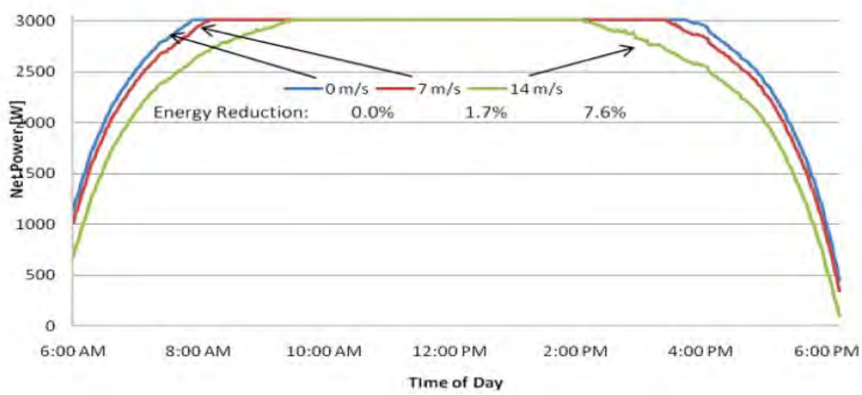


Figure 22.4 Impact of wind on daily energy production of solar electricity (Infinia, 2012*b*).

In Figure 22.4 it is shown that the impact of a constant wind on the Infinia for a full daylight solar cycle relates to considerable electrical energy losses (Infinia, 2012*b*). For the location used in their example, the resulting impact on energy generation for a steady wind with speeds between 7.0-14.0 m/s can result in energy output reduction as large as $\pm 1.7\% - 7.6\%$.

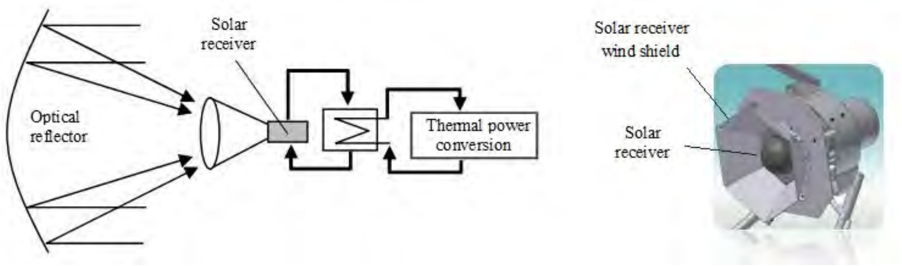


Figure 22.5 Solar receiver modification to counter wind cooling power de-gradation in the solar receiver (Infinia, 2012*b*).

In order to counter the effect of power de-rating caused by winds cooling the aperture cavity of the solar receiver mechanism, schematically presented in Figure 22.5 (left), engineers devised a wind-shield mechanism Figure 22.5 (right) (Infinia, 2012*b*). The power de-rating effect of the wind is an aspect of particular concern, since it may have a direct bearing on the self tracking abilities of the system. From an energy perspective, the wind effect needs to be monitored and factored into the control loop logic for the control mechanism.

Power degradation due to structural deflection in high wind speed conditions is yet another consideration. Similar to the drive design and implementing a solar receiver wind-shield, the solar reflector frame or chassis also needs to be structurally designed to withstand certain high wind conditions and large temperature variations. However, these specifications are however outside of the scope of study, but it is important to mention as these effects can cause power de-rating and cause the solar reflector system to operate at less than its rated maximum power levels.

22.3.5 Cloud Interruptions

The weather and especially clouds is the Achilles heel of CSP systems. Cloud transients are therefore one of the effects which the designer needs accommodate for in the design of a self-tracking solar tracking system as it directly impacts on the power source to drive the solar tracking and power generation subsystems.

Solar Stirling type concentrators are effected by the screening effect of the clouds may lead to temporal changes in levels of solar radiation. The operation of a Stirling engine may for example be interrupted if clouds/control errors cause the system to lose its connection with the sun.

In CSP systems, cloud transients causes intermittent power generation level changes and interruptions due to passing clouds. This is due to the screening effect of the clouds leading to temporal changes in levels of solar radiation available to the solar receiver. This interrupts the operation of the PCU as the clouds causes the PCU to lose its connection to the sun and energy source.

Figure 22.6 Hourly solar radiation and power generation curve for a solar receiver system operating in some overcloud conditions (Infinia, 2012*b*).

Figure 22.6 presents the hourly solar radiation pattern and associated variations in the power generation curve for a system operating in cloudy conditions around 08h15, 09h00 and between the hours of 12h00 and 12h30 (Infinia, 2012*b*). The graph clearly shows a reduction in the power generated around 08h15 as well as a significant drop in the power generated (user supply) curve around 12h00 due to a cloud interruption.

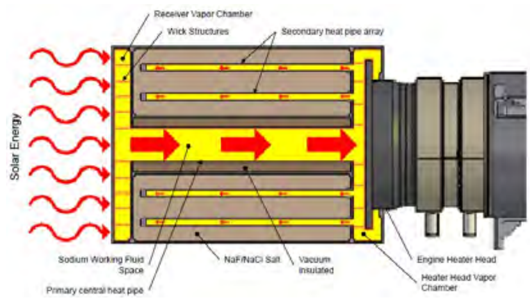


Figure 22.7 Solar receiver incorporating a salt storage device in solar receiver to counter cloud cover interruption of the PCU operation (Infinia, 2012*b*).

One solution to overcome interruptions in the operation of the PCU during *shorter* cloud transients is to develop a storage means for temporarily storing thermal energy to overcome the loss of the thermal source. The solution represented in Figure 22.7 proposes a solar receiver mechanism that uses salt as a thermal storage means to act as a continuous thermal reserve.

This mechanism acts like a thermal battery or charge module to help overcoming problems with interruption an restart of PCU following short cloud interruptions. Salt retains the heat much longer than metals and is able to carry the power generation through the cloud cover period for certain time periods at least.

22.3.6 High Wind Conditions

Parabolic dish type solar tracking platforms require a high degree of accuracy to ensure that the sunlight is directed at the focal point of the reflector. At the same time the mechanical drive and electronic controls must ensure smooth transitions during stepwise or continuous dynamic tracking movement to allow the tracking system to lock onto the source or sun and to remain stable irrespective of changes in external environmental conditions.

Optics in CSP applications accept the direct component of sunlight light and therefore must be oriented appropriately to collect energy. Tracking mechanisms with associated tracking control systems are found in all concentrator applications because such systems do not produce energy unless oriented closely toward the sun.

One aspect that requires consideration in the selection of suitable dish framework and drives is the shock loads induced on the gears of the drives as a result of wind gusts and storms. Figure 22.8 shows the typical wind conditions experienced by a solar reflector system at an installation site in California in the USA (Stanford, 2014).

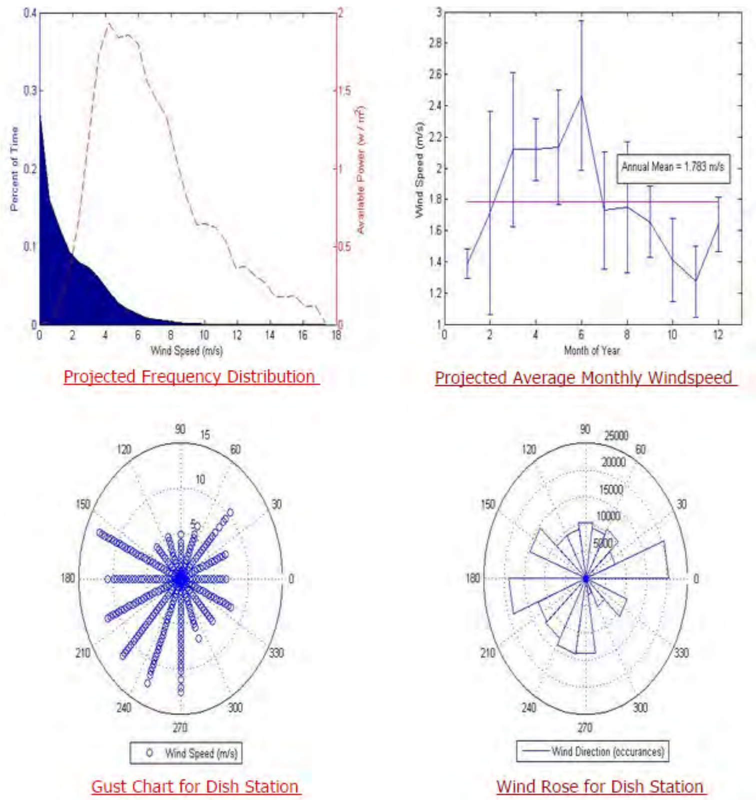


Figure 22.8 Wind measurements and profile taken at the Stanford dish station (Stanford, 2014).

Figure 22.8 also shows an example of a wind-rose to illustrate the importance of wind measurements at the installation site of a solar tracking system (Stanford, 2014).

In high wind conditions, a parabolic dish can provide significant resistance to the wind and in laymen's term act as a sail (similar to a sailboat). This is not only extremely dangerous in high speed winds and windstorms, but the wind also causes vibration on the dish structure. This in turn effects the optical accuracy of the dish and consequently effects the overall efficiency of the dish power system.

One solution to overcome the problem in extremely high wind conditions (i.e. ¿65mph) is to steer the dish that it faces directly upwards towards the sky, in other words to point the

PCU vertically upwards or downwards so that the largest surface area of the parabolic dish is orientated parallel to the ground, as shown in Figure 22.9 (right). In this orientation, the edge of the parabolic dish "cuts into the wind", reducing air draft on the larger dish area.

Using the positional configuration shown in Figure 22.8, ESE engineers conducted simulation experiments to determine the influence of the wind as well as the forces which the mechanical drives and the dish structure design should be able to withstand.

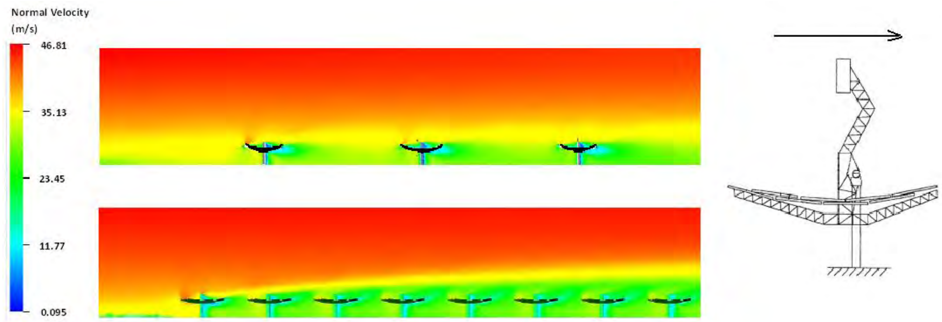


Figure 22.9 Simulation of wind load on an array of Suncatcher solar systems orientated in the windstow position (Linden, 2007).

In order to determine the effect of wind loading and wind pressures on the solar parabolic dish, Edison Solar used Computational Fluid Dynamics (CFD) to simulate wind impact. Figure 22.9 shows graphic results of the CFD simulation analysis, in which the effect of wind on a solar reflector system can be observed. The figure shows the simulated effect of steady wind load patterns on an array of three (top) and eight (bottom) Suncatcher®solar systems. The systems are orientated vertically upwards during high wind conditions in order to reduce wind load on the dish structure (the so called wind-stow position) (Linden, 2007). It can be observed that an individual reflector dish or the reflector dish on the edges of an array has to be able to withstand a substantial wind load while the dish structure itself causes turbulence in the wind stream. The drives needs to be designed with sufficient safety margins in order to be able to bear these loads during gusty wind conditions.

In at least one prominent commercial solar tracking system, practical experiences with gusty wind conditions caused serious problems in downtime on the solar power generating system. A few years after the Sterling Engine Systems (SES) obtained the design rights from McDonnell Douglas, regular wind damage forced the company to change the planetary harmonic gear drives on all their future designs in order to overcome wind-load limitations in the original design (Lopez and Stone, 1993*b*).

22.3.7 Dish Reflectivity Losses and Cleaning

In concentrated solar reflector systems, there is a direct correlation between the peak power efficiency of the optical reflector and the level of reflectivity of the reflective mirrors suspended on the parabolic dish. Solar dish/mirror reflectivity and problems with mirror soiling is another power de-rating effect which causes substantial declines in annual electricity power generation and an associated increase in income losses.

Excess soiling results in lower mirror/dish reflectivity, which in turn results in loss of solar electric power and income, especially in dryer climates and desert conditions. Mirrors located lower on the solar dish structure soil more quickly due to the gravitational suspension the dish provides for dust particles. Soil deposits on the dish mirrors also results in uneven solar flux reflected from the dish and reaching the solar receiver. *Sensor soiling* is yet another cause for special consideration, especially with the environment sensors and solar irradiation sensors as soiling on these sensors influence the system operations, parameter settings and reporting aspects of the solar reflector system.

In practice, dust and plant matter from Agricultural activities is a common cause of the so-called *Soiling Effect* or *Solar Clouding*, in which soil particles and plant material are carried by the wind and deposited onto the solar reflector mirrors and sensors. Debris such as soil dust, bird droppings, plant matter, soothing, iron dust, and urban pollution add to the solar reflector soiling problem. Lopez (Lopez and Stone, 1993*b*) reported that some of their solar dish stations, oil leaks from the PCU/Stirling and some actuator drives caused oil to spill onto the solar optic reflector mirrors which resulted in severe mirror soiling problems due to the oil attracting soil particles. Expensive manual scrubbing had to be employed to remove the oil from the dish mirrors as the normal washing techniques proved to be insufficient to remove lubrication oil from the reflective mirrors.

In yet another interesting study, solar farms located near an airport reported solar power generation losses due to the deposition of fine particles of oily residues onto the solar systems which increased soiling problems. These residues were believed to be emanating from aircraft activities. This led to an official study to investigate the causes and impact of various sources of soiling on solar power generation (Miller, 2009). It was eventually determined that the oily residues originate from pollution, mainly from power plants, marine activities, vehicle exhaust gas, railroad and to a lesser extent airport activities. Although the official study focussed on the power de-rating effects on PV arrays, the results hold equally true to solar reflector systems.

Apart from agricultural activities, land excavation and construction activities in the vicinity of the solar power station are factors to be considered the cause excess soiling (also in determining the solar dish wash cycles). Such activities can lead to higher than normal soiling on the solar dish mirrors and have shown to have an exponential reduction on mirror dish reflectivity, from 91% after a wash cycle to 64% before the next wash cycle approximately one month later (compounding income loss estimated to grow by 0.005% for every unwashed day) (Lopez and Stone, 1993*b*).

These reports confirm that mirror soiling is one of the highest contributors of concentrated solar system power losses (Miller, 2009), totalling as much as 37% of the overall system losses on a concentrated solar reflector system (Lopez and Stone, 1993*b*).

Although the presence of rain-clouds reduces the power generation levels of a concentrated solar reflector system, rain proves to be one of natures CSP support mechanisms as it reduces soiling and helps to wash the dish mirrors during rain showers. Infinia however reported that in some cases soiling combined with light drizzling rain introduces yet another problem in parabolic solar systems. Light drizzles deposits water drops on the mirror surface causing chemical reactions to take place between the mirror surface and substances in the composition of the soil particles. The same reactions occur during high humidity and with night-time condensation, when water drops form on the mirror surfaces which can start negative chemical reactions. In many cases this results in permanent damage to the reflector mirror surface. This problem was found to be quite severe in the vicinity of industry regions where the soil/mirror surfaces and sensors are exposed to industrial pollution, chemical industry pollution and acid rain, resulting in permanent damage to the mirror surfaces.

Mirror and sensor cleaning operations should be regularly scheduled to reduce the impact of soiling on the solar reflector system. The recommended wash cycle frequency for reflective solar systems is once every month, or 12 washing cycles per year (takes on average 15 minutes per dish, depending on the dish size) for which a non-contact spraying field mirror method is the recommended (Lopez and Stone, 1993*b*). Edison Solar followed a more scientific approach and determined that each solar dish should be washed when reflectivity drops below 75%. Using simulation models, they determined that on average around 11 washes per year should be sufficient, provided that frequent intermittent rain washes supports this wash cycle. They determined empirically that on average, a solar plant require around 10 water was cycles per year but will vary from site-to-site (Lopez and Stone, 1993*b*).

Alternatively small robotic system can be used to clean the dish. systems have been developed for heliostats and it may be possible to modify these for a solar dish. Examples are the Sener's robotic mirror cleaning system `www.sener.aerospace.com` and the Gekko Robot `www.Serbot.ch`.

Metal type mirror facets are prone to greater chemical reaction damage and is therefore considered not to be ideal for use in solar reflector systems. Specific caution is also expressed in terms of the use of chemicals to wash and rinse the solar dish. Requirement for using clean water to reduce chemical, reactions forming on the solar dish, while selection of soap to reduce such reactions is extremely important.

Since the present project is concerned with the design of a solar reflector system for rural Africa application, dust and soiling considerations should take preference. The designer was unable to find a sensor to detect solar reflector mirror reflectivity losses due to soiling. Most systems predict soiling levels from power reductions levels but this is highly subjective. It is envisaged that such a direct measurement sensor could be developed and that this may be a novel innovation to supplement the unique design. The sensor should be able to detect soiling and reflectivity losses using an optic means, from which the control system could alert the operator or sound a maintenance alarm in a remote control centre.

22.3.8 Solar Reflector Glinting and Glaring Disturbances

The solar reflector dish structure supports a grid of curved glass mirror facets which collect and concentrate solar energy onto the solar receiver and PCU head. In some areas, by-passers have filed complaints about a distraction from light flashes when sun rays are reflecting at random off the mirror surface of solar reflectors. Excessively bright light glows (glaring caused by concentrated light near the solar receiver) were also noted to be a reason for concern. These visual disturbances are particularly distracting in the vicinity of solar parks where a large concentration of solar reflectors are installed.

From a solar reflector concentrator design perspective, attention should be given to resolve this problem, since such glints off the parabolic dish generally raise safety and liability concerns as it may disturb motorists and airline pilots (Figure 22.10). In one case, the California Energy Commission requested a study from the company Tessera Solar to determine the cause of these reflections and to propose design solutions to overcome these problems at their Imperial Valley Solar Project (Meyer, 2010).

Figure 22.10 shows typical glint (left) or flash of light from the SunCatcher $25kW_e$ solar reflector system. While the dish is tracking the sun to collect solar energy and generating electrical energy, the figure also shows light glare reflecting of the solar receiver/PCU head(right).

Figure 22.10 Glint and Glare can cause disturbance to motorists and airline pilots (Meyer, 2010).

Following an in depth investigation from various key observation points, the study (Meyer, 2010) found that the solar concentrator may reflect light from a direction not parallel to the axis of the solar reflector, especially when the reflector is not in the *"on-sun" position* (directly facing the sun). This off-axis radiation will be reflected to regions other than the solar receiver or parabolic focus and may cause disturbances to motorists and airline pilots for periods of up to 30 minutes (depending on the time of day). The main factors causing this problem were found to be caused by the control logic procedures used during cloud transients.

When the sun is blocked by a cloud, the controller moves the payload (PCU) away from the focal plane to prevent thermal heat damage to the PCU when the sun re-appears and the concentrated energy may not be focussed precisely on the solar receiver. This control procedure is dubbed *solar-walk-off* and is managed as one of the *states of operation* by the electronic controller. During such state, the sun reflects light randomly at off-axis angles as a result of the solar-walk-off state, a necessary operation to ensure thermal protection through solar de-tracking.

The study acknowledged that the problem could raise safety concerns around solar parks located near automotive highways and airports where glints from consecutive rows of parabolic dishes may reflect a stream of flashing glints towards roadways and airways passing the area. Extended off-axis sources such as Earth albedo and local point sources or reflections were also found to be additional contributors to these problems while solar tracking malfunction was identified as yet another potential cause of solar glinting (Meyer, 2010).

The study furthermore acknowledged that excessive light glare reflected off the solar receiver could be a second concern for the safety of motorists and observers. This glare was found to be caused by diffused light reflected from the solar receiver plane during PCU operation, where the concentrated sunlight scattered off the solar receiver/PCU head appears excessively bright, compared to ambient lighting. The problem was found to be of biggest concern when viewed from the side of the dish.

The Glint and Glare Study (Meyer, 2010) offered recommendations on how to resolve problems associated with sunlight reflection and glaring light disturbances caused by concentrated solar reflector devices. In order to mitigate these problems and minimize the risk of glints, Tessera Solar proposed changes to control mode logic and the implementation of an additional tracking control mode as solution, namely *"Off Angle Tracking"*. Off-Angle-Tracking, shown in Figure 22.11, was introduced as a new mode of operation whereby solar tracking is continued during a cloud transient, but tracking is not done directly on-sun but at an elevation angle equal to that of the sun vector minus 10 degrees during cloud-cover.

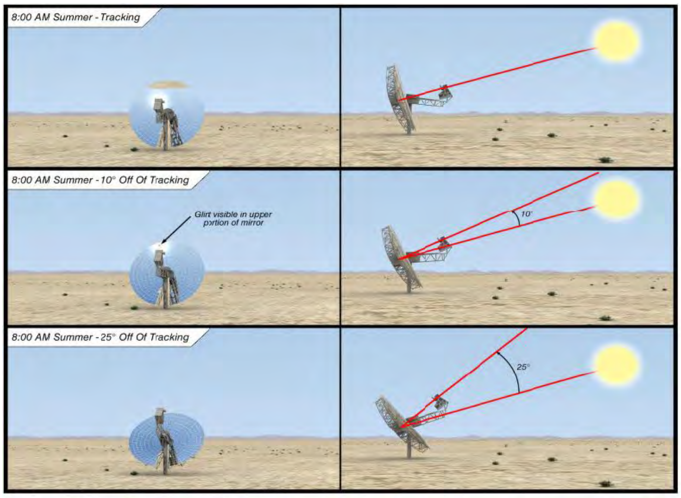


Figure 22.11 Off axis tracking to prevent Glint during solar walk-off and walk-on to limit disturbance to motorists and airline pilots (Meyer, 2010).

This mode enables the solar reflector to remain tracking on-sun in terms of the *azimuth angle* during cloud transients (forcing any solar glint reflections directly forward and down to the ground), but assists the receiver to engage back onto the sun from below (vertical elevation lift) when sun re-appears. 3D simulation results proved that reflector/PCU engagement directly from below (using only the elevation angle lift as single axis of change) reflects light downwards and not randomly away from dish as with the case of solar engagement during a sideways movement.

Two options were proposed in the mitigation of the problem with light glare from the solar receiver, namely using a cavity type solar receiver or install a screen/shield around the solar receiver head to screen away the sideways reflection of light. Other solutions proposed by Tessera Solar (to overcome glint and glare) included the installation of barricades or perimeter fencing around solar parks located close to automotive roadways (Meyer, 2010).

In considering the liability risks of solar glaring and glinting, he design of any solar tracking system should incorporate to prevent visual distraction from such disturbances. In this study it is recommended, firstly, that a special control mode of operation be included in the digital control system of the concentrated solar reflector system in order to prevent the problem of glint, and secondly, the design of the solar receiver should incorporate light shielding (which will also act as wind shield). The next section will describe problems experienced in practice from lightning strikes and the effect this has on the design or parabolic solar reflector systems.

22.3.9 Solar De-tracking and Walk-off

Finally, in digital satellite and radio telescopes, the control system can freely engage and disengage the dish onto the target since the energy input is limited and unable to cause damage to the receiver payload. In parabolic solar reflector systems, the concentrated thermal solar energy beam near the focal place is extremely hot and can cause serious burning and damage to the solar receiver and PCU mechanisms. Engagement and disengagement of the dish onto the sun should therefore be managed with the greatest care and management of this control aspect should be planned and provided for in the logic of the solar tracking control system.

The process of dish engagement in Solar reflector systems should also be planned from an energy perspective. Each time the dish engages onto the sun target, a certain amount instantaneous energy is required to start-up or kick-start the PCU operation. In cloudy conditions, continuous engagement and disengagement of the dish can drain the backup power supply. Controller must ensure that start-up would generate sufficient energy to restore lost energy during kick start process.

During certain operational scenarios or mode of operation changes, the concentrated solar beam needs to walk-off the aperture across the face of the receiver. The focussed solar flux can cause considerable damage to the receiver or PCU if a strategy is not implemented to remove the energy source from the solar receiver in a safe, cost effective and energy efficient manner.

This section consider design options to ensure solar walk-off prevention or solar de-tracking to protect the solar received mechanism. Options such as control logics or mechanical will be considered for a specific assumed generic dish module and electric plant design are identified.

During normal operation of a point-focus solar reflector system, the dish is pointed directly at the sun while concentrated solar flux is directed into the solar receiver aperture. In one scenario, clouds may block the site of the sun, causing damage to the solar receiver when the sun re-appears. In other scenarios, solar tracking control may be lost, mechanical failures may occur, or a human/operator error may cause potential damage, in which case it may also be required to safely remove the thermal source from the solar receiver.

In a self-tracking system, the problem is not as serious as with grid-connected tracking, where the connection to the grid or power failures in the grid-supply may cause serious problems and physical damage due to thermal. NASA has therefore done considerable work on solar de-tracking and walk-off schemes as well as on finding the safest and most efficient way to implement this (NASA, 1986). Design options proposed by the NASA study included the following:

- Move solar receiver away from focal point;
- Preventing light to receiver by blocking reflector;
- Fail-safe sun tracking control strategy;
- Emergency walk-off control logic;
- System sensor analysis and walk-off protection;
- power back up for grid connected systems.

In this study approach will be followed to have minimum mirrors during test phase. In operational phase, control logic will be used to prevent damage to the system.

22.3.10 Intercept and Parasitic Power Losses

Solar reflector design engineers recognizes that energy spillage due to solar tracking errors leads to a reduction in the solar power generation efficiency of a solar reflector system.

These losses are defined as *Intercept Losses*. Other factors which contributes to intercept losses are waviness in the mirror surface, deficiencies in the composition of the mirror material, errors in the mirror angle suspension, variations in the aperture size, variation from the parabolic dish curvature, solar reflector positioning errors resulting from wind changes and direction as well as wildlife or human interferences with the system (Lopez and Stone, 1993*b*).

Another effect which influences the efficiency of the solar power system is parasitic power drawn by various system components during unexpected/unplanned circumstances. Parasitic power is normally determined through tests during operation and change in operating modes of the system. In these tests electrical power consumption analysis is performed to evaluate and calculate the power requirements of the various system components of the solar tracking mechanism and the PCU.

22.4 Social Integration Considerations

Many rural villages experience good concentrations of solar radiation, but rolling out reliable CSP solutions for tapping into this resource at rural African sites poses some system design challenges. The issue of appropriate socio-cultural management of rural renewable energy projects is as important as that of the technological development and management.

History shows that attempts to introduce technology to communities who have no previous access to their underlying principles is rich with stories of failure. Enquiry into instances of failure revealed that the principal reason for failure is not technological but socio-cultural (Winkler, 2005).

It will not be sufficient to design, provide and install technology in communities who need such renewable energy provision. It is imperative that the needs of the community and their respective skills level is considered, both in the design as well as in the operation and maintenance.

The involvement and participation of the community in this respect is of utmost important to ensure social cohesion with the project (Mulaudzi and Qase, 2008). As part of the design considerations, the relevant communities will need to be considered owners of the process and that the technology meets with the levels of understanding of the community. The successful provision of modern technology in remote areas rely as much on socio-cultural management as technological innovation and expertise.

22.5 Solar Tracker Design Goals

Table 22.1 presents a list of design goals and factors typically appropriate to consider when designing a field robust solar harvesting and associated solar tracking system within the context of the practical challenges experienced when exposed to the conditions of nature.

As part of the design goals, the concentrating solar power system should be easy to transport, assemble and install at remote site, while ensuring low-cycle field maintenance preferably supported by remote monitoring/diagnostic capabilities.

22.6 Summary

This chapter presented examples to illustrate that the design of the control- and mechanical-drive systems of a solar tracking platform should not only focus on elements such as the mechanical platform, mechanical system behaviour, transmission drives, the control strategy, control system inputs, sensor mechanisms and control system outputs, but must also consider certain practical and environmental conditions under which the system should operate.

Table 22.1 Design goals for a field robust solar power system.

Typical Solar Tracking System Design Goals		
Design Goals	**Effected Components**	**Anticipated Results**
Dual axis tracking	Actuators and transmission system, dish structure weight balance	Support structure can be cantilevered space-frame beam that supports the receiver, engine and generator with minimum deflections.
Good energy collection performance	Dish, power unit tracking accuracy	The tilted axis design increase in performance over single axis trackers.
Tracking accuracy	Controller software, drive tolerances, encoder-tilt angle sensors	Maximum 1% error tolerances. The transition assembly firmly interfacing with Stirling/dish support structure with the elevation axis and the azimuth drive.
Reduce deployment time	Concentrator dish design and drives	Preassembled tracker and precast foundations allow for fast installation
Minimize impact of terrain variation	Pedestal, Actuators	Articulated drives, allow for system installation on uneven terrain, minimal site work
Minimize on site labour	Remote HMI interface, actuators, control system	Factory assembled to reduce onsite labour. Precast or preformed foundations and an adjustable mounting system
User-friendly	Control, alarms and remote feedback	A user-friendly interface
Self tracking	Control system, battery backup	Provide its own energy. Ensure low power solar tracking power consumption
High efficiency	Electric components, mechanic precision	Stirling/CPV power generation vs solar tracking consumption
Design for safety	Electrical parts, mechanical components	Adhering to modern safety and quality standards
Safety and emergency	Controller software, control strategy alarms	Power failure mode off focus, maintenance, environmental: wind, emergency defocusing, solar walk-off protection
Wind stow	Azimuth drive, elevation drive	Geometry considerations disclose wind load and inertia differences, keep to a minimum to reduce wind and inertia effects.
Lightning	Controller, comms system, drive motors	Lightning protection with proper earthing of electronics, drives and pedestal
Maintenance	Datalogger, feedback sensors	Control panel with maintenance and fault-finding procedures
Reliable operation	Off the shelf-components	The best quality at the lowest cost, components easy to source and replace
Strength and durability	IP55 environmental specifications	System components reliable and able to withstand various weather conditions
Local manufacturing	All components	The ability to be reproduced and manufactured locally for deployment into Africa

PART IX

GENERAL SOLAR TRACKING RESOURCES

CHAPTER 23

SOLAR TRACKING ONLINE SOFTWARE RESOURCES

23.1 Solar Position Algorithms

The Sun As A Source Of Energy Solar Astronomy Solar Energy Reaching The Earths Surface Calculating Solar Angles Irradiation Calculations http://www.itacanet.org/the-sun-as-a-source-of-energy/, in Spanish Una gua sobre la forma de calcular la cantidad de energa solar que incide sobre un plano inclinado en cualquier latitud. La inclusin de una seccin sobre la astronoma solar. El Sol como fuente de energa Astronoma Solar La energa solar llega a la superficie de la Tierra Clculo de los ngulos Solar Clculos de irradiacin

Plataforma Solar De Almera SunPos Algorthm in C, also for Arduino and other microporcessors http://www.psa.es/sdg/sunpos.htm

Function to compute the sun position (zenith and azimuth angle at the observer location) as a function of the observer local time and position. http://www.mathworks.com/matlabcentral/fileexchange/4605-sun-position-m

SunPy community-developed, free and open-source solar data analysis environment for Python http://sunpy.org/ and https://github.com/sunpy/sunpy

http://rredc.nrel.gov/solar/codesandalgorithms/spa/

University of Oregon Sun path chart program http://solardat.uoregon.edu/SunChartProgram.html

Solar Calculator can be a very useful tool for a photographer http://www.iesmith.net/tools/solarcalc.html

NREL Solar Position and Intensity C++ http://rredc.nrel.gov/solar/codesandalgorithms/solpos/

www.sunearthtools.com Solar tools: Calculation of sun's position in the sky for each location on the earth at any time of day. Azimuth, sunrise sunset noon

Program: Solar.bas http://users.telenet.be/nicvroom/solar.htm

Microsoft GW Basic http://files.seds.org/pub/software/pc/general/

C Code http://sources.freebsd.org/HEAD/src/usr.bin/calendar/sunpos.c Copyright 2009-2010 Edwin Groothuis ¡edwin at FreeBSD.org¿ All rights reserved

Windows PC http://article.sapub.org/10.5923.j.ijee.20110101.05.html

http://www.pc-control.net/pdf/032010/pcc_0310_e.pdf

Where is the Sun ?? (Solar position algorithms) in Fortran http://jpjustiniano.wordpress.com/2011/07/11/where-is-the-sun-solar-position-algorithms/

Sunpath http://www.biospherical.com/index.php?option=com_content&view=article&id=67&Itemid=109

Source code https://github.com/waneck/hx-javastd/blob/master/src/sun/tracing/dtrace/Activation.hx

Arduino Software code http://www.psa.es/sdg/sunpos.htm

Beckhoff TwinCAT PLC library Solar Position Algorithm it is possible to calculate the exact position of the sun http://www.beckhoff.co.za/english.asp?twincat/twincat_solar_position_algorithm.htm

Computing planetary positions - a tutorial with worked examples http://stjarnhimlen.se/comp/tutorial.html

Solar equations http://obex.parallax.com/search/solar higher precision C program in the auxillary file that could be adapted.

Pursuing the Sun A mathematical astronomy problem http://www.jgiesen.de/pursuit/index.html

23.2 Sunpath and Sun Chart Animations

Astronomie by JavaScript http://www.jgiesen.de/GeoAstro/sundials.html

Java Applets for detailed solar and lunar data and observe the daily and annual path of the sun and moon for any location http://www.jgiesen.de/GeoAstro/GeoAstro.htm

Animation of Sun Path and Solar Position Animation http://sustainabilityworkshop.autodesk.com/buildings/solar-position

A tiny JavaScript library for calculating sun and moon positions and phases, created by Vladimir Agafonkin https://github.com/mourner/suncalc

http://suncalc.net/#/51.508,-0.125,2/2014.09.28/19:39

http://iecosolar.co.za/sun-calculator

3D version http://10k.aneventapart.com/2/Uploads/660/

http://diva4rhino.com/forum/topics/sun-vectors-sun-position-tool

http://wiki.naturalfrequency.com/wiki/Sun-Path/Projections

http://andrewmarsh.com/blog/2010/01/17/sun-path-diagram-projection-methods

http://wiki.naturalfrequency.com/wiki/Sun-Path/Reading_Sun_Positions

23.3 Sunpath Software Code Resources

http://wiki.happylab.at/w/Solar_Arduino_tracker

http://www.pvlighthouse.com.au/calculators/solar%20path%20calculator/solar%20path%20calculator.aspx

http://www.psa.es/webesp/index.php

http://www.susdesign.com/tools.php

http://www.solarpathfinder.com/

http://www.esrl.noaa.gov/gmd/grad/solcalc/

http://wiki.happylab.at/w/Solar_Arduino_tracker

Great Circle Studio Solar Calculator http://www.gcstudio.com/suncalc.html

NOAA Solar Calculator http://www.esrl.noaa.gov/gmd/grad/solcalc/

Sustainable by design http://susdesign.com/sunangle/index.php

http://www.academia.edu/2641126/Real-Time_Projection_Shadow_with_Respect_to_Suns_Position_in_Virtual_Environments

http://pveducation.org/pvcdrom/properties-of-sunlight/sun-position-calculator

wiki.naturalfrequency.com/ A simple linear projection of altitude lines around the sky dome straight down onto a flat surface would make angles

http://www.new-learn.info/packages/clear/visual/daylight/analysis/hand/sunpath_diagram.html

http://www.usc.edu/dept-00/dept/architecture/mbs/tools/thermal/solarbasic.html

http://www.oglethorpe.edu/faculty/~m_rulison/Astronomy/Chap%2001/Celestial%20Sphere.htm

Solar Pathfinder www.solarpathfinder.com monthly climate data for about 250 U.S. cities

Education Service offered by the MINES ParisTech / Armines, Franceis, a joint service of the servers SoDa and HelioClim http://www.soda-is.com/eng/education/index.html

Chili radiation data http://www.labsolar.utfsm.cl/index.php?option=com_wrapper&view=wrapper&Itemid=9

23.4 Example Solar Tracker SDKs and Solar Position Algorithm SDKs

https://sam.nrel.gov/content/ssc-sdk-version-09-available-download
http://artsdigitalrnd.org.uk/insights/discovering-how-to-track-the-sun-with-a-phone/
http://stackoverflow.com/questions/4102873/objective-c-library-for-sunrise-and-sunset
https://github.com/erndev/EDSunriseSet
http://www.st.com/web/catalog/tools/FM147/CL1794/SC961/SS1743/PF257936
http://www.ecere.com/forums/viewtopic.php?f=2&t=135
https://thwack.solarwinds.com/thread/39001
http://eppleylab.com/instrumentation/automatic_solar_tracker.htm
http://www.esrl.noaa.gov/gmd/grad/instruments.html
http://www.wikitude.com/external/doc/documentation/3.0/android/targetmanagement.html

23.5 Solar Display Tools, Dials and Charting Packages

http://justbasic.wikispaces.com/dialsGauges
Renewable Energy Dashboard http://www.cf.missouri.edu/energy/em_renewable/dashboard.html#Top
http://simile.mit.edu/timeplot
Custom dials/gauges for raspberrypi http://www.raspberrypi.org/forums/viewtopic.php?t=42857&p=345866
SolarSystem is a simple widget that allows you to view a 3D solar system representation on your Dashboard http://mac.softpedia.com/get/Dashboard-Widgets/Webcams/Miscellaneous/SolarSystem.shtml
https://github.com/buntine/The-Solar-System-is-Badass/blob/master/doc/06-analytics-dashboard.txt
Animation of the Solar System, Development based on Quartz Composition https://www.apple.com/downloads/dashboard/justforfun/solarsystem.html

23.6 General Solar Astronomy Resources

Software for Positional Astronomy http://aa.usno.navy.mil/software/index.php
Astronomy Software - list of Freeware, Shareware, and Commercial Software http://www.midnightkite.com/index.aspx?URL=Software

23.7 Image processing based solar tracking

Optical tracking http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3690008/
https://www.researchgate.net/publication/224445376_Machine_vision_as_a_method_for_characterizing_solar_tracker_performance

http://www.ijarcsse.com/docs/papers/Volume_3/10_October2013/V3I10-0197.pdf

https://www.researchgate.net/publication/260844761_Automatic_positioner_and_control_system_for_a_motorized_parabolic_solar_reflector

Nootropic video experimenter board http://nootropicdesign.com/ve/

how to analyze the infrared sensor for pointing the Wii remote http://www.kako.com/neta/2008-009/2008-009.html

Web cam pictures tracking http://www.sciencedirect.com/science/article/pii/S0262407912625585

http://www.instructables.com/id/Wii-Remote-IR-Camera-Hack/

http://www.instructables.com/files/orig/FQL/9ZSM/FY3KH9ED/FQL9ZSMFY3KH9ED.gif

http://procrastineering.blogspot.com/2008/09/working-with-pixart-camera-directly.html

23.8 Wii Remote

http://onakasuita.org/wii/index-e.html

https://code.google.com/p/darwiinosc/downloads/list

23.9 Cellular Mobile Tablet Apps

SkySafari for Android or iOS http://www.southernstars.com/products/skysafari_android/data.html

http://www.anvartec.com/anvartecapps/tabid/978/language/en-US/Default.aspx

http://m.appszoom.com/android_applications/sun%2520path

http://www.morch.com/2011/11/14/seeing-the-suns-path-android-and-iphone-apps/

http://appcrawlr.com/ios-apps/best-apps-sun-position

http://www.100bestandroidapps.com/submitted-by-developers/286-sun-path

http://www.windowsphone.com/en-us/store/app/sun-path/cf70fa30-b3ac-4edc-a4e0-f9d1d18cd371

http://xayin.com/sunplan.html

sun path apps

http://www.robgalbraith.com/content_page7289.html?cid=7-12721-12764

http://www.solmetric.com/solmetric-isv-iphone-app.html

http://www.ozpda.com

http://suntrajectory.net

http://www.anvartec.com/anvartecapps/tabid/978/language/en-US/Default.aspx

HelioStat for BlackBerry Smartphones http://www.tworoads.net/~srp/software/heliostat/index.html

App http://www.ozpda.com

Sungraph App https://itunes.apple.com/za/app/sungraphhd/id504605785?mt=8 and http://www.analemma.com/pages/OtherPhenomenon/OtherPhenomenon.html

23.10 Optical Design Software

Nb NREL http://www.nrel.gov/csp/soltrace/

Sketchup Light Ray Reflection Simulator Plugin http://www.cerebralmeltdown.com/projects/Sketchup%20Light%20Reflection%20Plugin/default.html

23.11 Central Receiver Heliostat Systems

Review software http://blogs.sun.ac.za/sterg/files/2012/06/CSP-06.pdf

23.12 Satellite/Solar Systems

Satellite http://www.gano.name/shawn/JSatTrak/

Solar satellite http://www.celestrak.com/columns/v03n03/

http://www.dxzone.com/catalog/Software/Satellite_tracking/

http://www.dk1tb.de/programmeeng.htm

http://www.qsl.net/kd2bd/predict.html

http://www.stoff.pl

http://www.amsat.org/amsat/ftpsoft.html

http://www.saao.ac.za/~wpk/#software

Index provides links to information on satellite tracking software for popular tracking operating systems. http://www.celestrak.com/software/satellite/sat-trak.asp

CHAPTER 24

SOLAR TRACKING ONLINE HARDWARE RESOURCES

24.1 CAD Design Model for Solar Tracker and 3D Design Software

Solar Tracker Final Edition Solidworks http://grabcad.com/library/solar-tracker-final-edition

CAD files for desktop size Dual Axis Sun Tracker Kit http://www.ecocaddesigngroup.com/dual-axis-sun-tracker/

Assembly of tracking system for solar energy application http://www.youtube.com/watch?v=2GLJEYe1noc

Solar Tracker Solid Works http://www.youtube.com/watch?v=0n03X_hzDic

Solar Tracker 2-axis SolidWorks http://www.youtube.com/watch?v=6-aDAHUjkXI

THE DESIGNING, BUILDING, AND TESTING OF AN AZIMUTH-ALTITUDE DUAL AXIS SOLAR TRACKER (Solidworks) http://physastro.pomona.edu/wp-content/uploads/2012/09/Leo-Rosetti-Senior-Thesis-2012.pdf

Solar Project http://www.revanth.me/?page_id=832 http://www.revanth.me/?page_id=829

Optimum Shading Device A construction method using AutoCAD 2000 by Thanos N. Stasinopoulos http://www.ntua.gr/arch/geometry/tns/shadecad/

Actuators for elevation and azimuth solar tracking http://www.dpaonthenet.net/article/43686/Actuators-for-elevation-and-azimuth-solar-tracking.aspx

Autocad drawing of Telescope Mount http://coe.tsuniv.edu/eaton/eng_t13_constr.html

What are the considerations when designing a solar shading system http://www.coltinfo.co.uk/solar-shading-design-considerations.html

24.2 Mechatronics Mechanical Electronics Solar Platform Tracking

Review sun tracking systems http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3297124/

Design and Construction of an Automatic Solar Tracking System https://www.researchgate.net/publication/236577196_Design_and_Construction_of_an_Automatic_Solar_Tracking_System

tracking system using an electromechanical solution with C++ code http://web.vtc.edu/ELM/projects/2008-2009/Ground_Control/Team%20Ground%20Control.htm

http://www.nrel.gov/csp/troughnet/pdfs/2007/geyer_sbp_dish_stirling.pdf

Solar Dual Axis Tracker - Large http://ledlightingmanagement.com/led-lighting-management/content/solar-dual-axis-tracker-large

Following the Sun Project construction and development of a solar tracker Seguint el Sol Projecte de constructci i programaci d'un seguidor solar https://app.box.com/s/obmvr54yiu2kvt9nxt80

http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1034&context=techdirproj

http://inpressco.com/wp-content/uploads/2013/04/Paper35417-429.pdf

http://carnot.mech.columbia.edu/~sd/Design2014/Team2/

Technology of the solar trackers 1 axle or 2 axles http://www.desimone.be/en/index.php?p=20

Polar Mount tracking satellite system for tracking/tuning section http://www.geo-orbit.org/sizepgs/tuningp4.html

Diy FPV Antenna Tracker using stm32f4 Pololu motor Ardupilot autopilot Frsky telem http://www.youtube.com/watch?v=un9b23y9EsY

Rotating and Tilting Sun Tracking Solar Concentrator http://www.youtube.com/watch?v=9DobOOi7-Jk

24.3 Sun Follower Actuation Platform Tracking Design Concepts

Solar trackers for all technologies HCPV, CSP, PV Seguidores solares para todas las tecnologas HCPV, CSP, PV Nueva geometra patentada http://www.titantracker.es/v_portal/apartados/apartado.asp?te=684

Information brochure of PSA Nuevo folleto divulgativo de la PSA http://www.psa.es/webesp/index.php

The Oil Drum: The bright future of solar powered factories (concentrated solar system) http://www.theoildrum.com/node/8217

Full automatic sun tracker (Russian, Sun) http://ru.made-in-china.com/co_xgh613/product_Full-Automatic-Sun-Tracker_hussuyury.html

Energy from Sun, Solar energy stirling motor and sunpower http://www.youtube.com/watch?v=wLYJlpEOMcA

Dual-axis solar tracker (Chinese Ħ Ħ) http://www.baike.com/wiki/%E5%A4%AA%E9%98%B3%E8%83%BD%E8%B7%9F%E8%B8%AA%E5%99%A8

Dual-axis solar tracker (Chinese Ħ) http://worldiscoveries.asia/cn/technologiescn/%E5%8F%8C%E8%BD%B4%E5%A4%AA%E9%98%B3%E8%83%BD%E8%B7%9F%E8%B8%AA%E5%99%A8/

Sentinel Solar: Sentry Dual Axis Tracker http://www.youtube.com/watch?v=D7ijl25yLRs

SABO SOLAR TRACKING SYSTEM CLIMATIC CONDITIONS DATA LOG VIEWER http://www.sabo.gr/assets/files/ENERGY-ENGLISH%20low.pdf

Infinia PowerDish http://vimeo.com/48084629
http://vimeo.com/63935077

Stirling dish solar tracking time lapse http://www.youtube.com/watch?v=IKyBEPbIgzY

Tessera solar http://www.youtube.com/watch?v=yWECuQo7Ik0

How to Build Your Own Automatic Solar Tracker http://www.brighthub.com/environment/renewable-energy/articles/76226.aspx

CU-Boulder student designs solar energy tracker with Boeing http://www.youtube.com/watch?v=l_uphQqUbuw

Advanced Solar Tracking Motion Solutions by Dunkermotor (a brand of AMETEK Precision Motion Control) http://www.youtube.com/watch?v=iqyf8PUCd_w

Dual Axis Solar Tracker http://www.youtube.com/watch?v=cIC6237TLRA

European Solar Powered Stirling 10 Kilowatt Generator http://www.youtube.com/watch?v=EahfGfDdgNY

Hot Pot is a great solar cooker, but was designed for the Tropics http://www.instructables.com/id/Hot-Pot-is-a-great-solar-cooker-but-was-designed-/?ALLSTEPS

Design, construction and testing of a self-tracking solar concentrating reflector and solar concentrator for power generation Automatic positioner and control system for a motorized parabolic solar reflector https://www.researchgate.net/publication/260844761_Automatic_positioner_and_control_system_for_a_motorized_parabolic_solar_reflector

IMO Slew Drives - IMO Schwenktriebe SolarCraft http://www.youtube.com/watch?v=1TN7gOXTBFo

High accuracy angular position and rate capability Direct-drive brushless servomotors result in zero backlash http://www.aerotech.com/product-catalog/gimbals-and-optical-mounts/amg.aspx

Designing with solar tracking motors http://powerelectronics.com/content/designing-solar-tracking-motors

A high-precision drive system with two brushless maxon flat motors, planetary gearhead with spindle and encoder ensures accurate positioning of the laser http://www.maxonmotor.com/maxon/view/application/TNO-TELESCOPE-AB

Telescope-Inspired Solar Power Design Could Produce Twice as Much Energy http://www.treehugger.com/solar-technology/telescope-inspired-solar-power-design-could-produce-twice-html

WindyNation's Solar Tracker Electronics: A Demonstration in Solar Tracking Design http://player.mashpedia.com/player.php?q=2mpj6B58RT0&lang=

Solar Tracker http://www.youtube.com/watch?v=A1Uazd_Zaxs

Solar Tracker http://grenetek.com/products/

Infinia Stirling Solar Generator http://www.youtube.com/watch?v=rzhzeA4VRSc

Antenna Tracker 5.8ghz parabolic http://www.youtube.com/watch?v=V5TE8fdexHI

Antenna Tracker Design http://www.youtube.com/watch?v=w6zVhLLKwFY

http://cyberleninka.ru/article/n/matematicheskaya-model-solnechnoy-opresnitelnoy-ustanovki-s-ustroystvom-

http://www.cit.com.ru/produkcziya/solnechnaya-energiya/sistema-energii-na-ustrojstve-slezheniya-za-solnczem/

Solar automatic solar tracker solar tracker seguimento solar tracking rastreador solar seguimento solar seguidor solar automtico de seguimiento solar http://www.energizar.org.ar/energizar_desarrollo_tecnologico_seguidor_solar_que_es.html

24.4 Linear Trough and Fresnel Sun Follower Tracking Design Concepts

Linear Fresnel Collectors A Technology Overview http://sfera.sollab.eu/downloads/Schools/Fabian_Feldhoff_Linear_Fresnel.pdf

DEVELOPMENT OF A LOW COST LINEAR FRESNEL SOLAR CONCENTRATOR http://scholar.sun.ac.za/bitstream/handle/10019.1/85762/walker_development_2013.pdf?sequence=1

Secondary reflector for linear fresnel reflector system http://www.google.com/patents/US20110220094

Mechatronic design of the sun tracking system of a linear Fresnel reflector solar plant https://www.researchgate.net/publication/233842741_Mechatronic_design_of_the_sun_tracking_system_of_a_linear_Fresnel_reflector_solar_plant

Mid-temperature concentrating solar thermal collectors http://www.ecobuilding-club.net/downloads/RTD/HelioDynamics.pdf

Method of forming an energy concentrator http://www.google.com/patents/US4385430

Collector mirror for a solar concentrator comprising linear fresnel mirrors http://www.google.com/patents/US20140168801

THE PIONEERING WORK ON LINEAR FRESNEL REFLECTOR CONCENTRATORS (LFCs) IN ITALY http://mondosolare.it/pub/silvi-fresnel.pdf

24.5 Solar Tracking Motor Controller Boards

Motor controllers for Solar Tracking Systems http://uk.farnell.com/solar-system-tracking-applications
EasyDriver Stepper Motor Driver https://www.sparkfun.com/products/10267

24.6 Solar Tracking Kits

RF HAMDESIGN - MESH DISH KITs http://www.rfhamdesign.com/products/parabolicdishkit/index.php
SunTracking Prototype-Kit: basic kit to test SunTracking in a prototype solar tracker http://www.suntracking.es/en/products/suntracking-prototype-kit
2 Axis Heliostat Development Kit Test https://www.youtube.com/watch?v=HmnYpVEMJXM
KILOG69 tracker kit, installation and results http://www.youtube.com/watch?v=IexnXaZ782g
SUN TRACKER KIT, 6x6 POLE MOUNT KIT http://www.youtube.com/watch?v=x0bQHZUTw_I
SunTracking Prototype-Kit Automatic Sun Tracking System Kit: es un kit bsico para probar SunTracking en su prototipo de seguidor solar http://www.suntracking.es/es/productos/suntracking-prototype-kit
3D Print Files: 34m Deep Space Station Download Free of Charge http://spacecraftkits.com/BWG.html
Complete Solar Tracker Sun Tracker Kits http://m.ebay.com/itm/400187219850?cmd=VIDESC

24.7 Stepper motor solar tracking

Open Source Sun Tracking / Heliostat Project https://www.behance.net/gallery/4588151/The-Open-Source-Sun-Tracking-Heliostat-Project
PIC Processor based solar tracking http://files.spogel.com/abstracts/p-0456--automatic_solar_rad_tracker.pdf
Arduino Solar Tracker. Horizontal Axis. Linear Actuator Powered http://www.youtube.com/watch?v=3L7ddFZ9OME
Solar Arduino trackers http://wiki.happylab.at/w/Solar_Arduino_tracker
http://www.instructables.com/id/Arduino-Solar-Tracker/
http://blog.arduino.cc/2010/09/20/arduino-and-matlab/
http://www.cerebralmeltdown.com/
pilot Antenna solar Tracker Build http://www.youtube.com/watch?v=9Mnv10NcDC4
Dual axis Antenna / Solar Tracker Build http://www.youtube.com/watch?v=TMtHQD4gkoo
bi-axis Antenna / solar tracker http://www.youtube.com/watch?v=aQ20hPECWkQ
PAN/TILT antenna solar tracker http://www.youtube.com/watch?v=oLkQl2dsV_M
http://www.youtube.com/watch?v=9Mnv10NcDC4

24.8 Schematic Diagrams for Solar Trackers

Desktop http://www.altera.com/literature/dc/2007/t3c.pdf

http://kinashira.blogspot.com
http://www.solarnavigator.net/sun_tracker_wings.htm
http://ijtra.com/view/a-study-on-automatic-dual-axis-solar-tracker-system-using-555-timer.pdf
http://www.electroschematics.com/8019/diy-solar-tracker-system/
http://www.mdpub.com/suntracker/
http://electronicsforu.com/electronicsforu/circuitarchives/view_article.asp?sno=745&article_type=1&id=674&tt=unhot#.VDWju9oaySM
http://www.tehnomagazin.com/Solar-photovoltaic/Solar-tracker.htm
http://www.janspace.com/b2evolution/arduino.php/2014/07/13/mobile-sun-tracking-solar-power-plant
http://www.thingiverse.com/thing:53321
http://www.picbasic.co.uk/forum/showthread.php?t=15192
http://www.josepino.com/?simple_sun_tracker
http://www.arindambose.com/html/docs/Helianthus.pdf
http://www.binaryorbit.org/RelayCircuit.asp
Solar Battery Charger Circuit http://www.electroschematics.com/6888/solar-battery-charger-circuit/
12V LDO Solar Charge Controller http://www.electroschematics.com/6899/12v-ldo-solar-charge-control/
DIY Solar Tracker System http://www.electroschematics.com/8019/diy-solar-tracker-system/
electronics projects and circuits http://www.electroschematics.com

24.9 Solar Tracker Printed Circuit Board PCB Design Software

ALTIUM NEXT GENERATION ELECTRONICS DESIGN http://www.altium.com/en/solutions/rigid-flex/learn
PCB Design Software http://www.build-electronic-circuits.com/pcb-design-software/
CadSoft EAGLE PCB Design Software http://www.cadsoftusa.com

24.10 Solar tracking motors

Motors http://www.dunkermotor.com/default.asp?id=109&lang=2
http://www.dunkermotor.com/start.asp
http://powerelectronics.com/content/designing-solar-tracking-motors
https://www.sparkfun.com/products/10267
Microchip motor control http://www.microchip.com/pagehandler/en-us/technology/motorcontrol/
Gallery motor curves http://www.gophoto.us/key/electric%20motor%20efficiency%20curve
Motors http://m.alibaba.com/product/905215119/product.html
solar tracking motor http://www.pneudrive.co.za/LinkClick.aspx?fileticket=aqsw3CO5E50%3D&tabid=124
Coaxial motors http://www.framo-morat.com/engl/Mini.html

24.11 Actuators, Gear Drives and Transmission Systems

Solar tracking linear actuators http://www.gemcodirect.com/images/products/ldt/950MD%20Mill-Duty%20Linear%20Displacement%20Transducers%20Manual.pdf

SKF linear actuators and slewing drive for solar tracking http://www.skf.com/portal/skf_mec/home/products?contentId=897618&lang=en

http://www.skf.com/group/industry-solutions/solar-energy/applications/solar-tracking/index.html

Sumitomo cyclo drives http://www.sumitomodrive.com/

Kinematics http://www.kinematicsmfg.com/markets/solar/

http://www.kinematicsmfg.com/products/le-locking-drive/

http://www.kinematicsmfg.com/products/sde-dual-axis-positioner/

H-Fang and Company china http://www.h-fang.com.cn/

http://www.h-fang.com.cn/product.aspx?gclid=COby6amqm8ECFfSWtAod_B4AxQ

Joyce Dayton http://joycedayton.com/products/solar-products

http://joycedayton.com/products/solar-products/solar-tracking-actuators-sa

Linak drives text http://www.linak.com/techline/?id3=2236

Nabtesco drives http://www.expo21xx.com/motion21xx/14615_st2_torque_motor/default.htm

http://www.expo21xx.com/renewable_energy/14615_st2_wind_turbine_gear/default.htm

Cycloial drive http://hengtai-reducer.en.made-in-china.com/product/fKimNPsrXuce/China-Cycloial-Robot-Precision-Gearbox-Nabtesco-RV-200-C-Series-for-Welding-Positioner.html

SEW Eurodrive http://www.sew.co.za/

Nord Drives Germany http://www.nord.com/cms/en/home.jsp

Peerless Winsmith http://www.winsmith.com/catalog/

Planetary gear drives http://www.anaheimautomation.com/products/brush/dc-gearmotor.php?tID=103&pt=t&cID=46

Micro spur drives http://www.precisionmicrodrives.com/dc-geared-motors

Solar Bearings http://www.creativemotioncontrol.com/home-copy/grooved-roller-bearings/

Actuation motion control solutions for military land systems supporting a myriad of platforms, Launcher turret azimuth and elevation drives, Reload Actuation, Ground-based antenna array actuation, PTO gearboxes, Travel lock actuators http://www.whipactsys.com/land-system-products/

Pneumatic Robohand Rotary Actuators (Rotaries) http://www.destaco.com/rotary-actuators.html

Pneumatic Actuator Solutions for Solar Tracker Movement http://www.pneumatictips.com/274/2009/02/pneumatic-equipment-components/actuators/actuator-solutions-for-solar-tracker-movement/

Hydraulic Devices Help Solar Collectors Track Sun http://www.pneumatictips.com/275/2009/02/pneumatic-equipment-components/actuators/hydraulic-devices-help-solar-collectors-

Pneumatic and Hydraulic Actuators and Pneumatic Cylinders for solar tracker http://www.parker.com/portal/site/PARKER/menuitem.338f315e827b2c6315731910237ad1ca/?vgnextoid=361aeea74775e210VgnVCM10000048021dacRCRD&vgnextfmt=default&vgnextfmt=default&vgnextcat=ACTUATORS+AND+PNEUMATIC+CYLINDERS&vgnextcatid=2748645&vgnextdiv=687577&productcategory=productline

Concept Aplicaciones Solares Apolo lanza al mercado un seguidor solar con tecnologa propia http://www.construible.es/noticias/aplicaciones-solares-apolo-lanza-al-mercado-un-seguidor

Concept seguidor-solar-con-concentrador-parabolico La invencin est relacionada con el aprovechamiento de las radiaciones solares para la generacin de formas de energa consumibles http://www.economiadelaenergia.com/2012/01/seguidor-solar-con-concentrador-parabolico/

Actuator and bearing solutions for solar tracking http://www.motioncontrol.co.za/49461N

24.12 Angle Sensors as Angle Encoder

Angle encoder http://www.renishaw.com/en/resolute-true-absolute-encoder-with-siemens-drive-cliq-interface-

Inductive position coding system for controlling the azimuth angle in solar tracker applications http://www.pepperl-fuchs.com/global/en/15517.htm

Triple Axis Accelerometer and Gyro Breakout https://www.sparkfun.com/products/11028

Choosing an accelerometer http://electronics.stackexchange.com/questions/33374/choosing-an-accelerometer

combine the accelerometer and gyroscope data http://www.pieter-jan.com/node/11

ST PT sensor portfolio includes MEMS (microelectromechanical sensors including accelerometers, gyroscopes, digital compasses, inertial modules, pressure sensors, humidity sensors and microphones), smart sensors and sensor hubs, temperature sensors and touch sensors. http://www.st.com/web/en/catalog/sense_power/FM89

http://www.digikey.com/en/articles/techzone/2011/apr/mems-accelerometers-gyroscopes-and-geomagnetic-

Inertia Measurement Systems Gyroscopes and Accelerometers Sensor fusion I2C MPU-6050 Code http://www.cs.unca.edu/~bruce/Fall13/360/IMU_Wk8.pptx

24.13 Optical Sensors as Angle Encoder

Sensor http://cr4.globalspec.com/thread/66442/Sun-Position-Sensor

https://www.wpi.edu/Pubs/E-project/Available/E-project-121710-140419/unrestricted/Dual_Axis_Tracker_Final_Report.pdf

24.14 Solar Tracking Controllers

Solar Tracking Controllers http://www.suntrackpro.com/#!solar-tracking-controllers/c1xms

Atmel Mega168 micro controller http://www.mikrocontroller.net/articles/Sonnenfolger_/_Heliostat

http://www.bbastrodesigns.com/BBAstroDesigns.html#Computer_Operated_Telescopes

Installation equipment http://www.solarcube.com/

Yokogawa Electric Corporation SolStation Solar Tracking Controller Software Setup and Solar Tracker Configuration http://www.yokogawa.com/ns/support/onepoint/hxs10/ns-onepoint-hxs01.htm

24.15 Solar Batteries Deep cycle

http://www.sinetech.co.za/voyage.htm
http://www.ecodirect.com/Deep-Cycle-Battery-s/5.htm
http://www.solarpanelenergy.co.za/pg/76320/deep-cycle-gel-batteries
http://www.solar-electric.com/deep-cycle-battery-information-faq.html/

24.16 Solar Thermal Power Generation

http://www.mpoweruk.com/heat_engines.htm
http://www.stirlingengine.com/
Two-Stage Traveling Wave Thermoacoustic engine http://www.youtube.com/watch?v=nVMjrI0T5n4
http://www.stirlingengines.org.uk/
PHILIPS STIRLING CYCLE GENERATOR http://www.youtube.com/watch?v=M9UKu-AP02k
Rhombic Drive Stirling Engine http://www.youtube.com/watch?v=MzqbK7p9EmU
http://mac6.ma.psu.edu/stirling/
Animations http://www.animatedengines.com/
http://touch3d.net/stirling_b.html
Dearman engine cryo cooling http://youtu.be/bm6kiCquIE8
http://www.dearmanengine.com/#!dearman-liquid-engine/c6i4
Heat Engine Projects http://www.redrok.com/engine.htm
Brayton Energy, Brayton SolarCAT Solar Power Conversion System http://queltanews.com/info/368

24.17 Solar Thermal Collector Model

How Solar Thermal Collector Performance was Modeled http://andyschroder.com/SolarEnergyResearch/HowCollectorWasModeled/
Model-Based Simulation of an Intelligent Microprocessor-Based Standalone Solar Tracking System http://cdn.intechopen.com/pdfs-wm/39366.pdf
Flat plate systems http://www.nrel.gov/docs/legosti/old/5607.pdf
http://matlab.ru/products/thermolib
http://www.cybernet.co.jp/fclib/
Simulis Thermodynamics Mixture properties and fluid phase equilibria calculations http://www.prosim.net/en/software-simulis-thermodynamics-3.php
Thermolib - Modeling Thermodynamics in Simulink Part 1 of 3 http://youtu.be/2SkdyEYxAP0
Thermolib The key to thermal management in Matlab Simulink http://www.eutech-scientific.de/products-services/thermolib.html
Thermolib Toolbox for thermodynamic calculations and thermodynamic systems simulations in MATLAB and Simulink http://www.mathworks.com/products/connections/product_detail/product_35808.html?refresh=true
Catch the Fire Innovative dotcom engineers ReInvent Solar Power http://discovermagazine.com/2003/aug/featfire

Energy Innovations http://www.idealab.com/our_companies/show/all/energy_innovations

24.18 Solar Thermal Energy Storage Cogeneration in Trigeneration, Polygeneration and Quadgeneration

http://energystorage.org/energy-storage/technologies/liquid-air-energy-storage-laes

http://energystorage.org/energy-storage/storage-technology-comparisons/caes

http://www.lowcarbonfutures.org/liquid-air-and-birmingham-centre-cryogenic-energy-storage

http://www.lowcarbonfutures.org/sites/default/files/potential-guide.pdf

Liquid Air as an Energy Vector https://www.stfc.ac.uk/resources/PDF/DearmanEngineCompanyClusterDayPresentation.pdf

http://cleantechnica.com/2011/03/02/liquid-air-tested-to-store-renewable-energy-in-uk/

http://www.extremetech.com/extreme/137231-british-company-efficient-energy-storage

http://www.ecopedia.com/technology/energy-storage-method-uses-liquid-air-as-battery/

http://solar.calfinder.com/blog/solar-research/wind-or-solar-power-can-now-be-stored-as-liquid-

High-Concentration Systems (HCPV) http://www.ise.fraunhofer.de/en/business-areas/iii-v-and-concentrator-photovoltaics/research-topics/high-concentration-systems-hcpv

24.19 Solar Thermal Energy Convey Transport

7

Review on thermal energy storage with phase change materials and applications http://www.seas.upenn.edu/~meam502/project/reviewexample2.pdf

http://www.rgees.com/solutions_solar-thermal.php

Flow and heat transfer in a closed loop thermosyphon, theoretical simulation http://www.erc.uct.ac.za/jesa/volume18/18-4jesa-dobson.pdf

Flow Regime Recognition in Two-Phase Thermosyphon Loops Using Pressure Pulse Analyses http://www.thermalfluidscentral.org/e-resources/download.php?id=205

http://www.worldcat.org/title/transient-modelling-of-a-loop-thermosyphon-transient-effects-in-

Thermosyphon Thermosyphin Water Heating System http://www.builditsolar.com/Projects/WaterHeating/ThermosyphonDIY/ThermosyphonDIY.htm

24.20 Solar System Dashboard, Dials, Gauges, Sensors and Instrument Panels

Dials, Gauges, and Instrument Panels http://www.pinterest.com/wednesdave/quantified-dials-gauges

Industrial Sensors Products Positioning Systems, Inductive Positioning Systems, Data Matrix Positioning System, Position Guided Vision and Rotary Encoders http://www.pepperl-fuchs.com/global/en/classid_1522.htm

Dual Axis Sun Tracker Example Design and Instrumentation http://www.ni.com/example/31252/en/

24.21 Fabricating Solar Reflector Solar Parabolic Dish 3D Printer and CADS Models

How to create a parabola with Autodesk http://forums.autodesk.com/t5/autocad-2007-2008-2009/how-to-create-a-parabola/td-p/1976034

Shaping Of Parabolic Cylindrical Membrane Reflectors For The Dart Precision Test Bed http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/37943/1/04-1118.pdf

parabolic dish 3D printer http://iblog.ahands.org/2013/02/3d-printing-wifi-antenna-enhancers.html

http://spacecraftkits.com/BWG.html

http://forums.autodesk.com/t5/inventor-general-discussion/parabolic-reflector/td-p/2976844

http://www.cbliss.com/inventor/iFeatures/ParabolaSketch.zip

http://www.thingiverse.com/thing:84564

https://www.youmagine.com/designs/paramike

How to create a parabola with Autodesk http://forums.autodesk.com/t5/autocad-2007-2008-2009/how-to-create-a-parabola/td-p/1976034

How to create a parabola with Solidworks http://help.solidworks.com/2013/English/SolidWorks/sldworks/t_Sketching_Parabolas.htm

http://help.solidworks.com/2012/English/SolidWorks/sldworks/Sketched_Parabola.htm?id=e7fe059bbd084d549bde00491d1b2d4b

http://www.freeantennas.com/projects/template/

parabolic dish desktop model http://www.personal.psu.edu/users/a/j/ajo5115/Project2/intro.html

http://www.instructables.com/id/How-to-build-a-strikeheliostatstrike-paraboli/

http://forums.autodesk.com/t5/inventor-general-discussion/parabolic-reflector/td-p/2976844

Cost-effective carbon composite reflector dish Modular manufacturing method forms different dish sizes with near mirror-perfect reflective surfaces, without resort to one-off tools. http://www.compositesworld.com/articles/cost-effective-carbon-composite-reflector-dish(2)

3D Printer design http://sustainabilityworkshop.autodesk.com/products/fea-lightweighting-uss-solar-tracker

http://archive.geogebra.org/en/upload/files/mrfox001/constructing_parabolas.html The geometric definition of a parabola is the set of all points that are equidistant from a directrix and a focus.

parabolic dish 3D printer http://iblog.ahands.org/2013/02/3d-printing-wifi-antenna-enhancers.html

http://forums.autodesk.com/t5/inventor-general-discussion/parabolic-reflector/td-p/2976844

http://www.cbliss.com/inventor/iFeatures/ParabolaSketch.zip

http://www.thingiverse.com/thing:84564

https://www.youmagine.com/designs/paramike

parabolic dish desktop model http://www.personal.psu.edu/users/a/j/ajo5115/Project2/intro.html

http://www.freeantennas.com/projects/template/

Dish https://www.google.com/patents/US20110247679

http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19780009202.pdf

http://www.iaeng.org/publication/WCE2011/WCE2011_pp1949-1951.pdf
http://www.heliotrack.com/Parabolic.html
http://solarcooking.org/plans/parabolic-from-flat-sheet.htm
http://arxiv.org/ftp/arxiv/papers/0903/0903.1601.pdf
https://www.google.co.za/search?q=fabricating+solar+parabolic+dish&espv=2&biw=1310&bih=715&tbm=isch&tbo=u&source=univ&sa=X&ei=AtY2VKTxLM2V7Aaj7YEI&ved=0CG4Q7Ak

24.22 Solar Parabolic Dish Shapes and Designs

A lightweight reflector with a load bearing structure based on a tensile spoke-wheel, which spoke structure is especially compatible with dish parabolic mirrors utility as a carrier structure for any round functional surface, including flat or slightly-curved mirrors used in central tower solar systems, parabolic dishes for concentrating thin film panels https://www.google.com/patents/US20110247679

Design and Fabrication of a Low-Specific-Weight Parabolic Dish Solar Concentrator http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19780009202.pdf

Carbon Fibre Satellite Dish Spray Painted https://www.youtube.com/watch?v=adfxRbiCPeQ

Thin film coating for parabolic dish http://www.reynardcorp.com/optical-production-capabilities/thin-film-coatings-custom.html

High Reflectance ReflecTech PLUS mirror film has high reflectance in the wavelength range important for sunlight http://www.reflectechsolar.com/technical.html

High Reflection Composite Material http://xxentria-europe.com/wp-content/uploads/2013/04/SolarMir_ACP_technical_datas.pdf

Comparative Analysis of SK-14 and PRINCE-15 Solar Concentrators http://www.iaeng.org/publication/WCE2011/WCE2011_pp1949-1951.pdf

parabolic solar concentrator dish collects about 3 square meters of sunlight. http://www.heliotrack.com/Parabolic.html

Making a Parabolic Reflector Out of a Flat Sheet http://solarcooking.org/plans/parabolic-from-flat-sheet.htm

Parabolic-Dish Solar Concentrators of Film on Foam http://arxiv.org/ftp/arxiv/papers/0903/0903.1601.pdf

https://www.google.co.za/search?q=fabricating+solar+parabolic+dish&espv=2&biw=1310&bih=715&tbm=isch&tbo=u&source=univ&sa=X&ei=AtY2VKTxLM2V7Aaj7YEI&ved=0CG4Q7Ak

CHAPTER 25

SOLAR TRACKING ONLINE DESIGN RESOURCES

25.1 Patented Sun Tracker Positioning Systems

http://www.google.com/patents/US20120068899
https://www.google.com/patents/US6442937
https://www.google.com/patents/US6336452
https://www.google.com/patents/US4583520
https://www.google.com/patents/US4586334
Polar Mounting Configuration http://www.google.com/patents/US8253086
Patent Russia http://bd.patent.su/2286000-2286999/pat/servl/servlet1eda.html
http://www.ntpo.com/patents_electricity/electricity_1/electricity_45.shtml
Solar tracking system using periodic scan patterns with a shielding tube or mini tracker http://www.google.com/patents/US20130320189

25.2 Solar Tracker Simulation and Synthesis Models

Matlab Simulink http://www.researchgate.net/profile/Cheng_Siong_Chin/publication/215544128_Design_Modeling_and_testing_of_a_Standalone_Single-Axis_Active_Solar_Tracker_using_MATLABSimulink/links/046f65c98bcf547160964f8b

25.3 Solar Tracker Designs

System design http://www.gearseds.com/files/solar_tracker_const_guide_rev4_all3units.pdf
System http://espace.library.curtin.edu.au/cgi-bin/espace.pdf?file=/2011/03/01/file_1/153149
System http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3658738/
System http://www.ijens.org/105501-3939%20IJMME-IJENS.pdf
Systems Pic processor http://www.edaboard.com/thread224055.html
Stepper motor based Solar Tracker in the Internet Cloud http://www.instructables.com/id/Solar-Tracker-in-the-Internet-Cloud/?ALLSTEPS
http://www.susdesign.com/tools.php
http://rredc.nrel.gov/solar/codesandalgorithms/solpos/ http://www.nrel.gov/gis/data.html
http://jpjustiniano.wordpress.com/page/3/
http://www.mps.mpg.de/dislin/
http://jpjustiniano.wordpress.com/2013/04/04/solar-site-monitoring-bankable-data/
http://pysolar.org/ Pysolar Pysolar is a collection of Python libraries for simulating the irradiation of any point on earth by the sun.
http://sunpy.org/ SunPy Open-source library for solar physics using Python
http://physastro.pomona.edu/wp-content/uploads/2012/09/Leo-Rosetti-Senior-Thesis-2012.pdf

NREL Solar Prospector In Solar Energy http://jpjustiniano.wordpress.com/2012/05/05/nrel-solar-prospector/
Solar irradiance on sunny and cloudy days In Solar Energy http://jpjustiniano.wordpress.com/2011/10/09/solar-irradiance-on-sunny-and-cloudy-days/

http://trackeripm.com/?page_id=236
Systems http://www.mdpi.com/1424-8220/13/3/3157/pdf
http://jpjustiniano.wordpress.com/page/2/
Dislin http://www.dislin.de/
remember dashboards dataloggers http://plot.micw.eu/
http://git-scm.com/
https://github.com/
http://progit.org/
http://ac.els-cdn.com/S1876610213000234/1-s2.0-S1876610213000234-main.pdf?_tid=363af65e-2629-11e4-9293-00000aab0f6b&acdnat=1408292097_5ca84bdd00f2182e447a52c4eb4e5926
http://www.ni.com/example/31252/en/

25.4 Mechatronics Platform Tracking

Calculation of Sun Position and Tracking the Path of Sun for a Particular Geographical Location http://www.ijetae.com/files/Volume2Issue9/IJETAE_0912_12.pdf
Model-Based Simulation of an Intelligent Microprocessor-Based Standalone Solar Tracking System http://cdn.intechopen.com/pdfs-wm/39366.pdf
http://www.nrel.gov/csp/troughnet/pdfs/2007/geyer_sbp_dish_stirling.pdf
http://www.innova.co.it/eng/catalog/products/trinum.html
http://www.qnergy.com/products_overview
http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1034&context=techdirproj
http://inpressco.com/wp-content/uploads/2013/04/Paper35417-429.pdf
http://carnot.mech.columbia.edu/~sd/Design2014/Team2/
Siemens system http://www.ptolemeo.gr/wp-content/uploads/2013/04/Ptolemeo-2axes-Solar-Tracker-April13.pdf

Arduino Spanish http://vac2.net/bitacora/seguidor_solar.html.es.
http://www.hindawi.com/journals/ame/2013/146352/
Plc http://www.suntracking.es/en/support/downloads/185-suntracking-cathalogue/download
http://www.koutsikossolar.com/dual-axis-tracker-tr---13.html
DUAL AXIS SOLAR PANEL CONTROLLER TRACKER WITH ACCELEROMETER FEEDBACK http://blog.solutions-cubed.com/dual-axis-solar-panel-controller-tracker/
Systems http://www.sersc.org/journals/IJCA/vol7_no4/19.pdf
Systems http://www.treehugger.com/renewable-energy/sun-cube-by-green-and-gold-energy-of-australia.html

25.5 Satellite Positioner and Antenna Positioning Systems as Solar Tracker

WiNRADiO ARP-ELAZ-100 Antenna Rotator and Positioner with Controller with automatic calibration. Control software provided with control unit as Automated satellite tracking system. http://www.winradio.com/home/arp-elaz-100.htm
Motorized Satellite Positioner System http://www.groundcontrol.com/Motorized_Satellite_Dish.htm
Sun pointing http://www.hindawi.com/journals/ijp/2011/806518/

Solar Satellite tracking http://www.solar-motors.com/gb/solar-tracker-d487.shtml

Satellite http://www.gano.name/shawn/JSatTrak/

http://www.standa.lt/products/catalog/motorised_positioners

http://www.edmundoptics.com/optomechanics/positioning-stages-slides/motorized-positioners

http://eksmaoptics.com/opto-mechanical-components/motorized-positioners-and-controllers-900/

Motorised satellite dish positioner https://m.youtube.com/watch?v=FhL1Moq99iM

http://www.micropositioners.net/micropositioner.htm

www.altechna.com/categories.php?

Motorised, Positioners, Stepper, Motor, Controllers, Controllers, Translation, Rotation, Stages, Stage Motorized http://www.altechna.com/categories.php?main_category=6amp;category_name=Motorized+Positioners+%26+Controllers

http://www.spacetv.co.za/pages/products/satellite/dishes-accessories.php

Motorized drive http://www.sauter-controls.com/pdm/docs/en_ds_en522192.pdf

25.6 Fuzzy Logic and PDA or FPGA based Intelligent Solar Tracking Control

Intelligent Solar Tracking Control System Implemented on an FPGA http://www.altera.com/literature/dc/2007/t3c.pdf

Fuzzy Controller Design using FPGA for Sun Tracking in Solar Array System http://www.mecs-press.org/ijisa/ijisa-v4-n1/IJISA-V4-N1-6.pdf

http://www.techdesignforums.com/practice/technique/implementing-an-intelligent-solar-tracking-

http://thesai.org/Downloads/IJARAI/Volume1No3/Paper_3-Fuzzy_Controller_Design_Using_FPGA_for_Photovoltaic_Maximum_Power_Point_Tracking.pdf

25.7 Desktop Scale Platform Solar Tracking

https://www.wpi.edu/Pubs/E-project/Available/E-project-121710-140419/unrestricted/Dual_Axis_Tracker_Final_Report.pdf

Plc control https://www.pc-control.co.uk/howto_tracksun.htm

Window motor solar tracker http://www.engedu2.net/v1/ES-E11.pdf

Desktop http://blog.solutions-cubed.com/dual-axis-solar-panel-trackercontroller-part-4/

http://www.engineersgarage.com/contribution/how-to-make-a-solar-tracker

http://www.janspace.com/b2evolution/arduino.php/2014/07/13/mobile-sun-tracking-solar-power-plant

http://all-about-embedded.blogspot.com/2012/10/solar-tracking-project.html

http://www.8051projects.info/proj.asp?ID=33

http://www.instructables.com/id/Solar-Tracker-in-the-Internet-Cloud/?ALLSTEPS

http://www.next.gr/power-supplies/solar-cell-circuits/index3.html

Desktop http://www.electroschematics.com/8019/diy-solar-tracker-system/

http://www.reuk.co.uk/Simple-Solar-Tracker-Concept.htm

http://www.thingiverse.com/thing:53321

http://hackaday.com/2012/05/02/sun-powered-stirling-engine-with-automatic-tracking/

http://www.cerebralmeltdown.com/heliostatprojects/Arduino%20Sun%20Tracker%20Program/index.html

Arduino tracker http://www.pololu.com/product/1220

http://wiki.happylab.at/w/Solar_Arduino_tracker

Arduino Software code http://www.psa.es/sdg/sunpos.htm

Arduino tracking code https://code.google.com/p/arduino-solar-tracking/downloads/list

Micro controller sun tracking http://www.ijser.org/researchpaper%5CSun-Tracking-System-with-Microcontroller-pdf

Polar http://www.mdpub.com/suntracker/

Build your own http://educypedia.karadimov.info/library/solar-tracker.pdf

http://forum.arduino.cc/index.php?topic=87877.0;wap2

http://quixand.co.uk/?p=6

http://forum.pololu.com/viewtopic.php?f=10&t=3102

Solar Tracker with the BASIC Stamp ftp://ftp.parallax.com/EDU/Old/Tracker/PDF%20Docs/Solar%20Tracker%20with%20the%20BASIC%20Stamp%20_Draft%20029_.pdf

Arduino Controlled Sun Tracking Solar Panel http://quixand.co.uk/?p=6

http://research.ijcaonline.org/volume31/number9/pxc3875325.pdf

http://wiki.happylab.at/w/Solar_Arduino_tracker

Design and Construction of an Automatic Solar Tracking System https://www.researchgate.net/publication/236577196_Design_and_Construction_of_an_Automatic_Solar_Tracking_System

A Novel Low Cost Automatic Solar Tracking System http://www.ijcaonline.org/archives/volume31/number9/3965-5325

System https://bib.irb.hr/datoteka/514646.mipro-2011-paper-650.pdf

http://www.esi2.us.es/~rubio/ECM_07_Solar.pdf

http://www.nt.ntnu.no/users/skoge/prost/proceedings/afcon03/Papers/011.pdf

SOLAR TRACKER SYSTEM USING LM358 http://electrosome.com/solar-tracker-system-using-lm358/

Design and Development of an Automated Multi Axis Solar Tracker Using PLC http://portalgaruda.org/journals/index.php/EEI/article/download/205/109

CHAPTER 26

SOLAR TRACKING
ONLINE SOLAR RESOURCES

26.1 Solar Resource Maps

South African Resources http://egis.environment.gov.za/frontpage.aspx?m=27

https://redzs.csir.co.za/

http://pointfocus.com/index.php?v=theimages&dir=charts

Solar Resource Information http://www.nrel.gov/gis/solar.html

http://andyschroder.com/SolarEnergyResearch/SolarCollectorPowerOutput

http://www.soda-is.com/eng/education/index.html

http://solargis.info/doc/postermaps

http://solargis.info/doc/free-solar-radiation-maps-GHI

http://rredc.nrel.gov/solar/spectra/am1.5/

http://peswiki.com/index.php/Directory:Stirling_Engines

Magnetic declination calculator http://solardat.uoregon.edu/index.html

http://www.nrel.gov/rredc/

26.2 Solar Resource Measurements

http://www.kippzonen.com/ ipp and Zonen Kipp and Zonen equipment for solar radiation measurement

http://eko-eu.com/products/solar-radiation-and-photonic-sensors/sun-trackers Sun Trackers

http://www.esrl.noaa.gov/gmd/grad/instruments.html Solar Radiation Instrument Descriptions

Effect of cloud-scattered sunlight on earth's energy balance depends on wavelength of light http://www.pnl.gov/NEWS/release.aspx?id=861

solar data acquisition, solar prospecting, or the analysis and modelling of solar power systems http://www.nrel.gov/midc/

Clouds Effect on Solar Power Spectrum and System in 1-Second Intervals http://cleantechnica.com/2011/09/05/nrel-data-set-shows-clouds-effect-on-solar-pv-system-in-1-second-intervals/

The Meteocontrol weather station can be installed an monitored using the Meteocontrol online interface http://www.meteocontrol.com/en/

Safersun Professional (weather station) mobile app http://www.meteocontrol.com/en/industrial-line/portals/safersun-professional/

Solar site survey shading issues http://rimstar.org/renewnrg/solar_site_survey_shading_location.htm

Applications - Solar Radiation and Photonic Sensors http://eko-eu.com/applications/solar-radiation-and-photonic-sensors

New Cloud analysis software http://eko-eu.com/news/new-cloud-analysis-software

26.3 Solar Resource Surveying and Analysis

climate visualization with Matlab http://www.tedngai.net/?p=571

Calculate Your Solar Energy NREL's PVWatts Calculator http://pvwatts.nrel.gov/

Solar Calculator http://www.solarenergy.org/solar-calculator

Solar calculator and system design tools http://www.energymatters.com.au/climate-data/

Calculate the amount of clean electricity you can generate from the Sun http://www.wunderground.com/calculators/solar.html

How to calculate the annual solar energy output of a photovoltaic system http://photovoltaic-software.com/PV-solar-energy-calculation.php

Solar Radiation Databases http://photovoltaic-software.com/solar-radiation-database. php

Measurement Stations Solar Radiation in various locations in Latin America and the Caribbean En esta seccin, podrs encontrar datos obtenidos desde Estaciones de Medicin de Radiacin Solar, en diversas locaciones de Latinoamrica y el Caribe http://redsollac.org/nuevo/informacion-radiacion/

CHAPTER 27

SOLAR TRACKING
ONLINE MONITORING RESOURCES

Solar Tracking, First Edition.

27.1 Examples of SCADA Solar Server Monitoring

http://www.sma-america.com/en_US/products/software/sma-opc-server.html

https://www.behance.net/gallery/560816/Acciona-Energy-(SCADA)

http://etap.com/real-time/distributed-electrical-scada-technology.htm

http://www.nacleanenergy.com/articles/17100/optimizing-solar-pv-energy-generation-plant-performance-

http://www.iplon.in/products/scada-systems/

http://www.solarnovus.com/scada-optimizes-solar-pv-energy-generation-and-performance_N6986.html

http://solarcraft.net/scada-substation-power-systems/

InduSoft Web Studio Harnesses the Wind in Wind SCADA Systems http://indusoft.com.pl/blog/index6236.html?tag=wind-scada

27.2 PC and microprocessor Based Measuring Equipment and Dataloggers

EEVblog Part 1 of 2 - Comparison of PC Based Oscilloscopes https://m.youtube.com/watch?v=Ev121xAt_k4

EEVblog Part 2 of 2 - Comparison of PC Based Oscilloscopes https://m.youtube.com/watch?v=JTG6jWL0ZqA

Pc based ossiliscope http://sourceforge.net/projects/lxardoscope/

Arduino Poor Man's Oscilloscope

http://www.instructables.com/id/Arduino-Oscilloscope-poor-mans-Oscilloscope/

http://hackaday.com/2011/09/20/lxardoscope-is-a-linuxarduino-oscilloscope/

http://mitchtech.net/arduino-oscilloscope/

http://m.instructables.com/id/DPScope-Build-Your-Own-USBPC-Based-Oscilloscope/

http://www.usbee.com

27.3 Performance Monitoring

http://webapp1.dlib.indiana.edu/virtual_disk_library/index.cgi/4298428/FID666/m94004676.pdf

http://libres.uncg.edu/ir/asu/f/Sabry,%20Muhammad_2013_Thesis.pdf

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3297124/

Understanding Tracker Accuracy and its Effects http://steelandsilicon.com/pubs/ICSC5_Understanding_Tracker_Accuracy_Davis_20081119.pdf

27.4 Energy Monitoring

http://openenergymonitor.org/emon/guide

SolarBeam has the capability to be monitored via the SolarBeam Dashboard http://www.solartronenergy.com/solar-concentrator/dashboard-monitoring/

https://github.com/openenergymonitor/documentation

Fluke 435 Series II Power Quality and Energy Analyzer http://www.fluke.com/fluke/sgen/power-quality-tools/logging-power-meters/fluke-435-series-ii. htm?PID=73939

27.5 Carbon conversions

http://www.carbonify.com/carbon-calculator.htm
http://www.epa.gov/cleanenergy/energy-resources/refs.html
https://www.springer.com/engineering/energy+technology/book/978-1-4471-6253-7

27.6 datalogging

solar tracking error plot cross-hair http://sourceforge.net/projects/lxardoscope/
http://sourceforge.net/projects/lxardoscope/files/
http://sine.ni.com/nips/cds/view/p/lang/en/nid/209835
http://vishots.com/getting-started-with-the-labview-interface-for-arduino/
http://www.angstromdesigns.com/software/faq/58-labview-arduino-driver-larva
http://pingswept.org/2008/01/24/the-sl1-is-out-the-door/
http://www.practengineering.com/storage/SL1Datasheet.pdf
https://github.com/pingswept/

The DNI is determined by an Eppley NIP mounted on the CPV tracker, determined using a Licor LI-200, also mounted on the tracker. The GHI is determined by a Middleton pyranometer, mounted on a horizontal surface. www.uapv.org

Measuring degradation rates without irradiance data http://www.nrel.gov/docs/fy11osti/47597.pdf

CHAPTER 28

SOLAR TRACKING ONLINE PROPRIETARY RESOURCES

28.1 Commercial Solar Tracking Systems

http://trabantsolar.com/siemens%20trabant%20solar%20tracker%20success.pdf

http://homecsp.com/store/product.php?id_product=51

https://www.industry.siemens.com/verticals/global/en/solar-industry/Documents/Solartracker_en.pdf

System http://sustainabilityworkshop.autodesk.com/project-gallery/lightweighting-solar-tracking-drive

Proprietary http://www.tapthesun.com/PDF/SolarTrak%20-%20PC%20Interface%20Software%20Manual%20Rev%2001.pdf

https://geneticmail.com/scott/library/text/solaris/solaris-dynamic-tracing-guide.pdf

Proprietry tracker controller http://www.suntrackpro.com

http://www.ni.com/example/31252/en/

Plug n play http://eko-eu.com/products/solar-radiation-and-photonic-sensors/sun-trackers/str-22g-sun-tracker

Siemens prop. systems http://suntraksynergy.com/Technical2.htm

Delta Automation http://deltautomation.wordpress.com/2011/03/11/delta-solar-tracking-system/

ftp://ftp2.euro.delta-corp.com/deltronics-eindhoven/customer-service/Industrial%20Automation%20Products/_Delta%20Application%20Guide/Solar%20Tracking/AN%20Solar%20tracking-.pdf

http://www.cebe-energy.com/products/suntrakk-solar-tracking-systems/tracking-technology

http://www.gransolar.com/files/1813/5781/5073/AXONE_Europa.pdf

http://www.mltdrives.com/systems.htm

http://www.solar-motors.com/files/TECHNICAL_DATASHEETS/SOLAR_TRACKERS/ST44M3V15P/Technical_datasheet_for_Solar_Tracker_2-axis_ST44M3V15P_MR.pdf

http://www.solar-motors.com/files/PRODUCTS/SIGMA_TRACKER_SOLAR_SERVER/User%20manual%20for%20SIGMA%20-%20Solar%20tracker%20WEB%20server%20with%20LAN,%20RS485,%20DIN%20rail,%20EAN%20383106394105.pdf

http://www.ramayes.com/Antenna_Positioners.htm

http://www.bandp.co.kr/new/include/down.php?filepath=/_data/board/1214264985_72_f2.pdf&filename=kipp_brochure_2ap_1579.pdf

28.2 Commercial Solar Tracking Software Systems

Beckhoff TwinCAT Solar Position Algorithm software library http://www.designnews.com/document.asp?doc_id=229315&dfpPParams=ind_182,aid_229315&dfpLayout=article

Siemens PLC S7-1200 http://www.siemens.com

Beckhoff http://www.automationworld.com/pc-based-solar-tracking-software

Beckhoff automation http://www.beckhoff.co.za/english.asp?twincat/twincat_solar_position_algorithm.htm http://www.automation.com/product-showcase/beckhoff-introduces-twincat-solar-position-software https://bib.irb.hr/datoteka/514646.mipro-2011-paper-650.pdf

NI CompactRIO Dual Axis Sun Tracker Example Design http://www.ni.com/example/31252/en/

Solar MEMS solar tracking system http://www.solar-mems.com/smt_pdf/renewable_energy_catalogue_sept2013.pdf

https://www.automation.siemens.com/WW/forum/guests/PostShow.aspx?PageIndex=1&PostID=144072&Language=en

http://tao.wordpedia.com/show_pdf.ashx?sess=0e32ztapk2uenw5532pgft55&file_name=JO00001163_2-1_133-150&file_type=r

Schneider SPA http://www.biztechafrica.com/article/schneider-electric-solution-manage-operations- 8850/

http://www.lfb.rwth-aachen.de/bibtexupload/pdf/DS12a.pdf

http://www.engnet.co.za/showcase/product.aspx/10897

HP Basic http://www.hpmuseum.org/cgi-sys/cgiwrap/hpmuseum/archv015.cgi?read=83378

Rockwell Automation Allan bradley http://literature.rockwellautomation.com/idc/groups/literature/documents/wp/oem-wp009_-en-p.pdf

http://www.wpi.edu/Pubs/E-project/Available/E-project-010713-112634/unrestricted/Dual-Axis_Tracker_Report.pdf

http://literature.rockwellautomation.com/idc/groups/literature/documents/ap/oem-ap113_-en-p.pdf

Beckhoff TwinCAT PLC library Solar Position Algorithm it is possible to calculate the exact position of the sun http://www.beckhoff.co.za/english.asp?twincat/twincat_solar_position_algorithm.htm

ABB spa http://www05.abb.com/global/scot/scot397.nsf/veritydisplay/26715ccc7867052ec1257c22002e8f60/$file/1TXH000213B0201.pdf

http://www.abb.de/cawp/seitp202/cb1597cfeff9dd26c125759e0030b476.aspx

Muthibishi Spa http://www.acarelektrik.com.tr/katalog/uygulamalar/Application_Reference_Guide-Solar_Track.pdf

Yokonawa automation http://www.yokogawa.com/us/products/systems-integration/yokogawa-integrated-solutions/solar-tracking-control-systems.htm

Panasonic tracking http://www.pidtechinsights.com/2011/07/06/meeting-the-challenge-of-accurate-solar-
https://www.panasonic-electric-works.com/eu/9672.htm

Omron Plc http://www.academia.edu/4528324/A_Solar_Panels_Automatic_Tracking_System_Based_on_OMRON_PLC

http://www.infoplc.net/files/descargas/delta/infoPLC_net_Delta_Seguidor_Solar.pdf

Sustainable Energy in the Built Environment - Steps Towards nZEB

AC500plc ABB http://www.ien.eu/uploads/tx_etim/page_35_37072.pdf

Ercam plc http://www.ercam.es/index.php/en/solar-tracking

http://www.ijarcsse.com/docs/papers/Volume_3/10_October2013/V3I10-0197.pdf

Pic processor http://files.spogel.com/abstracts/p-0456--automatic_solar_rad_tracker.pdf

28.3 Commercial Solar Harvesting Tracking Systems

http://www.innova.co.it/eng/catalog/products/trinum.html

http://www.qnergy.com/products_overview
http://www.rrs.co.za/commercial-products/renewable-energy-products
schlaich bergermann und partner http://www.sbp.de/en#sun/index
Field of work Line-focusing Point-focusing Additional Technologies http://www.sbp.de/de/sun/technology/100-Punktfokussierend
Sun Cube By Green and Gold Energy Of Australia http://www.treehugger.com/renewable-energy/sun-cube-by-green-and-gold-energy-of-australia.html

28.4 Installation equipment

Solmetric SunEye www.solmetric.com
Fluke 117 Troubleshooting solar systems http://www.fluke.com/fluke/sgen/Community/fluke-news-plus/ArticleCategories/DMMs/SolarPower117.htm
Installation and resources http://commonsensehome.com/how-much-energy-will-a-solar-electric-system-produce/
http://www.verdegro.com/en/products/led-lighting-systems/Led+Light+ Tower+Cube

Solar site surveying tool http://www.solardesign.co.uk/survey.php

28.5 Mounting Systems

Wiley Electronics LLC ASSET www.we-llc.com
PROINSO Solar Catalogue http://www.proinso.net/pub/doc/File/ingl/proinso_solar_catalogue_2013_2014.pdf

CHAPTER 29

SOLAR TRACKING ONLINE EDUCATIONAL RESOURCES

Solar Tracking, First Edition.

29.1 History of Concentrated Solar Power Systems

THE PIONEERING WORK ON LINEAR FRESNEL REFLECTOR CONCENTRATORS (LFCs) IN ITALY http://mondosolare.it/pub/silvi-fresnel.pdf

History of Solar Energy Revisiting Solar Power's Past http://solarenergy.com/power-panels/history-solar-energy

29.2 Understanding Astronomy The Sun and the Seasons The Sun's Daily Motion

Understanding Astronomy The Sun and the Seasons The Sun's Daily Motion http://physics.weber.edu/schroeder/ua/SunAndSeasons.html

Equitorial Coordinates Latitude and Longitude altitude (elevation) and azimuth (direction) Ascension and Declination Right Ascension and Sidereal Time http://www.astronomy.org/astronomy-survival/coord.html

Understanding the seasons through pictures http://www.astronomy.org/programs/seasons/

Motion of Our Star the Sun http://www.astronomynotes.com/nakedeye/s5.htm

Introductory Astronomy: The Celestial Sphere Motions Visible Without Optical Aid http://astro.wsu.edu/worthey/astro/html/lec-celestial-sph.html

Sun Seasons and elliptical simulator http://astro.unl.edu/naap/motion1/animations/seasons_ecliptic.html

The Path of the Sun https://www.e-education.psu.edu/astro801/content/l1_p4.html and

https://www.e-education.psu.edu/astro801/content/l1_p5.html

29.3 Educational Solar Sun Position Animations and Applets

Animations palying with the solar poosition Experimenting various plug-ins for solar calculations, I found Daniel Da Rochas powerful implementation of solar position algorithm in vb.net. It calculates the solar angle of any place and time http://www.designcoding.net/playing-with-solar-position/

http://www.designcoding.net/decoder/wp-content/uploads/2012/05/2012_05_31-solartest-ocl.ghx

Animation Position of the sun on the horizon at sunrise http://astro.unl.edu/animationsLinks.html#ca_coordsmotion and http://astro.unl.edu/classaction/animations/coordsmotion/horizon.html

Juergen Giesen GeoAstro Applet Collection http://www.jgiesen.de/GeoAstro/GeoAstro.htm

University of Oregon Solar Radiation Monitoring Lab http://solardat.uoregon.edu/SoftwareTools.html

How can I calculate the position or path of the Sun for a given time and location? http://curious.astro.cornell.edu/question.php?number=147

How do I calculate altitude and azimuth of sun? http://www.stjarnhimlen.se/comp/tutorial.html#5

29.4 Educational Solar Radiation Calculations Animations and Applets

JavaScript example and formulas to calculate Solar Radiation on a Tilted Surface http://pveducation.org/pvcdrom/properties-of-sunlight/arbitrary-orientation-and-tilt

29.5 Concentrated Solar Technology Books

Power From the Sun Book http://www.powerfromthesun.net/book.html My object uses these formulas and is cross referenced to the equations on the site. The website and object also have heliostat formulas. The object has a linear actuator formula too

Book Excerpts from: New Inventions in Low-Cost Solar Heating by Dr. William Shurcliff http://www.builditsolar.com/Experimental/ShurcliffPart1/TOC.htm

Solar Design Book http://www.thesolardesignbook.com/index.php/solar-design-book

Solar Power 101 Book http://www.offgridwinchester.com/Solar%20Power-101.pdf

Solar Electricity Handbook 2014 Edition http://www.solarelectricityhandbook.com/free-solar-book.html

29.6 Educational Training Tutorials

Teaching Tools are a series of utilities and applets initially developed to explain and demonstrate important building analysis concepts through animation and interactive play http://wiki.naturalfrequency.com/wiki/Ecotect_Tutorials http://wiki.naturalfrequency.com/wiki/Teaching_Tools

Education Sun, Earth, and Code http://www.codecademy.com/courses/web-beginner-en-ymqg0/0/1

Computing planetary positions - a tutorial with worked examples http://stjarnhimlen.se/comp/tutorial.html

Solar Time, Solar Geometry Single Issue Tools and Simple Sun Charts http://www.esru.strath.ac.uk/Courseware/Design_tools/Sun_chart/sun-chart.htm

http://abyss.uoregon.edu/~js/ast122/lectures/lec02.html

EcoTect Solar and shadowing analysis http://wiki.naturalfrequency.com/

A field guide to renewable energy technologies land art generator initiative http://landartgenerator.org/LAGI-FieldGuideRenewableEnergy-ed1.pdf

Photovoltaics http://solarcellcentral.com/solar_page.html

http://www.electronics-tutorials.ws/io/io_4.html

http://staging.edn.com/design/sensors/4324812/Speed-acquisition-made-simple

http://www.semiconductorstore.com/cart/pc/viewPrd.asp?idproduct=46655.

Renewable Energy Sources and solar energy harvesting systems https://www.eac.com.cy/EN/EAC/RenewableEnergySources/Pages/educationalmaterialres.aspx

Book Sun Position-High Accuracy Solar Position Algorithms A Resource for Programmers and Solar Energy Engineers

http://bookstobelievein.com/SunPosition-HighAccuracySolarPositionAlgorithms.php

Renewables Are Ready A Guide to Teaching Renewable Energy in Junior and Senior High School Classrooms http://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean_energy/renewablesready_fullreport.pdf

29.7 Technical Training Tutorials

http://www.plcengineers.com/plc_vs_pac.html

PWM Tutorial http://www.electronics-tutorials.ws/blog/pulse-width-modulation.html

https://embeddedmicro.com/tutorials/mojo/pulse-width-modulation/

Properties of light http://pveducation.org/pvcdrom/properties-of-sunlight

AC Drive tutorial http://jabelektrikk.blogspot.com/2013/09/inverter-vfd-or-asd-or-vsd-and-motor.html

http://eng-electric.blogspot.com/p/welcome.html

http://eng-electric.blogspot.com/2013/11/microchip-ac-induction-motor.html

brushless dc motor performance curves

http://just-like.club/page/news/brushless-dc-motor-performance-curves

An Assessment of Solar Energy Conversion Technologies and Research Opportunities http://gcep.stanford.edu/pdfs/assessments/solar_assessment.pdf

Atmospheric effects have several impacts on the solar radiation at the Earth's surface http://pveducation.org/pvcdrom/properties-of-sunlight/atmospheric-effects

29.8 Solar Electronic Components, Electronic Circuits Diagrams and Models

https://learn.adafruit.com/

https://learn.sparkfun.com/

https://learn.sparkfun.com/tutorials

http://www.electronics-tutorials.ws/

NASA Stanford Solstice and Equinox Suntrack Model http://solar-center.stanford.edu/AO/Sun-Track-Model.pdf

29.9 Astronomical Training Resources and Tutorials

Solar Altitudes on Equinoxes and Solstices - Imagine The Universe! http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/970210b.html

http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/970210b.html

Sun and Shadows - Kean University http://www.kean.edu/~fosborne/resources/ex11a1.htm

http://www.math.nus.edu.sg/aslaksen/gem-projects/hm/0304-1-66-sun_and_architecture.pdf

book Astronomical Algorithms http://www.willbell.com/math/mc1.htm

29.10 3D Design and 3D Printing Resources and Training Equipment

http://help.solidworks.com/2013/English/SolidWorks/sldworks/c_introduction_toplevel_topic.htm

http://area.autodesk.com/tutorials

http://www.youtube.com/watch?v=lEheFEer5Is

http://www.solidworks.com/sw/resources/solidworks-tutorials.htm

http://www.youtube.com/watch?v=cy3ExIAcI2Y

29.11 Solar Training Equipment and Resources

Use the Gears-IDS Invention and Design System to build an autonomous Solar Tracking Device http://www.gearseds.com/solar_tracker.html The solar tracker uses a friction drive coupled to a motor, belt, and pulley drive to track the azimuth (East to West) motion of the sun. The tracker uses a two (2) position pneumatic actuator to optimize the altitude position of the collector surface. Using both a motor speed reduction drive and a pneumatic actuator controlled by a microprocessor, provides ample opportunities for hands on engineering education and real world system integration challenges.

Homemade Meccano Solar Tracker http://www.youtube.com/watch?v=TiADZWlL7Uw

Fischertechnik solar gearbox early project (lego meccano knex kit) http://www.youtube.com/watch?v=dGe6FL4_xfc

LEGO Solar Tracker http://www.youtube.com/watch?v=s6xBOaQJY9M

google search - kit stirling dish http://www.thamesandkosmos.com/products/ste/ste.html

http://www.stirlingshop.de/GT03-Solar-Set-Indoor

http://www2.schneider-electric.com/documents/training-workstations/didactic-solutions-catalogue-2013.pdf

Intrumentation education http://www.highpointscientific.com/telescope-accessories/mounts/telescope-mounts/alt-azimuth-mounts

CHAPTER 30

SOLAR TRACKING
INTERESTING PRACTICAL APPLICATIONS

Solar Tracking, First Edition.

30.1 Alternative Power Technologies and Solar Power Applications

CSP Concentrating Solar Power CPC Compound Parabolic Concentrator Compound Parabolic Trough Solar Parabolic Reflectors Solar Parabolic Receivers Solar Parabolic Troughs Solar Parabolic Dishes Stirling Solar Spherical Bowls Solar Linear Concentrator Systems Solar Heliostats Central Solar Power Towers for Solar Concentration Central Receiver Power Plant Solar Concentrating Receivers Solar Concentrating Reflector Solar Concentrating Troughs Solar Concentrating Dishes Solar Concentrating Bowls Dish Engine Systems for CSP Solar Concentrators Compact Linear Fresnel Mirror Reflector Solar Thermal Heating Power Concentrated Solar Thermal Plant Solar Thermal Concentrator Solar Thermal Collectors Solar Thermal Energy Solar Air Conditioners Solar Air Cooling Systems Solar Air Heating Systems Solar Water Heating Systems Solar Hot Water Systems Solar Furnace Solar Oven Solar Stove Solar Cooker and Cooking Solar Lighting Solar Illumination

http://www.otherpower.com/

http://altenergymag.com/emagazine/2012/04/solar-energy-applications-in-industrial-and-commercial-1868

Solar Thermal- Market, Policy and Industry Trends http://israel.ahk.de/fileadmin/ahk_israel/Dokumente/Praesentationen/EE/Knaack.pdf

Experimental Solar DIY (and commercial) Projects and Solar renewable energy ideas http://www.builditsolar.com/Experimental/experimental.htm

Solar Parabolic Mirror Reflectors for CSP n CPC Concentrating Solar Power n Solar Thermal Systems http://xinology.com:888/Glass-Mirrors-Products/CSP/applications.html

Pgina de la Universidad del Estado de Nuevo Mxico con informacin tcnica sobre sistemas de energa fotovoltaica http://www.itacanet.org/esp/electricidad.html

http://www.tecnologiasapropiadas.com/ It is a site for the development and promotion of appropriate technologies in Latin America.

http://www.cepis.ops-oms.org/sde/ops-sde/bv-tecapro.shtml Site of CEPIS-WHO OPM Appropriate Technology

http://www.cepis.org.pe/bvsatp/e/redtap.html RedTAP: Regional Network for Appropriate Technologies

30.2 Solar Coffee Roasting/Brewing

http://www.solarpowerbeginner.com/solar-cooker.html

http://www.coffee-tech.com/products/shop-roasters/solar/

http://www.trendhunter.com/trends/eco-friendly-solar-roasted-coffee

30.3 Solar Bakery, Solar Cooker and Solar Oven

Solar Cooking After Dark with plans to build a A Stored Heat Solar Cooker http://www.builditsolar.com/Projects/Cooking/StoredHeat/StoredHeat.htm

http://www.jamesdysonaward.org/projects/infinity-bakery/

The Rotating Solar Boiler Master Thesis http://www.builditsolar.com/Experimental/RSB/The_RSB.pdf

http://www.solarfood.org/projects/85-solar-food-phase-ii-gambia

http://www.instructables.com/id/Best-Solar-Oven/?ALLSTEPS

http://solarcooking.org/plans/
http://www.sunoven.com/sun-cooking-usa/how-to-use
http://www.ijmer.com/papers/Vol2_Issue6/BU2642284230.pdf
GIANT 70inch satellite Dish conversion solar cooker HIGH PWER http://www.instructables.com/id/GIANT-70-satellite-Dish-conversion-solar-cooker-H/

30.4 Solar Ice Cream Cart

http://www.solaricecreamcart.eu/Solar_ice_cream_cart/home_2.html
http://www.finamac.com.br/en/noticias/2012/08/361/solar-powered-ice-cream-cart-is-a-success-in-
http://m.thehindu.com/news/cities/Vijayawada/solar-power-to-rescue-of-icecream-vendors/article5659955.ece/

30.5 Solar Ice and Solar Refrigeration Systems

Solar powered fridge and freezer http://www.softice.co.za/Solar%20DC%20fridge%20&%20Freezers.htm
http://www.solaripedia.com/13/389/5542/solar_ice_maker_saaim.html
http://www.pssurvival.com/ps/Refrigeration/Ice_Maker_Manual_2004.pdf

30.6 Solar Powered Medicine, Solar Autoclave, Solar for Medical Centres and Dentists

http://cleantechnica.com/2012/05/27/solar-power-suitcase-medical-situations/
http://www.folgat.com/solarmedicus.html
http://www.sciencedaily.com/releases/2013/09/130909092330.htm

30.7 Solar powered water and milk pasteurization

Beverages such as milk, fruit juice, beer and wine can use solar pasteurisation to extend shelf life of the products.

Pasteurization of goat milk using a low cost solar concentrator http://www.sciencedirect.com/science/article/pii/S0038092X07002253

Design and Development of Paraboloid Solar Concentrator for Milk Pasteurization http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1595370

Solar pasteurisation has proven to be a very low-cost disinfection method http://www.sswm.info/category/implementation-tools/water-purification/hardware/point-use-water-treatment/solar-pasteurisa

FABRICATION AND PERFORMANCE STUDY OF A SOLAR MILK PASTEURIZER http://pakjas.com.pk/papers%5C114.pdf

30.8 Solar water distillation distiller

Solar stills Destilador solar http://www.energizar.org.ar/energizar_desarrollo_tecnologico_destilador_solar_que_es.html Un Destilador Solar es un sistema muy sencillo y eficiente que permite reproducir de manera acelerada los ciclos naturales de evaporacin y condensacin del agua, que al utilizarlos de manera controlada, se puede obtener agua pura

Home Made Solar Water Distiller http://www.thesietch.org/projects/distiller/ A Solar Distiller is a very simple and efficient system that allows playback of accelerated natural cycles of evaporation and condensation of water, which when used in a controlled manner, you can get pure water

http://m.instructables.com/id/Build-a-simple-solar-still/?ALLSTEPS

http://m.youtube.com/watch?v=GrPRnaS449w

30.9 Solar Alcohol Distillery Solar Fuel Solar Petrol

http://www.heliotrack.com/Solar-Ethanol.html

http://www.nariphaltan.org/ethanoldist.pdf

http://www.scienceinafrica.com/old/index.php?q=2006/april/solarstill.htm

http://www.appropedia.org/Solar_fuel_alcohol_distillation

http://homedistiller.org/equip/jesse

30.10 Solar Water Pumping

Solar Pump Calculation Sheet including Pump Spreadsheets and Calculations, Pumped Water Systems, Solar Photovoltaics using mechanised pumps, solar panels, solar power, solar water pumping, spreadsheet, water pumps PDF calculation sheet for designing solar pumping systems http://www.itacanet.org/solar-pump-calculation-sheet/

http://www.ruralpowersystems.com/

http://www.hybridpower.co.za/hybridsystems.php

30.11 Solar for Carwash

Solar car wash invention and patent http://www.google.com/patents/US20100089427

AQUASOLA MOBILE CAR WASH SYSTEM http://www.legacyventures.co.za/index.php/our-products/mobile-car-wash-system

design and installation of photovoltaic solar panels, small-scale wind turbines and anaerobic digesters http://news.uwgb.edu/featured/alumni/04/07/andy-williams-greensky-energetics/

30.12 Agricultural Farming and Residential Household Systems

http://www.sundropfarms.com/

http://pesn.com/2006/02/01/9600228_Sun_Ball_Released/

30.13 Solar Hot Water and Solar Assisted Water Heating

Concentrating Solar Power (CSP) technologies use mirrors to concentrate (focus) the sun's light energy and convert it into heat to create steam http://solareis.anl.gov/guide/solar/csp/

Griggs pump solar assisted Cavitation Water Heater http://www.n-atlantis.com/griggs_pump.htm http://www.martincwiner.com/over-unity-cavetation-water-heater/

Solar assisted Cavitation Heater - Overunity https://www.youtube.com/watch?v=DjGSXKSLpfY

Water turbine heater FUELLESS HEATER NO FUEL NO GAS NO WOOD NO GREEN HOUSE GASES https://m.youtube.com/watch?v=yh_-DUKQ4Uw

30.14 Solar Lighting, Sky-lighting, Daylighting, and Solar Fibre Optic Lighting

http://cdn.intechopen.com/pdfs-wm/12217.pdf

http://www.sunlight-direct.com/hybrid-solar-lighting/

http://www.builditsolar.com/Projects/Lighting/lighting.htm

http://www.himawari-net.co.jp/e_page-index01.html

http://www.limitless.uk.com/parans-solar-collector/

http://www.sciencedirect.com/science/article/pii/S0378778808000376

Theoretical thermal limits of photothermal system based on the idea of transmission solar energy via optical fibers http://jith2013.uca.ma/JITH2013/Communications/JITH506.pdf

Optical fibre http://www.laserfocusworld.com/articles/print/volume-48/issue-10/features/optofluidics-optofluidics-assists-solar-fuel-generation.html

30.15 Solar Cheese Making

Dairy (pasteurization of milk, cheese manufacturing)

http://m.missoulian.com/news/state-and-regional/polson-couple-starting-solar-powered-artisanal-article_4b10789a-5c48-11e1-b129-0019bb2963f4.html?mobile_touch=true

Cheese Factory Installs Solar Flexrack Tracker System http://www.solarnovus.com/cheese-factory-installs-solar-flexrack-tracker-system_N7908.html

Ancient Cheesemaking http://solarfamilyfarm.com/?p=188

30.16 Solar Yogurt Making

http://www.cheeseandyogurtmaking.com/blog/flathead-lake-cheese-montana/

http://rachelstinyfarm.blogspot.com/2008/06/solar-yogurt.html?m=1

30.17 Solar Beer and Solar Brewing

https://byo.com/stories/item/2004-last-call-solar-brewing

http://www.nola.com/business/index.ssf/2013/09/abita_brewing_co_now_using_sol.html

http://za.adforum.com/creative-work/ad/player/14089

30.18 Solar Milling and Maize Grain Milling

http://solarmilling.com/wp-content/uploads/2012/06/Concept-Solar-Milling-Ethiopia-case.pdf

https://m.youtube.com/watch?v=a10bMcyDODU
http://www.wisions.net/technologyradar/technology/solar-mill

30.19 Solar Sugar Cane, Solar Sugar Beet and Solar Sugar Refinery

http://shrijee.com/sugar-refinery-equipments/introduction.html
https://www.researchgate.net/publication/228816489_Alternative_power_technologies_a_decision_model_for_a_sugar_refinery

30.20 Solar Abattoirs, Solar Meat Processing and Solar Meat Drying

Meat processing Beverages (bottling plants, breweries)
http://solar.org.au/papers/02papers/2b4.pdf
http://www.renewablesinternational.net/70-of-german-pig-and-bird-farms-have-pv/150/452/75232/
http://www.fao.org/docrep/010/ai407e/AI407E18.htm
http://www.sesinter.com/our-solutions/solar-abattoirs/
http://mobile.abc.net.au/news/2014-07-23/uterne-solar-power-loan/5617948

30.21 Solar Winery

Solar winery http://www.winecountrygetaways.com/tasting-room-guide/solar-wineries/
http://www.practicalwinery.com/janfeb04/janfeb04p58.htm
http://books.google.co.za/books?id=lb3cAwAAQBAJ&pg=PA156&lpg=PA156&dq=solar+meat+processing&source=bl&ots=iQzsltRaKd&sig=zZ5AKGSW8aGLQGegQEWhYsv9q2M&hl=en&sa=X&ei=1Xg1VKjQBMHB7gbKm4FA&ved=0CC4Q6AEwBjgK

30.22 Industrial Solar Process Heat and Steam

Process Heat - NEP SOLAR AG http://www.nep-solar.com/applications/process-heat/
Design, Construction and Testing of a Parabolic Solar Steam Generator http://lejpt.academicdirect.org/A14/115_133.pdf
Parabolic solar steam boiler http://www.alternative-heating.com/solar_steam_boiler.html
STEAM ENGINE 12KW GENERATOR Solar Mirror Array Death Ray http://www.youtube.com/watch?v=jTvAL7ty53M
SolarBeam Concentrator Parabolic Solar Concentrator Dish http://www.youtube.com/watch?v=ORELqy4jiPQ
Zenith Solar - Z20 Solar Field http://www.youtube.com/watch?v=5-UpSPUULI4

30.23 Solar Laundry Washing Machine

http://www.instructables.com/id/Building-a-Parabolic-Solar-Hot-Water-Heater-using-/?ALLSTEPS

http://www.loupiote.com/photos/18327559.shtml

30.24 Community Development Systems

Schneider Electric inaugurate a BipBop Microsol technology for producing electricity, drinking water and heat
http://en.starafrica.com/news/africa-schneider-electric-inaugurate-a-technology-html

SOLAR POWER VILLAGE An integral concept to create Energy and stable local jobs in southern rural areas http://www.world-renewable-energy-forum.org/2004/download/Kleinw_chter.pdf

Rural electrification with single wire earth return SWER, an inexpensive method of extending the electricity grid to rural areas http://ruralpower.org/

http://www.schneider-electric.com/solutions/ww/en/sol/293322906-villasmart/

http://www2.schneider-electric.com/sites/corporate/en/group/sustainable-development-and-foundation/access-to-energy/presentation.page

http://www2.schneider-electric.com/documents/training-workstations/didactic-solutions-catalogue-2013.pdf

Incremental upgrades for slums http://www.ishackproject.co.za/

http://www.bsrsolar.com/sv/produkte3_e.html

http://solarsunsa.co.za/products_rural.php

http://www.ascotinternational.com/hybrid-solar-and-wind-power-system.aspx

http://panacea-bocaf.org/solarnetmetering.htm

30.25 Solar Carbon Footprint Reduction and Sustainable Environment

http://sustainabilityworkshop.autodesk.com/products/fea-lightweighting-uss-solar-tracker

http://www.uvm.edu/sustain/tags/solar-trackers

http://www.sunpower.com.au/commercial/most-bankable/environmental-consciousness/

http://www.renewableenergyworld.com/rea/companies/allearth-renewables/news/article/2014/06/solar-tracker-project-powering-woodchuck-hard-cider-recognized-with-national-

Cool Earth Solar CPV Technology, inflatable solar http://www.coolearthsolar.com/our-technology

http://peswiki.com/index.php/Directory:Cool_Earth_Solar

http://www.ecochunk.com/6361/2013/02/22/cool-earth-solar-develops-inflatable-solar-concentrators-

http://archive.fortune.com/galleries/2008/fortune/0810/gallery.tech_windpower.fortune/5.html

30.26 Solar GHG Emission Reduction, Solar Clean Development Mechanisms CDM Reporting

Solar Incentive Program Dashboard https://www.ladwp.com/ladwp/faces/wcnav_externalId/r-gg-sip-dashboard http://mac.softpedia.com/get/Dashboard-Widgets/Webcams/Miscellaneous/SolarSystem.shtml

30.27 Eco Villages Eco Property Development

http://www.earthactionmentor.org/articles/Solar_Solutions_and_Water_Landscape_at_Tamera_Ecovillage

http://www.greenoptimistic.com/2012/10/20/dean-kamen-stirling-engine-power-cable-installations/#.VDUkffmSzTo

electrical infrastructure for housing developments and residential property as green field eco development. http://www.greenbusinessguide.co.za/new-green-estate-set-for-off-grid-electricity/

http://www.htxt.co.za/2013/11/15/sun-fuelled-domestic-power-station-launched-across-africa/

Eskom embedded power generation-self reliance https://www.google.co.za/search?q=eskom+embedded+power+generation&ie=UTF-8&oe=UTF-8&hl=en&client=safari

30.28 Solar water splitting solar hydrogen oxygen electrolysis and thermal oxidisers, using concentrated sunlight

Inexpensive, efficient production of hydrogen and oxygen from water using solar power http://marketplace.yet2.com/app/insight/techofweek/64292?sid=200

Thermal dissociating water vapor into hydrogen and oxygen using solar energy http://www.google.com/patents/US4405594

Direct solar-thermal hydrogen and oxygen production from water http://www.hionsolar.com/n-hion96.htm

Thermal oxidisers, using concentrated sunlight http://www.google.com/patents/US20130053613

Improvements in thermal oxidisers, using concentrated sunlight http://www.google.com/patents/WO2011092456A1?cl=en

Solar thermal aerosol flow reaction process http://www.google.com/patents/US20030208959?cl=en

30.29 Solar Photochemistry

https://www.psa.es/webesp/areas/tsa/docs/solar_photochemistry_technology.pdf

PART X

GENERAL SOLAR TRACKING SEARCH TIPS

CHAPTER 31

SOLAR TRACKING RESOURCES ONLINE SEARCH TIPS

Google, Bing, Yahoo and other search engine search text tricks that generally provides good results in terms of solar tracking resources

31.1 Searches for Source Code for Solar Trackers

To get source code for solar trackers and solar tracking systems, search for:
code solar position
sourceforge.net solar position
github solar position algorithm
github solar tracker
github solar tracking
code.google.com solar position algorithm
code.google.com solar tracker
code.google.com solar tracking
sourcecodeonline sun position

31.2 Searches for Solar Position Algorithms and Sun Position Calculators

solar position calculator excel
solar position app
solar position calculator noaa
solar position equations
solar position algorithm for solar radiation applications
solar position and sun path
solar position chart
solar position calculator excel
solar position app
solar position calculator noaa
solar position equations
solar position algorithm for solar radiation applications
solar position and sun path
solar position chart
Download solar tracker code
solar tracking source code (look at images search)

31.3 Searches for Solar Tracker and Solar Tracking Systems

simplified solar tracking prototype
design of a solar tracker
automatic positioner solar tracking
Programmable automatic positioner
embedded solar tracking instrumentation system
Home made solar tracker
Motorized positioner and controller for motorised drive
automatic solar tracking system
solar tracking system using microcontroller

solar tracking mechanism
Automated solar tracker
Automatic solar tracking
Low budget Sun tracker
stepper motor for solar tracker
solar tracker with stepper motor control
solar tracking motor
simplified solar tracking prototype
method for automatic positioning of a solar array
Simplified solar tracking tracking prototype
Sun tracker
method for automatic positioning of a solar array
solar tracker motor drill
simplified solar tracking prototype
sun tracing software
solar tracker motor drill
design of single axis sun tracking system
design of a solar tracking system
solar tracking mechanism
solar tracking system project
solar tracking system ppt
solar tracking system pdf
dual axis solar tracker kit
solar tracker kit set
simple solar tracking
dual axis solar tracker
single axis solar tracker kit
solar tracking pdf
solar tracking system project
solar tracking ppt

31.4 Searches for Solar Tracker and Solar Tracking Electronics

solar tracker schematic (look at images search)
solar tracking system circuit diagram
Servo solar tracking control
Motorized positioners (search)
solar position navigation systems
open source solar tracking
Simple Solar Tracking circuit
solar tracking system circuit diagram
solar tracking circuit
sun tracking circuit
electronic kits solar tracker
LDR solar tracker
sun follower circuit
solar tracking system circuit diagram

31.5 Searches for Computerised and Processor based Solar Tracker Developments

raspberry pi solar tracker
solar tracking arduino
raspberry pi solar tracker
parabolic tracker design
solar tracking pic processor
pc based solar tracking
programmable automation controller solar tracking
Solar Tracker Robot using microcontroller
automatic solar tracking system
solar tracking system using microcontroller
automatic solar tracking system
solar tracking system using microcontroller

31.6 Searches for Solar Power Generation Developments

stirling dish model
stirling dish engine model (see image search results)
stirling dish desktop model
parabolic dish desktop model
System Design Approach for solar harvesting
Unattended Solar Energy Harvesting Supply

31.7 Searches for Dish Designs

parabolic dish collector (image search)
point focus solar collector (image search)

31.8 Searches for Patents and Inventions for Solar Trackers

patents.google.com solar tracker `https://www.google.com/?tbm=pts&gws_rd=ssl#tbm=pts&q=solar+tracker`
patents.google.com solar energy harvesting

31.9 Searches for Solar Surveying, Solar Resource Analysis

ecotect solar analysis - image search
vasari solar analysis - image search

31.10 Searches for Educational Material on Solar Tracking and Sun Surveying

Solar Resource Analysis

solar tracking tutorials
Sun Surveying
solar tracking book
advantages of solar tracking system

Bibliography

Aaron Weiss (2010). Example Sketch for Arduino TinyGPS. *Sparkfun Electronics, USA*, , no. August, pp. 1–3.
Available at: https://cdn.sparkfun.com/datasheets/Dev/Arduino/Boards/gps_arduino_1_0.ino

Adene Energy (2013). Promotion of tri-generation technologies in the tertiary instritutions. , no. 128, pp. 1–6.
Available at: http://www.managenergy.net/download/nr128.pdf

Agafonkin, V. (2014). SunCalc JavaScript Library.
Available at: http://github.com/mourner/suncalchttp://10k.aneventapart.com/2/Uploads/660/

Aktuator (2014). Sun tracking system - a device for orienting a solar panel or to hold a solar reflector or lens pointed at the sun, like heliostats.
Available at: http://www.aktuator.ru/Solar_Actuator/

American Clean Energy (2014). Solar Power Green Savings Calculator.
Available at: http://americancleanenergy.com/about-solar

Analemma.com (2014). The analemma and the Equation-of-Time are a result of the sum of the effects of the Earths elliptical orbit around the sun and the tilt of the Earths axis in relation to the plane of its orbit around the sun.
Available at: http://www.analemma.com/pages/Summation/SummationEffect/Summation.html

Andrews, R. and Pearce, J. (2013). The effect of spectral albedo on amorphous silicon and crystalline silicon solar photovoltaic device performance. *Solar Energy*, vol. 91, pp. 233–241.

Available at: http://www.appropedia.org/Spectral_effects_on_amorphous_silicon_photovoltaic_cells_literature_reviewhttp://www.appropedia.org/The_effect_of_spectral_albedo_on_amorphous_silicon_and_crystalline_silicon_solar_photovoltaic_device_performance

Angel, R.P. and Davison, W.B. (2009). Solar Concentrator Apparatus with Large, Multiple, Co-axial Dish Reflectors, PCT patent WO2009140174.
Available at: http://www.google.com/patents/WO2009140174A3

Angstrom Designs (2014). A Simple Graph Application using LArVa on Labview.
Available at: http://angstromdesigns.com/software/download

Arturo, M. and Alejandro, G. (2010). High Precision Solar Tracking System. *Proceedings of the World Congress on Engineering, London, U.K.*, vol. 2.
Available at: http://www.iaeng.org/publication/WCE2010/WCE2010_pp844-846.pdf

ASTM (1999). Standard G173-03: Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on a 37˜Tilted Surface. *ASTM Standard G173-03, American Society for Testing and Materials, West Conshohocken, PA*, , no. June.

AstroTempus (2014). World Astro Clock Light App.
Available at: http://www.world-timezone.com/daylight-map/

AutoCAD (2014). AutoCAD. *AutoDesk Inventor*, pp. 1–4.

Autodesk (2014*a*). Energy Analysis Charts and Tables.
Available at: http://help.autodesk.com/view/RVT/2015/ENU/?guid=GUID-51F923AF-836B-4B64-B9FA-BB8288A06004

Autodesk (2014*b*). Massing and Orientation for Heating.
Available at: http://sustainabilityworkshop.autodesk.com/buildings/massing-orientation-heating#sthash.SdvNwS8c.dpuf

Autodesk (2014*c*). Reading Sun Path Diagrams.
Available at: http://sustainabilityworkshop.autodesk.com/buildings/reading-sun-path-diagramshttp://sustainabilityworkshop.autodesk.com/buildings/vasarirevit-solar-radiation

Awaya, H. and Bedard, R. (1985). Solar walk-off protection. *NASA Technical Reports Server and Sandia National Laboratories, SAND 84-7019*, , no. April, pp. 1–30.

Ayoub, H. (2012). Improving the energy capture of solar collectors for cloudy regions by using controlled tracking system. *Master of Science Sustainable Engineering: Renewable Energy Systems and the Environment, Department of Mechanical and Aerospace Engineering*, pp. 40–75.

Ayyagari, K., Becerra, F., Dhanraj, P. and Stoelting, P. (2014). Dual Axis Solar Tracking System. *Mechanical Engineering in Columbia University's Class of 2014*, , no. May.
Available at: http://carnot.mech.columbia.edu/~sd/Design2014/Team2/

Baños, R., Manzano-Agugliaro, F., Montoya, F., Gil, C., Alcayde, a. and Gómez, J. (2011 May). Optimization methods applied to renewable and sustainable energy: A review. *Renewable and Sustainable Energy Reviews*, vol. 15, no. 4, pp. 1753–1766. ISSN 13640321.
Available at: http://linkinghub.elsevier.com/retrieve/pii/S1364032110004430

Badea, N. (2015). *Design for Micro-Combined Cooling, Heating and Power Systems*. Springer. ISBN 978-1-4471-6253-7.
Available at: https://www.springer.com/engineering/energy+technology/book/978-1-4471-6253-7

Badea, N. and Voncila, I. (2012). Analysis by indicators performance of the conceptual structures mCCHP-SE using renewable energy sources. *Journal of Energy and Power Engineering*, vol. 6, pp. 1597–1604.
Available at: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5628492

Bazmi, A. and Zahedi, G. (2011 October). Sustainable energy systems: Role of optimization modeling techniques in power generation and supplyA review. *Renewable and Sustainable Energy Reviews*, vol. 15, no. 8, pp. 3480–3500. ISSN 13640321.
Available at: http://linkinghub.elsevier.com/retrieve/pii/S1364032111002061http://www.sciencedirect.com/science/article/pii/S1364032111002061

Beckhoff (2014). Beckhoff TwinCAT PLC library Solar Position Algorithm it is possible to calculate the exact position of the sun.
Available at: http://www.beckhoff.co.za/english.asp?twincat/twincat_solar_position_algorithm.htm

Bellamy, B. (2014). Greenhouse Gas Spectra.
Available at: http://www.barrettbellamyclimate.com/page15.htmhttp://www.barrettbellamyclimate.com/page11.htm

Bendt, P., Gaul, H.W. and Rabl, A. (1980). Determining the Optical Quality of Focusing Collector Without Ray Tracing. Tech. Rep., Solar Energy Research Institute, Colorado.
Available at: http://www.nrel.gov/docs/legosti/old/359.pdf

Berland, B. (2003). Photovoltaic Technologies Beyond the Horizon : Optical Rectenna Solar Cell Final Report Photovoltaic Technologies Beyond the Horizon : Optical Rectenna Solar Cell Final Report. *NREL/SR-520-33263 , ITN Energy Systems, Inc. Littleton, Colorado*, , no. February, pp. 1–21.

Bing (2014). Bing Maps API.
Available at: http://www.programmableweb.com/api/bing-mapshttp://www.bing.com/maps/

Bisenius, W. (2012). Degrees of Protection Provided by Enclosures (IP Code), Association of Electrical Equipment and Medical Imaging, Virginia, USA.
Available at: http://www.nema.org/Standards/Pages/A-Brief-Comparison-of-NEMA-250-and-IEC-60529.aspx

Blanco-Muriel, M., Alarcon-Padilla, D. and Lopez, T. (2001). Computing the solar vector. *Solar Energy*, vol. 70, no. 5, pp. 431–441.

Blarke, M. (2013). Compare Options for Sustainable Energy (COMPOSE).

Blarke, M.B. (2014). Quad-generation: Intermittency-friendly distributed generation concepts for flexible production of electricity, heating, cooling, and fuels. *DTU Energy Conference*, , no. June, pp. 1–8.

Blarke, M.B. and Jenkins, B.M. (2013). SuperGrid or SmartGrid: Competing strategies for large-scale integration of intermittent renewables? *Energy Policy*, vol. 58, no. March, pp. 381–390.
Available at: https://www.researchgate.net/publication/257126505_

SuperGrid_or_SmartGrid_Competing_strategies_for_large-scale_integration_of_intermittent_renewables?ev=pub_cit

BLM (2010). Solar Energy Plan of Development.
Available at: http://www.blm.gov/pgdata/etc/medialib/blm/wo/MINERALS__REALTY__AND_RESOURCE_PROTECTION_/cost_recovery.Par.96285.File.dat/Solar_POD.pdf

Bode, S.-j. and Gauché, P. (2012). Review of Optical Software for use in Concentrating Solar Power Systems. *SASEC 2012*, pp. 1–8.

Boxwell, M. and Glasbey, S. (2014). *Solar Electricity Handbook*.
Available at: http://solarelectricityhandbook.com/solar-questions.htmlhttp://www.solarelectricityhandbook.com/solar-calculator.html

Bracco, S., Delfino, F., Fabio, Pampararo, Robba, M. and Rossi, M. (2014). The Savona Campus (University of Genova) smart poligeneration microgrid. *OCOVA AlpMedNet Forum*, , no. June, pp. 1–9.

Buckley, B. (2014). A maximum power point tracking photovoltaic system.
Available at: http://bryanwbuckley.com/projects/mppt.html

BuiltItSolar (2014). Source Code for Solar Analysis Programs and Classes.
Available at: http://www.builditsolar.com/References/Source/SunClass/SunClass.htmhttp://www.builditsolar.com/References/Source/sourcecode.htmhttp://www.builditsolar.com/References/SunChartRS.htm

Burnett, K. (2000). Approximate Astronomical Positions: User defined functions in Excel.
Available at: http://www.stargazing.net/kepler/astrofnc.html#twig03http://www.stargazing.net/kepler/index.htmlhttp://www.stargazing.net/kepler/newlink.html

Butzkamm, C., Gmbh, S. and Bollati, D. (2012). Partial Networking for CAN bus systems : Any saved gram CO 2 / km is essential to meet stricter EU regulations .

Byrnes, S.J., Blanchard, R. and Capasso, F. (2014 March). Harvesting renewable energy from Earth's mid-infrared emissions. *Proceedings of the National Academy of Sciences of the United States of America*, vol. 111, no. 11, pp. 3927–32. ISSN 1091-6490.
Available at: http://www.ncbi.nlm.nih.gov/pubmed/24591604

Carbon Trust (2013). Conversion factors: Energy and carbon conversions, 2013 update. *The Carbon Trust 2013*, pp. 17–171.
Available at: http://www.carbontrust.com/resources/tools

Catarius, A. (2010). *Azimuth-altitude dual axis solar tracker*. Ph.D. thesis.
Available at: http://www.wpi.edu/Pubs/E-project/Available/E-project-121710-140419/unrestricted/Dual_Axis_Tracker_Final_Report.pdf

Cavalier, F. (2014). Angular Control.
Available at: http://publication.lal.in2p3.fr/2001/web/node33.html

CBPR (2014). New Zealand Sun Charts.
Available at: http://www.victoria.ac.nz/architecture/centres/cbpr/resources

CelesTrak (2014). Satellite Catalog (SATCAT).
Available at: http://www.celestrak.com/satcat/search.asp

Chen, X. (2013). *Integration and optimisation of bio-fuel micro-tri-generation with energy storage*. Ph.D. thesis, Newcastle University, UK.
Available at: https://theses.ncl.ac.uk/dspace/handle/10443/2126

Chengcong, G., Zhihong, W. and Yang, M. (2011). Lei, the world's first 8-inch wafer group III-V solar cell industry in the future may be a new trend of Green Box. *Nuclear Energy Institute Atomic Energy Commission, Executive Yuan solar photovoltaic project plan*, pp. 1–5.

Chiamiov, X. (2014). One composite of solar variability between 1975 and 2005.

Chong, K.-k., Wong, C.-w., Tunku, U. and Rahman, A. (2014). General Formula for On-Axis Sun-Tracking System. *Universiti Tunku Abdul Rahman Malaysia*, , no. Chapter 3, pp. 263–291.

Clarke, S. (2014). Chasing the Sun with Adafruit, Arduino, GPS, PSA, Solar, Teensy3.0, Tracking.

Collier, P., Conway, G. and Venables, T. (2008). Climate Change and Africa. *Oxford Review of Economic Policy, Oxford University Press*, vol. 24, Issue, no. 2, pp. 337–353.
Available at: http://oxrep.oxfordjournals.org/content/24/2/337.abstract

Connolly, D. (2012). Energy Tools for Analysing the Integration of Renewable Energy Terminology : Tool vs . Model. *Aalborg University Denmark*, , no. April, pp. 1–53.

Connolly, D., Lund, H., Mathiesen, B. and Leahy, M. (2010*a*). A review of computer tools for analysing the integration of renewable energy into various energy systems. *Applied Energy*, vol. 87, no. 4, pp. 1059–1082.

Connolly, D., Lund, H., Mathiesen, B. and Leahy, M. (2010 April*b*). A review of computer tools for analysing the integration of renewable energy into various energy systems. *Applied Energy*, vol. 87, no. 4, pp. 1059–1082. ISSN 03062619.
Available at: http://linkinghub.elsevier.com/retrieve/pii/S0306261909004188http://www.sciencedirect.com/science/article/pii/S0306261909004188

Corbin, C.D. (2014). Optimization of energy use through model-based simulations.
Available at: https://www.google.com/patents/US20140039686

Cowie, C. (2008). Variable-frequency drive. , no. December, pp. 1–2.

Crackberry (2014). SunCalc Premium for BB10 - advanced Sun tracking tool.
Available at: http://forums.crackberry.com/app-announcements-f281/suncalc-premium-bb10-advanced-sun-tracking-tool-946189/

Craig, J.C. (2011). *Sun Position - High accuracy solar position algorithms - a resource for programmers and solar energy engineers*. ISBN 978-1932344684.

Craig, J.C. (2013). *Sun Position - High accuracy solar position algorithms - a resource for programmers and solar energy engineers (VB.Net Programming by Example Book 2)*.

Damm, J. (1990). An active solar tracking system. *Homebrew Magazine*, , no. July, pp. 48–49.
Available at: http://qsl.net/ve1za/Projects/solartracker.pdf

Datasheet MS-100906 (2014). Rolling Ball Tilt Switch and Sensor. *Mouser Electronics*, pp. 1–3.

Davis, M., Lawler, J., Coyle, J., Reich, A. and Williams, T. (2008). Machine vision as a method for characterizing solar tracker performance. *IEEE Photovoltaic Specialists Conference*, vol. 33, no. May, pp. 1–6.

Davis, M. and Williams, T. (2008). Understanding Tracker Accuracy and its Effects on CPV: Accuracy Specs & Reporting Real-world Data. *Presented at the 5th International Conference on Solar Concentrators Palm Desert by GreenPower Engineering*, , no. Novermber, pp. 1–29.

de Greif, J. and Scharmer, K. (2000). *The European Solar Radiation Atlas - Volume 1*. June. ISBN ISBN : 9782911762215.

Delfino, F. Barillari, L. ; Pampararo, F. ; Rossi, M. ; Zakariazadeh, A. ; Molfino, P. ; Podesta, A. ; Venturin, A. ; Robertelli, N. (2014). A Review of Recent Development in Smart Grid and Micro Grid Laboratories. *The 5th International Conference on Information, Intelligence, Systems and Applications, IISA 2014*, vol. 7-9 July 2, pp. 125 – 130.
Available at: 10.1109/IISA.2014.6878746

Delta Automation (2014). Delta Solar tracking system.
Available at: http://deltautomation.wordpress.com/page/4/http://deltautomation.wordpress.com/2011/03/11/delta-solar-tracking-system/

den Haan, J. (2009). Solar cell efficiency.
Available at: http://www.solarpower2day.net/solar-cells/efficiency/

Destaco (2014). Pneumatic Robohand Rotary Actuators (Rotaries).
Available at: PneumaticRobohandRotaryActuators(Rotaries)http://www.destaco.com/rotary-actuators.html

Dietrich, J.J., Steinmeyer, D.A. and Hartmann, D.T. (1986). Balanced Solar Concentrator, US Patent US4583520.
Available at: http://www.google.com/patents/US4583520

Duffie, J.A. and Beckman, W.A. (2006). *Solar Engineering of Thermal Processes*. 3rd edn. Wiley. ISBN 0471698679.

Eco Instruments (2014). Environmental Management and Analysis.
Available at: http://eko-eu.com/http://eko-eu.com/news/new-cloud-analysis-softwarehttp://eko-eu.com/applications/solar-radiation-and-photonic-sensors

Ecotect (2014*a*). Sun-Path: Components.
Available at: http://wiki.naturalfrequency.com/wiki/Sun-Path/Componentshttp://wiki.naturalfrequency.com/wiki/Solar_Radiation_Analysishttp://wiki.naturalfrequency.com/wiki/Solar_Position_Calculatorhttp://wiki.naturalfrequency.com/wiki/Teaching_Tools

Ecotect, A. (2014*b*). Solar Radiation: Components.
Available at: http://wiki.naturalfrequency.com/wiki/SolarRadiation/Componentshttp://wiki.naturalfrequency.com/wiki/Solar_Availability_Tutorial

Ecotect, A. (2014*c*). Solar Radiation Metrics.
Available at: http://sustainabilityworkshop.autodesk.com/buildings/solar-radiation-metrics

EEP (2014). Prepaid electricity micro-grids for rural villages in Tanzania. *EEP Coordination Office (KPMG ECO)*, pp. 1–3.
Available at: eepafrica.org/portfolio-item/prepaid-electricity-micro-grids-for-rural-villages/

Eirik (2014). Solar calculation plugin.
Available at: http://www.grasshopper3d.com/forum/topics/solar-calculation-plugin

ElectronicsTutorials (2014). Light Sensors. *Basic Electronics Tutorials Site by Wayne Storr*, pp. 1–6.
Available at: http://www.electronics-tutorials.ws/io/io_4.html

Energizar (2014). Solar Tracker.
Available at: http://www.energizar.org.ar/energizar_desarrollo_tecnologico_seguidor_solar_que_es.htmlhttp://www.energizar.org.ar/energizar_desarrollo_tecnologico_seguidor_solar_como_funciona.htmlhttp://www.energizar.org.ar/energizar_desarrollo_tecnologico_energia_solar.html

Environmental Protection Agency (2012). eGRID2012. Tech. Rep., USA Evironmental Protectection Agency, Washington DC.
Available at: http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

EPIA (2014). Global market outlook for photovoltaics: 2014-2018. *European Photovoltaic Industry Essociation*.

Esmond, G., Tao, Z. and Yen, C. (2011). Array Module of Parabolic Solar Energy Receivers, US Patent US20110174359.
Available at: http://www.google.com/patents/US20110174359

ESRI (2010). GIS Best Practices: GIS for Renewable Energy. *ESRI, 380 New York Street Redlands, CA 92373-8100 USA*, , no. January.

ESTSC (2014). ESTSC Complete Software List: US Department of Energy Software.
Available at: www.osti.gov/estsc/catalog.jsp?Go=Search&pf=true&All=Y

Excide (2013). Industrial Batteries Powerfit S500 High Energy Density for Maximum Security, Exide Technologies Catalog.
Available at: http://elektropower.hu/Exideakkumulator/Powerfit.pdf

Fang, H. (2013*a*). Slewing Drive Manual, Jiangyin Huafang New Energy Hi-Tech Equipment Co. Ltd, China.
Available at: https://www.acosolar.com/media/productfile/s/l/slewingdrivemanual.pdf

Fang, H. (2013*b*). Slewing Drive Manual, Jiangyin Huafang New Energy Hi-Tech Equipment Co. Ltd., China.
Available at: https://www.acosolar.com/media/productfile/s/l/slewingdrivemanual.pdf

Fang, W. (2014). Introduction of Matlab program for Solar Engineering Fundamentals. *Dept. of Bio-Industrial Mechatronics Engineering National Taiwan University, ROC*, pp. 1–12.

FEiNA (2014). Solar tracker FEiNA SF70-1EH follower on the horizontal axis.
Available at: http://www.tracker.cat/seguidor-solar-feina-sf70-1eh-es/?lang=es

Feldhoff, J.F. (2012). Linear Fresnel Collectors A Technology Overview Overview of CSP Systems. *SFERA Summer School 2012 June 28, 2012, Almería, Spain*, pp. 1–30.

Ferry, R. and Monoian, E. (2012). A field guide to renewable energy technologies land art generator initiative. *Landartgenerator*, pp. 1–71.

Fluke (2014). Fluke 435 Series II Power Quality and Energy Analyzer.
Available at: http://www.fluke.com/fluke/sgen/power-quality-tools/logging-power-meters/fluke-435-series-ii.htm?PID=73939

ForumHaus (2009). Novel design for a solar tracker installation based on a satellite dish.
Available at: http://www.forumhouse.ru/threads/43523/page-16

Friesth, K.L. (2014). Hybrid Trigeneration System based Microgrid Combined Cooling, Heat and Power providing Heating, Cooling, Electrical Generation and Energy Storage using an Integrated Automation System for Monitor, Analysis and Control.
Available at: http://www.google.com/patents/US20140174080

Gabay, P.J. (2012). Motion Sensing Via Rotary Shaft Encoders Assures Safety and Control.
Available at: http://www.digikey.com/es/articles/techzone/2012/aug/motion-sensing-via-rotary-shaft-encoders-assures-safety-and-control

Garg, S.K., Yeo, C.S., Anandasivam, A. and Buyya, R. (2011). Environment-conscious scheduling of HPC applications on distributed Cloud-oriented data centers. *Journal of Parallel and Distributed Computing*, vol. 71, pp. 732–749. ISSN 07437315.

Gary, J., Turchi, C. and Siegel, N. (2011). CSP and the DOE Sunshot Initiative. In: *SolarPACES Conference*, vol. 1. Granada, Spain.

Gears (2007). Use the Gears-IDS Invention and Design System to build an autonomous Solar Tracking Device. *GEARS Educational Systems , Solar Tracker Construction Guide An Illustrated Assembly Manual*, pp. 1–43.
Available at: http://www.gearseds.com/solar_tracker.html

Ghosal, K., Burroughs, S., Lilly, D. and Gabriel, J. (2011). On-sun performance of a novel microcell based hcpv system based in tuscon and comparison with conventional systems. *IEEE Photovoltaic Specialists Conference (PVSC)*, vol. 37, pp. 978 – 983.
Available at: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6186115

Giesen, J. (2014). Sun and Moon Graphics , the Analemma Sundial Applet.
Available at: http://www.jgiesen.de/GeoAstro/sundials.htmlhttp://www.jgiesen.de/analemma/http://www.jgiesen.de/GeoAstro/GeoAstro.htmhttp://www.jgiesen.de/GeoAstro/english2.html

Gisi, M., Hase, F., Dohe, S. and Blumenstock, T. (2011 January). Camtracker: a new camera controlled high precision solar tracker system for FTIR-spectrometers. *Atmospheric Measurement Techniques*, vol. 4, no. 1, pp. 47–54. ISSN 1867-8548.
Available at: http://www.atmos-meas-tech.net/4/47/2011/

Glazner, L. (2013). Dual Axis Solar Panel Controller and Tracker.
Available at: http://blog.solutions-cubed.com/dual-axis-solar-panel-controller-tracker/

Godsell, S. and Franklin, H. (2013). Ecotect Grid Analysis (Solar).
Available at: http://mod.crida.net/thesis/S1-2013/uncategorized/tun/

Google (2014*a*). Brayton Project Overview.

Google (2014*b*). Heliostat Control and Targeting. *Google.org*, pp. 1–7.

GoshLab (2011). Solar Tracking Controller User Guide. *GoshLab, 106 Mawson Place Mawson ACT 2607 Australia*, , no. STC-UD-001.

Green Rhino Energy (2014). Energy Yield of Concentrated Solar Thermal (CST) Power Plants. *joachim@greenrhinoenergy.com*.
Available at: `http://www.greenrhinoenergy.com/solar/technologies/cst_energy_yield.php`

Greenenergy Star (2010). Optimizing PV Array with Orientation Tilt.
Available at: `http://www.greenergystar.com/shop/content/14-optimizing-pv-array`

Grena, R. (2008). An Algorithm for the Computation of the Solar Position. *Solar Energy*, vol. 82, pp. 462–470.
Available at: `http://www.scribd.com/doc/94455998/Grena-2008-An-Algorithm-for-the-Computation-of-the-Solar-Position`

Greyvenstein, G.e. (2011). Introduction To Dish Stirling - Main CSP Technologies. In: *Solar South Africa Conference*, vol. 2011, pp. 1–11.
Available at: `http://www.ennex.co.za/downloads/DishStirlingSolarSouthAfricaConference21June2011.pdf`

Griffin, M. and Burke, H. (2003). Compensation of hyperspectral data for atmospheric effects. *Lincoln Laboratory Journal*, vol. 14, no. 1, pp. 29–54.
Available at: `http://www.ll.mit.edu/publications/journal/pdf/vol14_no1/14_1compensation.pdf`

Groene Energie (2014). Mogelijkheden voor het opstellen en bevestigen van zonnepanelen.
Available at: `http://www.dgem.nl/nl/zonne-energie/opstellen-en-bevestigen-zonnepanelen`

Gross, B. (2014). A solar energy system that tracks the sun.
Available at: `https://www.ted.com/talks/bill_gross_on_new_energyhttp://www.genomicon.com/2009/03/stirling-sunflowers/`

Grotholt, C. (2014). 2G Energy AG Cogeneration: Highly Efficient Technology Hot Air. , no. May, pp. 1–10.
Available at: `http://www.japantag-duesseldorf-nrw.de/fileadmin/pdf/wirtschaftstag/Wirtschaftstag_Praesentationen/Liesner_2G_Japantag_2014.pdf`

Gueymard, C. (2004). The suns total and spectral irradiance for solar energy applications and solar radiation models. *Solar Energy*, pp. 423–453.
Available at: `http://www.pvlighthouse.com.au/resources/courses/altermatt/TheSolarSpectrum/Therearealotofphotonsintheinfrared.aspx`

Hamed, B.M. and El-Moghany, M.S. (2012 February). Fuzzy Controller Design using FPGA for Sun Tracking in Solar Array System. *International Journal of Intelligent Systems and Applications*, vol. 4, no. 1, pp. 46–52. ISSN 2074904X.
Available at: `http://www.mecs-press.org/ijisa/ijisa-v4-n1/v4n1-6.html`

Haniffin, P. (2005). Fundametals of Servo Motion Control (PID Control). p. 12.

Hebrink, T. (2012). Durable Polymeric Films for Increasing the Performance of Concentrators. *"Third Generation Photovoltaics", book edited by Vasilis Fthenakis, ISBN 978-953-51-0304-2*, , no. March, pp. 32–44. Available at: http://www.intechopen.com/books/third-generation-photovoltaics/durable-polymeric-films-for-increasing-the-performance-of-concentrators-

Heckendorn, C. (2009). Inclinometer for a solar array and associated systems, methods, and computer program products. *US Patent Application Number: US 20110114079 A1*, , no. November, pp. 1–15.

HelioDynamics (2009). Mid-temperature concentrating solar thermal collectors. Tech. Rep..

Hennings, D. (2014). SunPath copyrighted freeware Berechnung von Sonnenstands-Diagrammen A sun chart calculator (Sunpath copyrighted freeware for Calculation of sun position charts A sun chart calculator).
Available at: http://www.eclim.de/index5.htm

Ho, C., Ghanbari, C. and Diver, R. (2009). Hazard analyses of glint and glare from concentrating solar power plants. *Proceedings of SolarPACES, Berlin, Germany*, , no. September.
Available at: http://energy.sandia.gov/wp/wp-content/gallery/uploads/Glint_Glare_SolarPACES2009.pdf

Ho, C., Ghanbari, C. and Diver, R. (2011). Methodology to assess potential glint and glare hazards from concentrating solar power plants: analytical models and experimental validation. *... Solar Energy ...*, vol. 133, no. 3, p. 031021. ISSN 01996231.
Available at: http://solarenergyengineering.asmedigitalcollection.asme.org/article.aspx?articleid=1458650

Ho, C. and Khalsa, S. (2010). Hazard Analysis and Web-Based Tool for Evaluating Glint and Glare from Solar Collector Systems. *share.sandia.gov*.
Available at: https://share.sandia.gov/phlux/static/references/glint-glare/Glint_Webtool_SolarPACES2010_paper_v5_header.pdf

Hobley, S. (2009). Pixart/Wiimote sensor library for Arduino.
Available at: http://www.stephenhobley.com/blog/2009/03/01/pixartwiimote-sensor-library-for-arduino/

Homepower (2014). Optimizing a PV Array with Orientation & Tilt. , no. Online.
Available at: http://www.homepower.com/articles/solar-electricity/design-installation/optimizing-pv-array-orientation-tilt

Hoyer-Klick, C., Trieb, F., Schillings, C., Wald, L., Huld, T. and Schroedter-Homscheidt, M. (2009). Getting Solar Energy to Work: Resource Assessment by Remote Sensing as a Base for Investment Decisions. *Articles, Climate, Energy, Sustainability*, , no. May, pp. 1–8.

Hughes, R. (1980). Effects of tracking errors on the performance of point focusing solar collectors. *Solar Energy*, vol. 24, pp. 83–92.
Available at: http://www.sciencedirect.com/science/article/pii/0038092X80900237

IBM (2013). IBM Develops Economical Sunflower CPV System. *Sandra Henderson, Research Editor, Solar Novus Today*, , no. April, pp. 1–3.
Available at: http://www.zurich.ibm.com/news/14/dsolar.htmlhttp://www.solarnovus.com/ibm-develops-economical-sunflower-cpv-system_N6493.html

IC Haus (2014). 12 Bit Angular Hall Encoder with Sin/Cos Outputs. *Am Kuemmerling 18 D-55294 Bodenheim, Germany*, vol. 49, no. 6135, pp. 1–3.

ICC (2014). Part I Suns Radiation and Heating of the Atmosphere.
Available at: http://faculty.icc.edu/easc111lab/labs/labi/prelab_i.htmlhttp://faculty.icc.edu/easc111lab/geology2.html

IEC (2007). IEC 60904-9 ED. 2.0 B:2007 Photovoltaic devices - Part 9: Solar simulator performance requirements. *STANDARD by International Electrotechnical Commission*, , no. October, p. Defines classifications of solar simulators for us.

IMO (Ingo Müller Oberflächentechnik) (2013). IMO Slew Drives Product Catalog.
Available at: http://www.imo.de/uploads/media/Slew_Drive_Catalog_02.pdf

India Carbon Outlook (2014). SolarGIS satellite-based solar database for India.
Available at: %http://india.carbon-outlook.com/content/solar-resource-database-and-pv-assessment-tool-india

Infinia (2012*a*). Powerdish IV, Solar Energy Solution, The Infinia Corportation USA.
Available at: http://www.infiniacorp.dreamhosters.com/project/powerdish-iv/

Infinia (2012*b*). PowerDish Product update. *Infinia Corporation*, , no. March.

Infinia (2012*c*). Technical Specifications and Descriptions for an Infinia Solar System. *Infinia Corporation*.

Innova (2013). Trinum Thermodynamic Solar Cogenerating System, Innova Solar Energy, Italy.
Available at: http://www.innova.co.it/files/pdf-prodotti/datasheet_trinum_eng_25032.pdf

Invernizzi, C., Iora, P. and Silva, P. (2007). Bottoming micro-Rankine cycles for micro-gas turbines. *Applied Thermal Engineering*, vol. 27, pp. 100–110. ISSN 13594311.

ISEC (2001). Solar Resources Assessment: A Review. *In J. Gordon, ed. Solar Energy: The State of the Art. London: James & James Ltd.*, , no. Chapter 10, pp. 497–562.

ITACA (2014). A guide to how to calculate the amount of the Suns energy that is incident on an inclined plane at any latitude, including solar astronomy.
Available at: http://www.itacanet.org/the-sun-as-a-source-of-energy/
http://www.itacanet.org/the-sun-as-a-source-of-energy/part-2-solar-energy-reaching-the-earths-surface

J. Marshall (2014). Solar energy: Springtime for the artificial leaf. *Nature Magazine*, vol. 510, no. 5 June, pp. 22–24.

Jaafari, M., Hadachi, I., Elwarari, M., Boualila, S. and Salih-Alj, Y. (2013). A closed pneumatic-based solar tracking system. *IEEE Renewable and Sustainable Energy Conference (IRSEC), 2013 International*, , no. March, pp. 136 – 140.

Jaloxa (2014). Sunpath Diagrams for Daylighting, Radiance, and HDR Photography.
Available at: http://www.jaloxa.eu/resources/daylighting/sunpath.shtml

Johnson Electric (2014). Electric motor efficiency curves.
Available at: http://www.gophoto.us/key/electricmotorefficiencycurvehttp://www.johnsonelectric.com/common/en/images/resources-for-engineers/

automotive-applications/motion-technology/ec-motor-brushless/performance-curve-01.jpg

Juhuang (2013). Dual-axis Solar Tracker, Shandong Juhuang Photoelectric Technology Co. Ltd., China.
Available at: http://en.pv001.net/web.php?uid=24&wid=1&cid=2083

Kalkman, P. (2011). Solar Calculator - Calculate Sunrise, Sunset, and Maximum Solar Radiation. *Download source code (VS 2008)*, pp. 1–4.

Kandilli, C. and Ulgen, K. (2009 January). Review and modelling the systems of transmission concentrated solar energy via optical fibres. *Renewable and Sustainable Energy Reviews*, vol. 13, no. 1, pp. 67–84. ISSN 13640321.
Available at: http://linkinghub.elsevier.com/retrieve/pii/S1364032107001086

Kandilli, C., Ulgen, K. and Hepbasli, A. (2008 January). Exergetic assessment of transmission concentrated solar energy systems via optical fibres for building applications. *Energy and Buildings*, vol. 40, no. 8, pp. 1505–1512. ISSN 03787788.
Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378778808000376

Kcourtneynewark (2014). Alternative Energy Solutions - Solar Tracking System.
Available at: http://www.element14.com/community/docs/DOC-28364/l/alternative-energy-solutions--solar-tracking-system

Kelly, N. and Gibson, T. (2009). Improved photovoltaic energy output for cloudy conditions with a solar tracking system. *Solar Energy*, vol. 83, no. 2009, pp. 2092–2102.

Kelso, T. (2014). Satellite Tracking Software Index.
Available at: http://www.celestrak.com/software/satellite/sat-trak.asp

Kevin (2014). Analemma. *Built it Solar*.
Available at: http://www.builditsolar.com/Projects/Educational/Solargraphy/Solargraphy.htm

Khalsa, S.S.S., Ho, C.K. and Andraka, C.E. (2011). An Automated Method to Correct Heliostat Tracking Errors. In: *SolarPACES Conference*. SolarPaces2011, Granada, Spain.

Khan, A. (2006). Device physics: A bug-beating diode. *Nature 441*, vol. 299, no. May.

Kinoshita, G.S. (1985). The Shenandoah Parabolic Dish Solar Collector. *Sandia National Laboratories*, , no. January, pp. 1–12.
Available at: http://prod.sandia.gov/techlib/access-control.cgi/1983/830583.pdf

KippZonen (2014). Solar Instruments.
Available at: http://www.kippzonen.com/http://www.kippzonen.com/ProductGroup/1/Solar-Instruments

Koning, R. (1994). Light (Plant Physiology). *Plant Physiology Information Website*.
Available at: http://plantphys.info/plant_physiology/light.shtml

Krymsky, Y. (2013). A New Way of Visualizing Solar Radiation.
Available at: http://yazdanistudioresearch.wordpress.com/2013/01/13/a-new-way-of-visualizing-solar-radiation/

Kumar, B.A. (2011). Solar Power Systems Web Monitoring. *The 2nd Symposium on Renewable Energy Technologies (SoRET), October 2011, Raiwai, Fiji*, , no. October.

Kurtz, S. (2012). Opportunities and Challenges for Development of a Mature Concentrating Photovoltaic Power Industry.

Kyosemi (2012). New solar cell design harvests sun from all sides. pp. 1–2.
Available at: http://www.dvice.com/archives/2012/03/new_solar_cell.php

Lauritzen (2014). Tracker Accuracy. *Lauritzen Solutions*, pp. 1–3.
Available at: http://www.lauritzen.biz/static/solutions/accuracy.pdfhttp://www.lauritzen.biz/solutions.html

Lavagna, S.M. (2013). Process for improving the reflectivity of reflective surfaces of antennas.
Available at: http://www.google.com/patents/WO2013108225A1?cl=en

Le Roux, W.G., Bello-Ochende, T. and Meyer, J.P. (2012). Solar Tracking for a Parabolic Dish Used in a Solar Thermal Brayton Cycle. *CRSES Annual Student Symposium*.
Available at: http://www.crses.sun.ac.za/files/services/conferences/annual-student-symposium-2012/22_November/7_LeRoux.pdf

Lechner, N.M. (2014). Playing the Angles for Solar-Responsive Design.
Available at: http://greenpassivesolar.com/2014/06/playing-the-angles-for-solar-responsive-design/

Lee, C. (2014*a*). Measuring Global Solar Irradiance.
Available at: http://kippzonen-blog.nl/solar-energy/measuring-global-solar-irradiance/

Lee, C.-y., Chou, P.-c., Chiang, C.-m. and Lin, C.-f. (2009). Sun Tracking Systems: A Review. *Sensors*, , no. 9, pp. 3875–3890.

Lee, J. (2008). Hacking the Nintendo Wii Remote. *IEEE Pervasive Computing,*, vol. 7, no. 3, pp. 39–45.

Lee, K. (2014*b*). Astronomy Simulations and Animations, Flash animations and simulations for astronomy education, including seasons, moon phases, coordinate systems, light, and more.
Available at: http://astro.unl.edu/http://astro.unl.edu/animationsLinks.html#ca_coordsmotion

Li, L. and Dubowsky, S. (2012). A New Design Approach for Solar Concentrating Parabolic Dish Based on Optimized Flexible Petals. *Accept for publication in the Journal Mechanism and Machine Theory*, pp. 1–19.

Liang, D., Monteiro, F., Teixeira, R. and Pereira, C. (1999). Fiber-optic solar energy transmission and concentration. *Solar Energy Materials and Solar Cells*, vol. 54, no. 1-4, pp. 323–331.

Lin, D. (2008). Speed acquisition made simple. *iC-Haus GmbH*, , no. September, pp. 1–3.
Available at: http://staging.edn.com/design/sensors/4324812/Speed-acquisition-made-simple

Lin, V. (2007). Catching the sun's rays with wire. vol. 242, no. August 27.
Available at: http://web.ornl.gov/info/news/pulse/pulse_v242_07.htm

Lindemann, P. (2014). *Solar Secrets Debunking Myths of the Solar Industry*.

Linden, L. (2007). Stirling Energy Systems: Solar Dish Stirling Systems Report For NREL CSP Technology Workshop. *Stirling Engine Systems (SES)*, , no. March 7, 2007, pp. 1–23.

Link Light Solar (2014). Mini-watt Epoxy encapsulated Solar Panels 0.1-9W.
Available at: http://www.linklightsolar.com/mini-watt-solar-panels.html

Liu, J., Chou, P., Bagherzadeh, N. and Kurdahi, F. (2001). Power-aware scheduling under timing constraints for mission-critical embedded systems. *Design Automation Conference*, , no. June, pp. 18–22.

Lloyd, P., Dick, A. and Howells, M. (2004). Energy profile for a rural community. *Journal of Energy in Southern Africa*, vol. 15, no. 3, pp. 80–87.

Lopez, C. and Stone, K. (1993*a*). Performance of the Southern California Edison Company Stirling Dish. *Mako Enterprises, Southern California Edison Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract DE-AC04-94AL85000*, , no. October, pp. 78–89.

Lopez, C.W. and Stone, K.W. (1993*b*). Performance of the Southern California Edison Company Stirling Dish, Southern California Edison Co., Rosemead and Mako Enterprises, Huntington, CA., USA. Tech. Rep. October.

Luke (2014). Arduino Sun Tracking Solar Panel System.
Available at: https://code.google.com/p/arduino-solar-tracking/https://code.google.com/p/arduino-solar-tracking/downloads/list

Lund, H. (2007). EnergyPLAN Advanced Energy Systems Analysis Computer Model. *Aalborg University Denmark*, , no. December, pp. 1–114.

Lunde, P. (1980). *Solar thermal engineering : space heating and hot water systems*.
Available at: http://www.researchgate.net/publication/44461522_Solar_thermal_engineering__space_heating_and_hot_water_systems__Peter_J._Lunde

Makundi and Rajan (1999). United Nations Framework on Climate Change: Mitigation Options, UNFCCC CGE Global Training Workshop on Mitigation Assessment.
Available at: http://unfccc.int/resource/cd_roms/na1/mitigation/Module_3/Module3.ppt

Mancini, T.R. (1997). Solar-Electric Dish Stirling System Development.
Available at: http://mac6.ma.psu.edu/stirling/reports/DE98001305.pdf

Manfred, R. (2012). Installationsanleitung für Solarview, Datenlogger und Webvisualisierungstool, RichterData, Germany. pp. 1–32.

Manske, M. (2014). Sonnenstandsdiagramm Berlin.

Marsh, A. (2014). Sun-Path Diagram Projection Methods.
Available at: http://andrewmarsh.com/scripts/educational/solar-position-and-sun-path

Mathiason, S. (2014). Sun Position Calculator.
Available at: http://www.planet-source-code.com/vb/scripts/ShowCode.asp?txtCodeId=10537&lngWId=1

MathWorks (2014). Simulink Verification and Validation.
Available at: http://www.mathworks.com/products/simverification/

Matusiak, M. (2014). SolarBeam is an application for drawing solar diagrams.
Available at: http://sourceforge.net/projects/solarbeam/http://solarbeam.sourceforge.net/screenshots.php

Meeus, J. (1991). Astronomical Algorithms. *Astronomical Algorithms, Willmann-Bell, Inc., Virginia*.

Messenger, R. and Ventre, J. (2012). Photovoltaic Systems Engineering. *Third Edition ed. London: Taylor & Francis Group*.

MeteoControl (2014). SaferSun Professional: The monitoring system for professionally monitoring commercial PV systems.
Available at: http://www.meteocontrol.com/en/http://www.meteocontrol.com/en/industrial-line/portals/safersun-professional/http://www.meteocontrol.com/en/services/weather-data/

Meyer, C. (2010). Tessera Solar Imperial Valley Solar Project Glint and Glare Study. *Imperial Valley Solar (formerly Solar Two)*, pp. 1–52.
Available at: http://docketpublic.energy.ca.gov/PublicDocuments/Regulatory/NonActiveAFC's/08-AFC-5Imperial(SESSolarII)/2010/April/TN5645704-28-10Applicant'sSubmittaloftheGlint-GlareStudy.pdf

Michalsky, J.J. (1988). The asreonomical almanac algorithm for approximate solar position. *Solar Energy*, , no. 40, pp. 227–235.

Microsoft (2014). Microsoft virtual earth 3d.
Available at: http://en.uptodown.com/search/microsoft-virtual-earth-3dhttp://microsoft-virtual-earth-3d.en.uptodown.com/

Mikkelsen, M., Gröblacher, S., Schliesser, A., Ginzberg, P., Hayat, A. and Politi, A. (2011). Coupled nanoantenna and plasmonic lens. *EPS QEOD Thesis Prizes: Winners of 2011, Optics & Photonics Focus*, vol. 14, no. 2, pp. 1–2.
Available at: http://opfocus.org/index.php?topic=picture&v=14&s=2&p=5

Miller (2009). Impact of Soiling and Pollution on PV Generation Performance.
Available at: www4.eere.energy.gov/pv_module_soiling_impact.pdf

Miller, G. (2014). Sketchup Light Ray Reflection Simulator Plugin.
Available at: http://www.cerebralmeltdown.com/projects/SketchupLightReflectionPlugin/default.htmlhttp://www.cerebralmeltdown.com/projects/experimenting-with-the-sketchup_light-ray-reflection-simulator-plugin/

Montgomery, K.H., Heredia, C. and Woodall, J.M. (2013). Design and Modeling of a High Efficiency Hybrid Photovoltaic - Photo thermal Concentrator (PVPTC) System. *IEEE 39th Photovoltaic Specialists Conference, Tampa, FL.*

Montgomery College (2014). Parabolic Antenna Design Project Specifications and Formulas.

Mooney, T. (2009). Reflective coating for Solar Parabolic Dish Concentrator.
Available at: http://www.finishing.com/535/38.shtml

Morehead, J. (2012). Designing with solar tracking motors Motors that move solar panels can encounter conditions that are more severe than those associated with industrial uses.

Motion, I.I. (2013). STT series sealed tilt sensors. *Penny & Giles, 15 Airfield Road Christchurch Dorset BH23 3TG United Kingdom +44 (0) 1202 409499*, pp. 1–6.

Mottiar, S. and George, S. (2003). Electrification of the rural poor: lessons from an interim concession. *Centre For Policy Studies Research , P O Box 16488, Doornfontein 2028 , Johannesburg, South Africa*, vol. 104, no. September.

Mouzouris, M. and Brooks, M.J. (2010). Construction of a Composite Material Solar Concentrator for High Heat Flux Applications. *46th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit 25 - 28 July 2010, Nashville, TN*, , no. July, pp. 1–9.

Mueller, P. (2014). Celestial Sphere.

Muerza, A.F. (2007). Seguidores solares Solar Tracker.
Available at: `http://www.consumer.es/web/es/medio_ambiente/energia_y_ciencia/2007/11/09/171602.php`

Mulaudzi, S. and Qase, N. (2008). Mini-grid hybrid viability and replication potential: The Hluleka and Lucingweni pilot projects. *Department of Minerals and Energy Pretoria, New and Renewable Energy*, , no. August.

NASA (1986). Point focussing systems. *NASA Technical Report Server*, pp. 1–87.
Available at: `http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19860003320_1986003320.pdf`

NASA (2014). The Earth Radiation Budget Experiment.
Available at: `http://asd-www.larc.nasa.gov/erbe/ASDerbe.html`

National Instruments (2014*a*). NI CompactRIO Dual Axis Sun Tracker Example Design. *Online download*, pp. 1–5.
Available at: `http://www.ni.com/example/31252/en/`

National Instruments (2014*b*). What is a Pulse Width Modulation (PWM) Signal and What is it Used For. pp. 1–3.
Available at: `http://digital.ni.com/public.nsf/allkb/294E67623752656686256DB800508989`

Nelson, D. (2011). Geo Stars Library : Geodetic and Astrometry library.

Neuhaeuser, A. (2009). Polygeneration using concentrated solar thermal power. *SolarPACES Conference*, , no. September.

Ngai, T. (2014). incident solar analemma and climate visualization with Matlab.
Available at: `http://www.tedngai.net/?p=571http://www.tedngai.net/?p=270`

NOAA (2014). General Solar Position Calculations.
Available at: `http://www.esrl.noaa.gov/gmd/grad/solcalc/solareqns.PDFhttp://www.esrl.noaa.gov/gmd/grad/solcalc/`

Norton, B., Eames, P.C. and Lo, S.N.G. (1998). Full-energy chain analysis of greenhouse gas emissions for solar thermal electric power generation systems. *Renewable Energy*, vol. 15, pp. 131–136. ISSN 0960-1481.
Available at: `<GotoISI>://WOS:000076228900023`

NOS (2013). Photoflow - solar and rainwater collection system. *Designboom*, , no. August, pp. 1–4.
Available at: `http://www.designboom.com/technology/photoflow-solar-and-rainwater-collection-system-by-nos/`

Novack, S., Kotter, D., Pinhero, P. and Slafer, D. (2008). Solar Nanoantenna Energy Collectors. *Nanotech 2008 Conference Program, Idaho National Laboratory, US*, , no. June.

NREL (2008). Solar Position Algorithm (SPA) Source Code.
Available at: http://rredc.nrel.gov/solar/codesandalgorithms/spa/

NREL (2013). Climate Neutral Research Campuses.
Available at: http://www.nrel.gov/tech_deployment/climate_neutral/smart_grid.html

NREL (2014*a*). BMS Instrument Pictures, Photos of instrumentation and trackers at SRRL's Baseline Measurement System.
Available at: http://www.nrel.gov/midc/srrl_bms/pictures.htmlhttp://www.nrel.gov/midc/srrl_bms/http://www.nrel.gov/midc/

NREL (2014*b*). Modeling and Analysis of CSP Systems. *National Renewable Energy Laboratory 1617 Cole Boulevard, Golden, Colorado 80401 303-275-3000 www.nrel.gov*.

NREL (2014*c*). NREL PVWatts Calculator.
Available at: http://pvwatts.nrel.gov/

NREL (2014*d*). NREL Solar Prospector.
Available at: http://maps.nrel.gov/prospector

NREL (2014*e*). Research Cell Efficiency Records.
Available at: http://www.nrel.gov/ncpv/

NREL (2014*f*). SolTrace Optimal Modeling Software.
Available at: http://www.nrel.gov/csp/soltrace/

NREL (2014*g*). South America Direct Normal Solar Radiation.
Available at: http://maps.nrel.gov/SWERAhttp://en.openei.org/datasets/node/495

Onakasuita (2014). WiinRemote: A program for using Wii Remote on Windows PC.

Orecchini, F. (). The era of energy vectors. vol. 31, no. 14, pp. 1951–1954.

Oregon (2014). The sun path chart program plots the path of the sun across the sky.
Available at: http://solardat.uoregon.edu/SoftwareTools.html

Panasonic (2014). Green Automation Solutions for the Solar Industry, Solar tracking system. *Generate tracking algorithm control positioning monitor safety devices measure wind speed process alarms remote control*, pp. 1–4.

ParisTech (2006). Maps of Irradiation, Irradiance, and UV. *Centre for Energy and Processes, Ecole des Mines de Paris*.
Available at: http://www.soda-is.com/eng/map/maps_for_free.html#monde

ParisTech (2008). Yearly mean of daily irradiation in UV in the world (1990-2004). *Centre for Energy and Processes, Ecole des Mines de Paris*.

Parker Hannifin (2014). Hydraulic Devices Help Solar Collectors Track Sun.
Available at: http://www.parker.com/portal/site/PARKER/menuitem.223a4a3cce02eb6315731910237ad1ca/?vgnextoid=c00aeea74775e210VgnVCM10000048021dacRCRD&vgnextfmt=default&vgnextfmt=ENhttp://www.pneumatictips.com/275/2009/02/pneumatic-equipment-components/actuators/hydraulic-devices-help-solar-collectors-track-sun/

Pasolini, F. (2011). MEMS Accelerometers, Gyroscopes, and Geomagnetic Sensors - Propelling Disruptive Consumer Applications.
Available at: http://www.digikey.com/en/articles/techzone/2011/apr/mems-accelerometers-gyroscopes-and-geomagnetic-sensors---propelling-disruptive-consumer-applic

Pattanasethanon, S. (2010). The Solar Tracking System by Using Digital Solar Position Sensor. *American Journal of Engineering and Applied Sciences*, vol. 3, no. 4, pp. 678–682.

Pearce, J. (2014). Open source solar spectrum project. *Developed by The Universidad Privada Boliviana*, pp. 1–4.
Available at: http://www.appropedia.org/Open_source_solar_spectrum_project

Pepperl Fuchs (2014). inductive position coding system. *PCI application in Solar Tracking Systems, Effective sensor solution for rotary joints and slewing bearings*, pp. 1–3.
Available at: http://www.pepperl-fuchs.com/global/en/15517.htmhttp://www.pepperl-fuchs.com/global/en/15172.htm

Petrov, L. (2014). Solar Tracking Strategies: Source Code Written for the Project.
Available at: http://sts.ustrem.org/sCode.php

Pixart (2014). Multi Object Tracking Sensor.

PlanMyPower (2014). Alternative power solutions with Plan My Power.
Available at: http://www.planmypower.co.za/

Pneumatics (2014). Actuator Solutions for Solar Tracker Movement.
Available at: http://www.pneumatictips.com/274/2009/02/pneumatic-equipment-components/actuators/actuator-solutions-for-solar-tracker-movement/http://www.pneumatictips.com/275/2009/02/pneumatic-equipment-components/actuators/hydraulic-devices-help-solar-collectors-track-sun/

Powell, K. (2011). Dynamic optimization of energy systems with thermal energy storage. *Preliminary Research Proposal, Austin, Texas, USA*, , no. June, pp. 1–26.
Available at: http://apmonitor.com/wiki/uploads/Main/apm_energy_storage_13Dec11.pdf

Prinsloo, F. (2013). Impact of renewable energy structures on tourism.
Available at: http://www.researchgate.net/publication/262948582_The_impact_of_renewable_energy_structures_on_tourism

Prinsloo, G. (2014*a*). Infrared PixArt camera multiple object tracking based solar tracking. *Project on solar tracking sensors (in progress)*, pp. 1–5.

Prinsloo, G., Dobson, R. and Schreve, K. (2013*a*). Carbon Footprint Optimization as PLC Control Strategy in Solar Power System Automation. *Energy Procedia*, vol. 49, pp. 2180–2190. ISSN 18766102.
Available at: http://linkinghub.elsevier.com/retrieve/pii/S1876610214006857

Prinsloo, G., Dobson, R. and Schreve, K. (2013*b*). Mechatronic Platform with 12m2 Solar Thermal Concentrator for Rural Power Generation in Africa. *Energy Procedia*, vol. 49, pp. 1470–1480. ISSN 18766102.
Available at: http://linkinghub.elsevier.com/retrieve/pii/S1876610214006109

Prinsloo, G.J. (2014*b*). *Automatic positioner and control system for a motorized parabolic solar reflector by*. Ph.D. thesis, Stellenbosch University.

PSA (2014*a*). Plataforma Solar De Almería SunPos Algorthm in C.
Available at: http://www.psa.es/sdg/sunpos.htm

PSA (2014*b*). Solar photochemistry technology. *Plataforma Solar de Almería*, pp. 1–19.

PVEducation (2014). Solar Radiation on a Tilted Surface Sun's Position and Radiation DNI.
Available at: http://pveducation.org/pvcdrom/properties-of-sunlight/arbitrary-orientation-and-tilthttp://pveducation.org/pvcdrom/properties-of-sunlight/solar-radiation-on-tilted-surface

Pyle, W.R. (1983). Photo Separatory Nozzle.

Pzarch (2012). Bucharest Sun Shading Analysis.
Available at: http://pzarch14.wordpress.com/2012/12/09/henri-coanda-int-airport-terminal-2-systems-application/

Qnergy (2013). Meeting Todays Energy Production and Distribution Challenges with Combined Heat and Power (CHP) Systems. *En-Harod Ihud*, vol. Volume 1.
Available at: http://www.qnergy.com/sites/Qnergy/UserContent/files/Qnergy_Brochure_v1.pdf

RA Mayes (2014). Antenna Positioners.
Available at: http://www.ramayes.com/Antenna_Positioners.htm

Ray, S. (2012 September). Calculation of Sun Position and Tracking the Path of Sun for a Particular Geographical Location. *International Journal of Emerging Technology and Advanced Engineering*, vol. 2, no. 9, pp. 81–84. ISSN 03601285.
Available at: http://linkinghub.elsevier.com/retrieve/pii/S0360128506000244http://www.ijetae.com/files/Volume2Issue9/IJETAE_0912_12.pdf

Reda, I. and Andreas, A. (2008*a*). Solar Position Algorithm for Solar Radiation Applications. *Solar Energy*, vol. 76, no. 5, pp. 577–589.

Reda, I. and Andreas, A. (2008*b*). Solar Position Algorithm for Solar Radiation Applications. *Solar Energy*, vol. 76, no. 5, pp. 577–589.

Reddy, K.S. and Veershetty, G. (2013). Viability Analysis of Solar Parabolic Sish Stand-alone Power Plant for Indian Conditions. *Applied Energy Elsevier*, pp. 908–922.

RedSolLAC (2014). Solar tracker (Seguidor Solar).
Available at: http://redsollac.org/nuevo/solar-tracker-seguidor-solar/

Reflectech (2014). ReflecTech Plus mirror film is a silvered polymer film.
Available at: http://www.reflectechsolar.com/technical.html

RenuSol (2014). SRT/Renusol: Solar pyramid nominated for Solar Power Portal Award.

ResidentialSolar (2010). Solar Energy Monitoring Systems The Next Big Thing in Solar?

ReynardCorp (2014). Thin Film Coatings: Custom.
Available at: http://www.reynardcorp.com/optical-production-capabilities/thin-film-coatings-custom.html

RFHamdesign (2014). 3 Meter MESH DISH KIT (F/D=0.4 - 0.45).
Available at: http://www.rfhamdesign.com/products/parabolicdishkit/

3meterdishkit/index.phphttp://www.rfhamdesign.com/products/parabolicdishkit/index.php

Rockwell Automation (2012). A Rockwell Automation White Paper on Solar Tracking Application, Rockwell Automation, USA.
Available at: http://literature.rockwellautomation.com/idc/groups/literature/documents/wp/oem-wp009_-en-p.pdf

Romero, M., Buck, R. and Pacheco, J. (2002). An Update on Solar Central Receiver Systems, Projects, and Technologies.

Rosen, N. (2008). *How to Live Off-grid*. Random House Publishers. ISBN 9780553818192.
Available at: http://www.randomhouse.co.nz/books/nick-rosen/how-to-live-off-grid-9780553818192.aspx

Rotolo, G.E. (1980). Sun position sensor for two axis tracking.
Available at: http://www.google.com.ar/patents/US4361758

Rudra, S. (2013). Design and system analysis of quad-generation plant based on biomass gasification integrated with district heating. *PhD Thesis, AAlborg University*, , no. April, pp. 18–53.

S. Byrnes, Romain Blanchard, F.C. (2014). Harvesting renewable energy from Earths mid-infrared emissions. *Proceedings of the National Academy of Sciences*, vol. 111, no. 11, pp. 1–9.

Sabry, M.S. and Raichle, B.W. (2014). Determining the accuracy of solar trackers. *Department of Technology and Environmental Design Appalachian State University Katherine Harper Hall Boone, NC 28608*, pp. 1–8.

Sanchez, J. (2012). Project construction and programming of a solar tracker. Proyecto de construcción y programación de un seguidor solar.
Available at: http://jsbsan.blogspot.com/2012/12/proyecto-de-construccion-y-programacion.html

Sawubona (2014 August). Off the Grid in the Bush. *South African Airways*, pp. 68–73.

Scherrer, P. and Scherrer, D. (2014). Solstice and Equinox (Suntrack) Model. *Stanford Solar Center in Collaboration with NASA*.
Available at: http://solar-center.stanford.edu/AO/Sun-Track-Model.pdf

Schlegel, G. (2003). A TRNSYS Model of a Hybrid Lighting System by. *Master of Science Mechanical Engineering, University of Wisconsin Madison*, pp. 1–4.

Schlyter, P. (2014). Computing planetary positions, a tutorial with worked examples.
Available at: http://www.stjarnhimlen.se/comp/tutorial.html#5

Schneider (2012). StruxureWare Central Mobile Application for BlackBerry and Smartphones. *Schneider Electric*, pp. 4–7.

Schneider (2014*a*). Solar powered variable speed drives for 200V/400V, 3 phase AC. *Schneider Electrical*.
Available at: http://www.ops-ecat.schneider-electric.com/ecatalogue/browse.do?cat_id=BU_UNDEFINED_62208_L3&conf=seo_designer&el_typ=node&nod_id=0000000001&page=1

Schneider (2014*b*). StruxureWare Energy Data Center Operation and Monitoring. *Data Center Infrastructure Management (DCIM) software*, , no. Dcim.
Available at: http://www2.schneider-electric.com/documents/solutions/

struxureware/StruxureWare-data-center-operation_RMCR-8N2PLE_R7_EN.pdf

Schneider Electric (2013). MiCROSOL collaborative project inaugurates its first demonstrator. Available at: http://www2.schneider-electric.com/sites/corporate/en/press/press-releases/viewer-press-releases.page?c_filepath=/templatedata/Content/Press_Release/data/en/shared/2013/11/20131120_the_microsol_collaborative_project_inaugurates_its_first_demonstrator_.xmlhttp://en.starafrica.com/news/africa-schneider-electric-inaugurate-a-technology-for-producing-electricity-drinking-water-and html

Schnitzer, D., Lounsbury, D.S., Carvallo, J.P., Deshmukh, R., Apt, J. and Kammen, D.M. (2014). Microgrids for Rural Electrification : A critical review of best practices. Tech. Rep., University California Berkeley, Carnegie Mellon University.
Available at: http://wpweb2.tepper.cmu.edu/ceic/pdfs_other/Micro-grids_for_Rural_Electrification-A_critical_review_of_best_practices_based_on_seven_case_studies.pdf

Schroder, A. (2014). How much power do solar thermal collectors produce. *Fort Mitchell, KY, U.S.A., info@AndySchroder.com*, pp. 1–2.
Available at: http://andyschroder.com/SolarEnergyResearch/SolarCollectorPowerOutput

Schroeder, D. (2011). The Sun and the Seasons.
Available at: http://physics.weber.edu/schroeder/ua/SunAndSeasons.htmlhttp://physics.weber.edu/schroeder/sky/SkyMotionApplet.html

Seligman, S. (2014). Java applet code to calculate the sunrise, sunset, and solar noon given longitude and latitude coordinates.
Available at: http://www.scottandmichelle.net/scott/code/

Shanmugam, S. and Christraj, W. (2005). The tracking of the sun for solar paraboloidal dish concentrators. *Journal of Solar Energy Engineering*, vol. 127, no. 1, pp. 156–160.

Sharma, R. and Zhang, X. (2013). Optimal energy management of a rural microgrid system using multi-objective optimization.
Available at: http://www.google.com/patents/US20130024014

Shelef, B. and Erez, S. (2011). Solar Receiver on Lightweight Solar Reflector, US Patent US20110247679.
Available at: http://www.google.com/patents/US20110247679

Shibata, M. and Toyokazu, T. (2000). Dual Axis Light Sensor for Tracking Sun. *University of Toyama*, , no. Extended, p. 91.

Siegel, E. (2014). Why Our Analemma Looks like a Figure 8.
Available at: http://scienceblogs.com/startswithabang/2009/08/26/why-our-analemma-looks-like-a/

Siemens (2010*a*). Flexible PV Solar Tracker control with analogue feedback Applikationen & Tools.

Siemens (2010*b*). Flexible PV Solar Tracker control with analogue feedback Applikationen & Tools. *Siemens A.G.*, pp. 1–30.

Siemens (2011*a*). Control of CPV Solar Trackers: Applications & Tools, Siemens AG, Germany.
Available at: http://www.industry.usa.siemens.com/topics/us/en/solar/

solar-north-america-events/IntersolarNorthAmerica2012/Documents/Siemens_solar_tracking_control.pdf

Siemens (2011*b*). Smart Grid Innovation Contest.
Available at: https://www.smartgridcontest.com/about.php?tabs[]=about_contest

Siemens (2013*a*). How to Exploit Sunlight Toward Maximum Energy Yield. The Universal Solution for Solar Tracking Applications, Siemens AG, Germany.

Siemens (2013*b*). Spectrum Power TG Weather Adaptive Load Forecast.
Available at: http://w3.usa.siemens.com/smartgrid/us/en/microgrid/Documents/Spectrum-Power-TG_Weather-Load-Forecast.pdf

SKA (2007). KAT prototype update.
Available at: http://www.ska.ac.za/newsletter/issues/05/07.htmlhttp://www.ska.ac.za/newsletter/issues/06/02.html

SKF (2013). Tracking a star to power a planet: SKF solutions for the solar industry. *SKF Group portfolio of solar tracking solutions*, pp. 1–6.

SKF (2014). Motor encoder units.
Available at: http://www.skf.com/group/products/bearings-units-housings/engineered-products/sensor-bearing-units/motor-encoder-units/index.html

SMA (2014). SOLTRK Control unit for PV tracking systems. *SMA Technologie AG Hannoversche Strasse 1-5 34266 Niestetal Germany*, , no. NF11ST3xxAC, pp. 1–32.

Smith, R. and Cohn, L. (2010). Solar Support, Products and Solutions in the Solar Technology and Machine & Plant Manufacturing, IMO Anlagenbau GmbH, Germany. pp. 131–133.
Available at: http://www.energysmith.net/articles/heliofocus.pdf

Smith, T. (2007). Solar Technology Workshops. *Infinia Corporation*, , no. March.

SODA (2014). Time Series of Solar Radiation Data - for Free.
Available at: http://www.soda-is.com/eng/services/services_radiation_free_eng.php

Soitec (2014). Technology, Concentrix.

SolarChoice (2014). Solar Panel Tilt and Orientation in Australia.

SolarGIS (2014). Free Download of Solar Radiation Maps: Global Horizontal Irradiation (GHI).
Available at: http://solargis.info/doc/free-solar-radiation-maps-GHI

SolarMEMS (2013). Sun Sensor ISS-AX Technical Specifications, Solar MEMS Technologies S.L., Sevilla, Spain.

SolarMir (2013). High Reflection Composite Material.
Available at: http://xxentria-europe.com/wp-content/uploads/2013/04/SolarMir_ACP_technical_datas.pdf

SolarTech (2014). Sun tracking system automatically changes the angle of the solar panels,.
Available at: http://solar-tech.com.ua/

Solartron (2013). SolarBeam 7M Parabolic Concentrator, Solartron Energy Systems Inc., Nova Scotia, Canada.

Available at: http://www.solartronenergy.com/solar-concentrator/specifications/

Solidiance (2013). Chinas Renewable Energy Sector: An Overview of Key Growth Sectors. *Solidiance*, , no. January, pp. 1–7.
Available at: %http://www.solidiance.com/whitepaper/china-renewable.pdf

Solidworks (2014). 3D Solidworks. *Solidworks Corporation, USA*, pp. 1–3.
Available at: http://www.solidworks.com/

Sopogy (2014). Sopogy Solar Thermal Solar Power Systems Solar Air Heating Solar Panels Solar Generator. *Sopogy Solar Collectors Solar Solutions Solar Air Conditioning Solar Concentrators Solar Electricity Industrial Solar*.

SouthernStars (2014). SkyCube Satellite Technology.
Available at: http://www.southernstars.com/skycube/satellite.html

Southwest Solar Technologies (2013). SolarCAT Turbo Generator Solution, Brayton Energy, Hampton, USA.
Available at: http://www.braytonenergy.net/hybrid-solar/#solarcat

SparkFun (2014*a*). EasyDriver Stepper Motor Driver.
Available at: https://www.sparkfun.com/products/10267

SparkFun (2014*b*). Face Tracking with a Pan/Tilt Servo Bracket.
Available at: https://www.sparkfun.com/tutorials/304

Sproul, A. (2007). Derivation of the solar geometric relationships using vector analysis. *Renewable Energy*, vol. 32, no. 7, pp. 1187–1205.

Stadler, M., Lai, J., Marnay, C. and Berkeley, L. (2008). Distributed Energy Resources On-Site Optimization for Commercial Buildings with Electric and Thermal Storage Technologies , the Distributed Energy Resources - Costumer Adoption Model (DER-CAM). pp. 331–342.

Stadler, M., Marnay, C., Cardoso, G., Donadee, J., Wang, S., Feng, W., Lai, J., Bhattacharya, P. and Mégel, O. (2013). WebOpt User Manual, DER Web Optimization Service (WebOpt):. *Lawrence Berkeley National Laboratory (LBNL)*, vol. Version 2., no. 1.26, pp. 1–32.

Stadler, Michael, Gonçalo Cardoso, Nicholas DeForest, Jon Donadee, Tomás Gómez, Judy Lai, Chris Marnay, Olivier Mégel, Gonçalo Mendes and Siddiqui, A.S. (2011). Smart buildings with electric vehicle interconnection as buffer for local renewables? *Researching the Intelligent City: Key Challenges of Integrating Urban Energy and Mobility Systems Research Symposium*, vol. May 2011.

Stan, M., Aiken, D., Cho, B., Cornfeld, A., Diaz, J., Ley, V., Korostyshevsky, A., Patel, P., Sharps, P. and Varghese, T. (2008). Very high efficiency triple junction solar cells grown by MOVPE. *The 14th International conference on Metalorganic Vapor Phase Epitax*, vol. 310, no. 23, pp. 5204–5208.

Stanford (2014). Stanford Solar and Wind Energy Project: Wind Data from the Dish Station, 2003 - 2006:.
Available at: http://web.stanford.edu/group/atmosenergy/swep/data/dish/

Stine, W.B. and Geyer, M. (2001). *Power from the Sun, Published online by William B. Stine and Michael Geyer*.
Available at: http://www.powerfromthesun.net/book.html

STMicroelectronics (2014). MEMS and Sensors.
Available at: http://www.st.com/web/en/catalog/sense_power/FM89

Stone, K. and Rodriguez, G. (2001). Solar receiver adaptive tracking control.
Available at: http://www.google.com/patents/US6442937

Strobel, N. (2014). The stars rotate around the North and South Celestial Pole.
Available at: http://www.astronomynotes.com/nakedeye/s4.htmhttp://www.astronomynotes.com/nakedeye/s5.htm

Sunearthtools (2014). Tools for consumers and designers of solar.
Available at: http://www.sunearthtools.com/dp/tools/pos_sun.php

SunPower (2014*a*). Reduce your energy bills, not your curb appeal. *SunPower Mobile application*, pp. 1–2.
Available at: http://us.sunpower.com/homes/products-services/monitoring/

SunPower (2014*b*). SunPower SCADA provides the visibility to better manage your energy output.
Available at: http://global.sunpower.com/products/oasis-power-plant/

SunPy (2014). Free and open-source solar data analysis environment for Python.
Available at: https://github.com/sunpy/sunpy/blob/stable/doc/source/index.rst

Sunsurveyor (2014). Sun Surveyor: The Sun & Moon Position Visualization and Tracking App for iOS & Android.
Available at: http://www.sunsurveyor.com/

SunTracking (2014). SunTracking Prototype-Kit.
Available at: http://www.suntracking.es/en/products/suntracking-prototype-kit

Tanner, J. (2014). VB version of the complete VSOP87 planetary theory designed to be used to in a program to compute the heliocentric ecliptic longitude, latitude and distance of the planets.

Taylan, O. and Berberoglu, H. (2013). *Fuel Production Using Concentrated Solar Energy*. ISBN ISBN 978-953-51-0969-3.

ThermoSolGlass (2014). CSP System utilizes mirrors to redirect and concentrate solar radiations to heat fluids that are used to drive electric generators.
Available at: http://www.thermosolglass.com/solar/index.php?option=com_content&view=article&id=55&Itemid=127

TitanTracker (2013). Titan Tracker, Solar Parabolic Dish Concentrator Stirling, Cabanillas Ingenieros, Castilla-La Mancha, Spain.
Available at: http://www.titantracker.es/v_portal/informacion/informacionver.asp?cod=1229&te=720&idage=1491&vap=0

Treasury (2010). Reducing Greenhouse Gas Emissions: The Carbon Tax Option, Discussion Paper, Department of National Treasury, South Africa.
Available at: http://www.treasury.gov.za/publiccomments/DiscussionPaperCarbonTaxes81210.pdf

Tri-Sports Dasboard (2014). Solar-Dashboard.

Trigeneration (2014). Trigeneration, Demand Side Management, District Energy, Micro-Grid and Net Zero Energy Solutions.
Available at: http://www.trigeneration.com/

Tsadka, S., Segev, R., Migalovich, P., Levin, O., Tarazi, E. and Whelan, R. (2008). Solar Electricity Generation System, PCT Patent WO2009034573 A3.

Tsoutsos, T., Gekas, V. and Marketaki, K. (2003). Technical and Economical Evaluation of Solar Thermal Power Generation. *Renewable Energy*, vol. 28, no. 6, pp. 873–886.
Available at: https://www.etde.org/etdeweb/details_open.jsp?osti_id=20327746

UC Solar (2014). Full-Spectrum Photovoltaic-Photothermal Concentrator System. pp. 1–2.

V3Solar (2014). V3 Solar Dynamic Spin Technology. *V3Solar Corporation, Delaware , USA*.
Available at: http://v3solar.com/technology-2/

Vandenbrink, J.P., Brown, E.a., Harmer, S.L. and Blackman, B.K. (2014 July). Turning heads: the biology of solar tracking in sunflower. *Plant science : an international journal of experimental plant biology*, vol. 224, pp. 20–6. ISSN 1873-2259.
Available at: http://www.ncbi.nlm.nih.gov/pubmed/24908502

Vernier (2014). Solar Power at Vernier Software & Technology.
Available at: http://www.vernier.com/files/solar/vernier_solar.pdfhttp://www.deckmonitoring.com/solar-monitoring/solar-thermal.htmlhttp://live.deckmonitoring.com/?id=the_college_of_wooster

VFDs (2014). What is a variable frequency drive ? *VFDs, 501 West 700 South Salt Lake City, UT 84101*, pp. 1–4.
Available at: http://www.vfds.com/blog/what-is-a-vfd

VTP (2014). Virtual Terrain Project foster the creation of tools for easily constructing any part of the real world in interactive, 3D digital form.

Walker, G.S. (2013). Development of a Low Cost Linear Fresnel Solar Concentrator. *Master of Science in Engineering (Mechanical) in the Faculty of Engineering at Stellenbosch University*, , no. December, pp. 1–121.

Wallentin, J., Anttu, N., Asoli, D., Huffman, M., Å berg, I., Magnusson, M., Siefer, G., Fuss-Kailuweit, P., Dimroth, F., Witzigmann, B., Xu1, H.Q., Samuelson, L., Deppert, K. and Borgström, M.T. (2013). InP Nanowire Array Solar Cells Achieving 13.8% Efficiency by Exceeding the Ray Optics Limit. *Solid State Physics, Lund University, Box 118, 22100 Lund, Sweden.*, , no. January, pp. 62–90.

WGAssociates (2001). Solar Dish Stirling Power Systems, WGAssociates Texas, USA.

Wilson, L. (2014). Solar energy moves into a brighter future. *Joyce Dayton Inc.*, pp. 1–30.
Available at: http://www.joycedayton.com/sites/default/files/pdfs/ApplicationSolution#114.pdf

Winkler, H. (2005 January). Renewable energy policy in South Africa: policy options for renewable electricity. *Energy Policy*, vol. 33, no. 1, pp. 27–38. ISSN 03014215.
Available at: http://linkinghub.elsevier.com/retrieve/pii/S0301421503001952

WinRadio (2014). WR-ARP-ELAZ-100 Antenna Rotator/Positioner with WR-RCU-100 Controller.
Available at: http://www.winradio.com/home/arp-elaz-100.htm

Wood, T. (2010). Climate Analysis Using Autodesk Ecotect Weather Tool and Solar Tool, Integrated Design Lab, Montana State University, USA. Montana.
Available at: http://www.idlbozeman.com/storage/pdfs/Part3WeatherSolarCompatibilityMode.pdf

Woodbank (2014). Solar Power (Technology and Economics). *Woodbank, South Crescent Road , Queens Park Chester, CH4 7AU United Kingdom*, pp. 1–5.

WorlDiscoveries (2014). Dual-axis solar tracker.
Available at: http://worldiscoveries.asia/cn/technologiescn/????????/

Xayin (2014). SunPlan Augmented Reality Sun path diagram app for Android.
Available at: http://xayin.com/sunplan.html

Xie, N. and Theuwissen, A.J.P. (2013). Low-power high-accuracy micro-digital sun sensor by means of a CMOS image sensor. *Journal of Electronic Imaging*, vol. 22, no. 3.
Available at: http://electronicimaging.spiedigitallibrary.org/article.aspx?articleid=1741911

Xinhong, Z., Zongxian, W., Zhengda, Y. and Yingzhe, H. (2007). Intelligent Solar Tracking Control System Implemented on an FPGA. *Institute of Electrical Engineering, Yuan Ze University*, pp. 217–246.

Xinilogy (2014). Solar Parabolic Mirror Reflectors for CSP n CPC Concentrating Solar Power n Solar Thermal Systems.
Available at: xinology.com:888/Glass-Mirrors-Products/CSP/applications.htmlhttp://xinology.com:888/Glass-Mirrors-Products/CSP/introduction.html

Yedamale, P. (2003). Brushless DC motor Fundamentals, Microchip Technology Application Note-AN885.
Available at: http://ww1.microchip.com/downloads/en/AppNotes/00885a.pdf

Yokogawa (2014). Solar Power Generation -Features of the HXS10 SolStation Solar Tracking Controlery: Built-In Solar Position Algorithm. *Yokogawa Electric Corporation, Solar Power Generation -Making Use of Solar Energy- Volume 1*, , no. 1-8.
Available at: http://www.yokogawa.com/ns/support/onepoint/hxs10/ns-onepoint-hxs02.htm

Zhu, L.-Y. (2002). Making a Parabolic Reflector Out of a Flat Sheet.

Zidani, C., Benyoucef, B. and Madini, N. (2013). Theoretical thermal limits of photothermal system based on the idea of transmission solar energy via optical fibers. *International Journal of Thermal Technology (JITH 2013), Marrakech (Maroc), 15 November 2013*, , no. November, pp. 1–6.

Zimmermann, N. (2014). Climate Data Analysis Programs.
Available at: http://www.wsl.ch/staff/niklaus.zimmermann/programs/f77.html

LIST OF FIGURES

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ACRONYMS

Abbreviations and Acronyms

A	Area (m^2)
ADC	Analog-to-Digital Converter
AI	Artificial Intelligence
BTU	British Thermal Units
BBC	Backup Battery Capacity
CAD	Computer Aided Design
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CO_2	Carbon Dioxide
CFD	Computational Fluid Dynamics
CG	Centre of Gravity
CPU	Central Processing Unit
CSP	Concentrating Solar Power
CMOS	Complementary Metal Oxide Semiconductor
CPV	Concentrated Photovoltaic
CNC	Computer Numerical Control
DAC	Digital to Analog Converter
D	Diameter (m)
DC	Direct Current
DNI	Direct Normal Irradiation
DNSI	Direct Normal Spectral Irradiance
FFT	Fast Fourier Transform
FPGA	Field Programmable Gate Array
FPSE	Free-piston Stirling Engine
FTIR	Fourier Transform Infrared
GIS	Geographic Information System
F	Parabolic Focal Point
FC	Fuzzy Control
GPS	Global Positioning System
GUI	Graphic User Interface
HCPV	High Concentration Photovoltaics
HMI	Human Machine Interface
IP	Internet Protocol
IR	Infra Red
IRP	Integrated Resource Plan
ISP	Image Signal Processing
I2C	Inter-Integrated Circuit
LED	Light Emitting Diode
LDR	Light Dependent Resistor

MEMS	Micro Electrical Mechanical System
MOT	Multi Object Tracking
MPPT	Maximum Peak Power Tracking
MSA	Maximum Solar Altitude (e.g. 12pm)
P	Power (W)
PCU	Power Conversion Unit
PDS	Parabolic Dish System
PLC	Programmable Logic Controller
PSH	Peak Sun Hours
PV	Photovoltaic
PWM	Pulse-Width Modulation
R&D	Research and Development
RE	Renewable Energy
RTC	Real Time Clock
RMS	Root Mean Square
RPM	Revolutions Per Minute
SCADA	Supervisory Control and Data Acquisition
SE	Stirling Engine
SI	International System of Units
SNR	Signal to Noise Ratio
SPA	Solar Position Algorithm
TCP	Transmission Control Protocol
TES	Thermal Energy System
UPS	Uninterruptible Power Supply
UV	Ultraviolet
W	Work (J)
2D	Two-Dimensional
3D	Three-Dimensional
Q	Observer Location (GPS)

Finance and Economics

LEC	Levelized Energy Cost
SRB	Surface Radiation Budget

Companies, Institutions and Countries

ASTM	American Society for Testing and Materials
DOE	Department of Energy (South Africa)
DST	Departments of Science and Technology (South Africa)
EPIA	European Photovaltaic Industry Association
IITM	Indian Institute of Technology Madras

ESKOM	National Electricity Supplier (South Africa)
MDAC	McDonnell Douglas Astronomics
NASA	National Aeronautics and Space Administration (USA)
NREL	National Renewable Energy Laboratory (USA)
NRF	National Research Foundation (South Africa)
PSA	Plataforma Solar de Almerya
SA	South Africa
SCE	Southern California Edison Company (USA)
SES	Stirling Engine Systems (USA)
SoDa	Solar Energy Services for Professionals
STERG	Solar Thermal Energy Research Group
SUN	Stellenbosch University
UK	United Kingdom
USA	United States of America
USAB	United Stirling AB

SYMBOLS

Greek Letters

α	Angular sun position ref earth surface (degrees)
δ	Angular sun position ref equator (degrees)
ϕ	Latitude of installation
ζ	Longitude of installation
S	Sun vector or solar vector
δ	Declination solar noon ref to equator (degrees)
β	Slope angle horizontal (degrees)
ω	Hour angle solar time
γ	Azimuth angle (degrees)
θ	Elevation angle (degrees)
f	Parabolic focal distance (m)
ϵ	Solar tracking deviation error (degrees)
Δ	Solar tracking angle resolution (degrees)
λ	Wavelength
η	Efficiency of receiver
η_t	Total system efficiency (solar receiver and heat conversion)

Lowercase Letters

kB	kilobytes
kW_e	kilo Watt electrical
kW_t	kilo Watt thermal
kW	kilowatt, or 1000 Watts, a unit of power.
kWh	kilowatt-hour, equivalent to kilo x 3600 sec) = 3,600,000 Joules

Subscripts

a	ambient
az	azimuth
c	concentrator
e	electrical
el	elevation
m	mean
p	predicted
q	observer
s	sun/solar
t	thermal
z	zenith

GLOSSARY

Algorithm	A set of instructions that combine to accomplish a task, such as computer coded algorithms.
Azimuth Angle	The angle between the horizontal direction (of the sun, for example) and a reference direction (usually North, although some solar scientists measure the solar azimuth angle from due South).
Calibration	The process of comparing an instrument's output signal with reality.
Certified Reduction	A carbon credit created by a Clean Development Mechanism project.
Elevation Angle	The angle between the direction of interest (of the sun, for example) and the horizontal plane zenith (surface of the earth).
Insolation	Solar radiation on the surface of the Earth.
Irradiance	The rate at which radiant energy arrives at a specific area of surface during a specific time interval, also known as radiant flux density. A typical unit is W/m^2.
Latitude	The angular distance from the equator to the pole. The equator is 0°, the North Pole is 90° North, and the South Pole is 90° South.
Longitude	The East-West angular distance of a locality from the Prime Meridian. The Prime Meridian is the location of the Greenwich Observatory in England and all points North and South of it.
Photovoltaic	Technology for converting sunlight directly into electricity, usually with photovoltaic cells.
Pyranometer	An instrument with a hemispherical field of view, used for measuring total or global solar radiation, specifically global horizontal radiation;

	a pyranometer with a shadow band or shading disk blocking the direct beam measures the diffuse sky radiation.
Pyrheliometer	Instrument with a narrow (circumsolar) field of view which measures direct normal irradiance. Pyrheliometers are mounted on sun-following trackers so that the instrument is always aimed at the sun.
Solarimeter	An instrument for measuring the intensity of electromagnetic radiation.
Solar Receiver	A device that receives solar energy and converts it to useful energy forms.
Solar Tracking	Following the contour of the apparent movement of the sun as it progresses throughout the day.
Scattered Radiation	Radiation that has been reflected from particles, disrupting the original direction of the beam.
Solar Collector	A device that receives solar energy and converts it to useful energy forms.
Solar Concentrator	A solar collector that enhances solar energy by focusing it onto a smaller area through mirrored surfaces or lenses.
Solar Constant	Strictly more an average, this number is the amount of solar power flux that passes through the mean earth orbit, the currently accepted average value is 1366 W/m^2.
Solar Irradiance	The amount of solar energy that arrives at a specific area of a surface during a specific time interval (radiant flux density). A typical unit is W/m^2.
Solar Spectrum	The electromagnetic spectral distribution emitted by the sun or received by a collector or instrument on earth.
Sun Position	Same as Sun Vector, the location of the sun in the sky, expressed in terms of azimuth angle and zenith angle.
Wind Rose	Polar graphs that indicate the speed and relative duration of wind according to its direction.
Zenith Angle	The angle between the direction of interest (of the sun, for example) and the zenith (directly overhead).

Keywords Tags Tag Cloud Topics Tagged with:

Tracking the Sun Calculation of Sun Position Tracking Path of Sun Real-time Tracking Sun Position Calculator Solar Tracker Sun Tracker Actuator for Solar Tracker Sun Position Tracking Apps sun tracking podcast sun tracking positioner podcasting ebook self sufficient house building building off the grid energy autonomous house eco estate Sun-Calc sun position sunlight phases sunrise sunset sun tracker used as positioner sun tracking with position display Sun position tracking Sun position sensor two axis tracking Solar resource Tracking Tools Tracking the Sun tracking the Moon Pointing Sensors Sun Tracking Techniques Solar tracking device Sun-Tracking Controller Solar Collector Sun tracking solar panel Arduino Controlled Sun Tracking Solar Panel grid deprived rural village Microgeneration from renewable non-renewable sources Soltrain Solar heat for industrial applications Solar tracker Target acquisition and tracking system solar tracking algorithm matlab tutorial 3D CAD design collaborative design tools Optomechanics Motion Control Optical Tables Brackets Rails Base Mounts Accessories Optical Mounts Optical Positioners Base Positioners Translation Rotation stages Motorized Positioners Controllers Fine Adjustment Screws Control Positioner circuit diagram of sun tracker multi-target tracking algorithm adaptive cruise control Literature review on off grid moon tracking algorithm Equations for Solar Tracking reference algorithm Jean Meeus scheduler solar remote power system specific heat thermodynamic property OpenDSS project electricdss pv panel-solar energy solar tracker sun position-toolbox simulink matlab aerospace altaltitude astronomy azazimuth coordinates declination elevation equatorial horizontal julian day right ascension mathworks Receiver Plane Illumination Profile Ray Tracing Light-Trapping Structures Ray Tracing luminescent solar collector 3-d ray tracing Calculation Sun Position Tracking Computer Programming sun path where is the sun computing sun position Program Matlab building GUI Tools JPL Planetary Lunar Ephemerides galaxy dynamics Astrodynamic Constants Date/Time Converter Temperature Heat transfer Cooling Turbines Syngas Hydrogen Steam Heat transfer coefficients Airfoils Pressure solar sails solar dance ephemeres diy solar projects thermocline Sun Position Tracking pdf Owners Manual Download Sun Surveyor sun Moon position Visualization sun position tracking visualization tracking app ios android calculates sun moon positions sunrise sunset moonrise Microcontroller Based Solar Tracking System Intelligent Solar Tracking Control System Mechanical Electrical Software Team Design Prototyping solar tracking device Photovoltaic Efficiency Solar Angles Tracking Systems Calculation Sun Position Tracking Path Sun Robotics Automation Robotics Matlab Simulation PLC Programming PLC Computer Systems Engineering Computer Architecture computer engineer Masters degree Computer Architecture Digital Design Digital System Design Parallel Processing multicores distributed computers Image Processing Computer Vision Machine Learning Machine Vision Image Data Analysis Clustering Unsupervised Learning Face Recognition Solare Termodinamico Concentrazione Trinum Innova Solar Trackers Facing the Sun Solar Position Algorithm for Sun-Tracking Equations for Solar Tracking geometrical formulas Calculation of Sun Position Tracking the Path of Sun Rotation Angle for the Optimum Tracking of One-Axis Trackers Sun-tracking Open Source Solar azimuth angle smart poligeneration polygeneration Termoidraulica Riscaldamento Condizionamento Energie Alternative Infrastruttura tecnologica della microrete energia termica un impianto fotovoltaico Virtual Power Plant VPP elemento essenziale per la gestione di Microgrid Moontrack Software System Set-up Luminescent Solar Concentrator Squeezing Sun-Light sun position arduino code Bonfiglioli reducers Micro-motors Servo hybrid drive Power transmission Micro drive IP66 Hydraulik Oerlikon fairfield Black bruin Torque sensor Introduction to opensocial cloud tracking Parabolic solar cooker designs Solar cooker designs Solar calculations Absorber tube collector temperature Zenith Design Central Drive Gearboxes Golden Root Geometry Solar Path Structuring Polyhedra Plato Triangle Quadrature of Circle Data mining deep learning machine learning datasets artificial intelligence big data GPS sun tracking formula algorithm angle Sun path contour Solar contour Tools and Knowledge Sharing Platforms Geospatial Toolkit NREL developed the Geospatial Toolkit—a map-based software application that integrates resource data and geographic information systems (GIS) to enable countries to identify prime sites for renewable energy development NREL developed toolkits for Brazil, China, Ghana, India, and developed toolkits and resource maps for Afghanistan, Bhutan, Northwest India, and Pakistan Global Solar Opportunity Tool Developed by NREL for the Clean Energy Solutions Center and countries around the world, the Global Solar Opportunity Tool enables analysis and visualization of the technical and economic potential for solar electric technologies ranging from residential rooftop systems to utility-scale installations OpenEI Open Energy Information NREL created collect share energy data inform policy development Open EI information gateways for low emission development strategies West African clean energy development Latin American clean energy development energy access and energy poverty solar and wind energy resource assessments Algorithmic Solar Tracking System Solar Collector design solar-tracking heliostat mount Tracking Solar Concentrators Structural Dynamic Interaction Control of Solar Energy Systems Solar Tracking Control Load requirement Remote Area Power Supply (RAPS) Load and Resource Profiles Solar Stirling engine mount liquid piston stirling Liquid piston tracker Real sky overcast sky conditions Solar fire thermal heat electrical system renewable energy system planning and design software modeling simulation energy usage system performance financial analysis solar wind hydro behavior characteristics usage profiles generation load storage calculations on-grid off-grid residential commercial system sizing utility rate plans rate comparison utility costs energy savings Power Consumption Energy Planning Energy Modelling Rural Residential Hourly Load Curves Conditional Demand Analysis Curves Appliance Penetration Levels Energy Policy Development Process Planning Home Appliances Databases Data Models Load Modeling Mathematical Model Equations Design Engineering Power Engineering And Energy Process Design Domestic Appliances Demand Side Management Engineering Appliance Hourly Load Curves Spherical solar collector alignment template unattended solar cooking Concentrators Super Solar Tracker Solar Ovens Spherical solar reflectors Parabolic solar reflectors Fresnel solar reflectors Cylindro-parabolic solar cookers Solar plane mirrors Solar lenses Solar panel cookers Solar funnel cookers Solar box cooker reflectors Solar panel cookers Indirect solar cookers Moving collector Horizontal single axis tracker (HSAT) Minitrack antenna system Baker-Nunn satellite tracking camera Panorama Solar guard Optikinetics Cinematography Earth-cam tracker-cam track solar storms Capture the sun energy passenger tracking system Solar ranch Map view street view Power module Solar pump Solar powered Solar trough Hho fuel Tower energy Tablet Controller Implosion Solar powered HHO Zero point energy PSCad Simapro Autolab Nova Power GUI block local community island local energy systems 3D Geo Information rural household load profile rural country energy systems Hyperlapse Comsol DiSilent Digisilent Auxiliary power unit Hydrogen molecule flammability Code Library Source Code Backup Code Code Librarian Code Snippet Code Snippet Manager Library Source Code Library Sourcebook Circumsolar magnification factor percent circumsolar radiation direct irradiance diffuse 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every point of the sky Accurate altitude–azimuth tracking angle formulas Azimuth-Altitude Dual Axis Solar Tracker Real-time Streaming information from solar tracking system telemetry Key-in on information PWM control method SPWM SVPWM optimization Determination angular parameters general altitude–azimuth tracking angle formulas for a heliostat with a mirror-pivot offset geometrical errors altitude and azimuth of north celestial pole altitude and azimuth of saturn altitude and azimuth of constellations altitude and azimuth of vega altitude and azimuth of sunrise altitude and azimuth of stars altitude and azimuth of moon altitude and azimuth of polaris Azimuth-Altitude Dual Axis Solar Tracker Waterproof and dust tight top-up pay-as-you-go using the coordinates of the sun to rotate servo motor Sun's Path Over My House Sun Track on Earth Map Sun Tracking Solar System Sun's Path Map Google Earth Sun Path Tracking The Sun VII Tracing the path of the Sun Sun path chart program UO Solar Radiation Monitoring Sun sail tracking sundial Ecliptic Sun's Annual Pathon the Celestial Sphere the track of the Sun Dni MySQL DBMS tool programming languages navicat MySQL GUI software Free Track sun path in google maps Download Track sun Universal Maps Downloader Solar Tracking Systems Suntrix Solar Panels Solar Tracking Systems low cost automatic sun path-tracking system sunPATH Sun TrackingSoftware Wide Screen sun tracking software for filmmakers and photographers Tracking the Sun Observing Path of the Sun Throughout the year the earth's tilt and the effect of the sun movement tess component libraries TESS Libraries TRNSYS Transient System relative humidity aerosol light-scattering sunlight sky imager for cloud cover assessment Agrometeorology parola chiave inseguimento solare inseguitore solare energia termica sole seguito posizionatore motorizzato energia rinnovabile Renewable Energy Technologies Concentrated Solar Power Controllo automatico Satellite tracking Oggetto di monitoraggio Smart Grid solari Sun monitoraggio energia solare Stirling microgrids Efficienza Energetica Exergia Analisi energetici gratuiti Concentrated Solar Power Automatic Control Satellite Tracking Object Tracking Smart Grid Solar Sun tracking Solar powered Stirling Microgrids Energy Efficiency Exergy Analysis Free Energy Moon Astronomy Agroecology Hydrogen Generation Hydrogen solar Collectors Renewable Energy Power-Generating Windows series elastic actuator sea robotic tracker Series elastic actuator control powered exoskeleton joint level cable-driven rotary Series Elastic Actuator MARIONET Moment arm Adjustment for Remote Induction Of Net Effective Torque deliver torque to joint remote actuation independent control Series elastic actuator high fidelity force control force-controlled hydro-elastic actuator Parallel Coupled Micro-Macro Actuator Differential Rheological Actuator Differential-Clutch Actuator Tactile sensor Robotic sensing Piezoelectric motor Electroactive polymers Shape memory alloy Pneumatic artificial muscles flywheel energy storage Damper Actuator dynamic behavior rotor-bearing thermal force reduction bearing support structure Compact Rotary Series Elastic Actuator (cRSEA) Electric Drives and Electromechanical Systems Controller Motor load Force feedback Motor Output Ball screw nut Ball screw Spring series elastic actuator Biologically Inspired Intelligent Robots Neuro-robotics Brain Machine Interfaces AC Servomotor Segmented Stator Technology elastic Linear Actuator kinematics dynamics non-Cartesian actuators robotics cobots Biomass pyrolysis carbonisation liquefaction gasification Biocarbon biochar for agriculture Small- to medium-scale raw heat to electricity Stirling engine organic Rankine cycle small steam engines turbines Distant offshore marine current power generation Biogas PlantFly Ash Organic Waste Eco-web Water-Energy-Food Nexus Vermiculture Biochar Agriculture Charcoal Industry Earth Preservation Agriculture Waste Management Thermal Treatment Recycling Material Transformation Composting Processes Power Generation Biomass Energy Combined Heat Power Generalised Disjunctive Programming GDP Simulation Modeling Programming Autonomous Solar Robotic rotary joint actuator Programmable Springs Compliant Actuators Spring Actuators Programmable Springs Robot Servo Robotics Spring Servo Hybrid state approach modelling electrical mechanical systems time series forecasting python load forecasting matlab time series forecasting matlab demand forecasting weather forecasting solar dni forecasting Forecasting electrical consumption by integration of Neural net Multi-horizon solar radiation forecasting Predicting solar radiation Time series modeling large scale global solar radiation Hourly solar irradiance time series forecasting using cloud cover index Embedded nowcasting cloud speed persistence photovoltaic power plant solar resource assessment and forecasting Masters M-Tech thesis on parabolic solar reflector using Matlab electrical drawing for the control of dual axis slewing system ephimeris photographer ephemeris almanac Sun-Tracker program Solar Motors ephemeris software ephemeris data Astronomy Time and Motion in the Solar System and Universe sun tracker party hut sea series elastic actuator development biomimetic tracking robot GPS-powered sun tracker skylights direct natural daylight Unidirectional Series-Elastic Actuator Design Multi-objective optimization multi-objective programming vector optimization multicriteria optimization multiattribute optimization Pareto optimization multiple criteria decision making mathematical optimization problems involving more than one objective function to be optimized simultaneously trade-offs between two or more conflicting objectives Scholarly articles pareto multi objective optimization genetic algorithm for multi-objective optimization Multi-objective optimization using evolutionary algorithms Engineering ToolBox SketchUp Extension online 3D modeling Cryogenic Fluids Liquefied Gas Properties Cryogenic properties density boiling points heat evaporation for fluids hydrogen methane oxygen nitrogen fluorine and helium Specific heat capacity of Hydrogen Gas H2 temperatures ranging Specific Heat Capacities of Gases Links Adwords Machinery Lubrication Ozak nitrogen Sponsored Pipe flow software calculate pipe flow speed pressure salt fog spray Water air gas Dynamic and Kinematic Viscosity Ammonia NH3 Concentration in Air and Health Symptoms Acoustics Air Psychrometrics Combustion Drawing Tools Dynamics Economics Electrical Environment Fluid Mechanics Gas and Compressed Air HVAC Systems Hydraulics and Pneumatics Insulation Material Properties Mathematics Mechanics Miscellaneous Physiology Piping Systems Process Control Pumps Standard Organizations Steam and Condensate Thermodynamics Water Systems CO2 Unit Converter question Power informal settlements Global optimization Sun contour following Design Mobile app Best practice guide Advice and Tips Parabolic Practical research guide to Solar energy harvesting, digital control electronics, mechanical actuator and parabolic dish trough collector design concept guidelines with applications Going off grid eco estate village Power informal settlements Global carbon exchange invoke solar tracking patch invoke sun position pack library helical coil receiver Environmental life-cycle costing code of practice Sustainable Project Life Cycle Management sustainability performances of industries Cleaner Production self excited induction generator theory self excited induction generator simulink model single phase self excited induction generator self excited induction generator for isolated power generators doubly fed induction generator Design Oversimplified representation Tons of CO2 Solar pv charger Motion power cost Real time discrete digital power budget analysis Power Cost function Solar electric power Green energy power regulator Dni grid Seam Bubble diagram Sg4 dish Solo eurodish Anu angle dish electric flatter dish structure lightweight automotive chassis dish frame low cost non rusting concrete counter weight weight balance tilt stability structural stability absorb vibration less wind resistance opening between mirrors in dish for wind outlet Stirling mounted dish focal plane Sterling engine parts front and at back of dish reduced weight moment of payload weight reducing strain on az/el drives easy to wash clean flatter dish -Lower probability of dust deposit fixation onto dish surface homing device in pipe engagement damage Windshield Power bus Satellite flight solar pressure propulsion and attitude control Automated identification coronary arteriograms adaptive tracking algorithm digital coronary arteriograms spatial continuity centerline orientation diameter density algorithm extrapolation-update process matched filter parameters lumen width stenosis Numerical astronomy fast computation complete elliptic integrals Jacobian elliptic functions Celestial Mechanics Dynamical Astronomy Transformation Cartesian Geodetic Coordinates Accelerated solar ephemeris traction system power electronics Halley Method trnsys sun position Azen trnsys Solar Energy Laboratory ambient temperature AZEN zenith angle for calculating the actual sun position direct and diffuse radiation mode Report of the IAU Working Group on Cartographic Coordinates and Rotational Elements cold storage materials air conditioning application Astrology Ephemeris Files Moon tracking and scheduling Moon bounce Earth-Moon-Earth communication Communication Moon Relay meteor scatter moon bounce communication moon bounce remix Moonbpounce HamRadio Microwave moonbounce Amateurfunk Satellitenfunk Erde-Mond-Erde EME HamRadio Afuflohmarkt moon calendar trajectory computation tool calculates elevation azimuth range satellite for the nominal computed trajectory from observer position Complete Moonbounce Scheduling Tracking solution Macintosh Windows Linux MoonSked supported Antenna Rotators Macintosh Windows Linux MoonSked can automatically control antenna tracking moon tracking software moon tracking app moon tracking website visual moon tracking stage of the moon moon phases this week when does the moon rise tonight what time will the moon rise tonight set criteria towards simplicity ease of assembly design faceted dish structure parabolic dish curvatures tiled with reflective mirror facets circular square array configurations conventional uniform continuous parabolic dish symmetrically about common axis perpendicular to target plane characterized plurality ring-like segments arranged about common axis each segment having concave spherical configuration dish-shaped monolithic reflectors co-axially aligned array supported moveable frame system modular transported erected rooftops remote locations without special equipment fabricated small workshop local materials simple tools optimally designed particular load demand hybridization cogeneration modular structure lends itself to economical production techniques reflector concentrator efficient effective reasonably inexpensive does not involve labor intensive complex adjustment and alignment procedures effectively deployed attains uniform intensity distribution over a target plane accounts for real world optical errors sun shade effects plurality of reflective elements surfaces tailored to provide desired moderate flux level and uniform profile compact faceted Fresnel type dish design ensure flatter dish structure require less skill during assembly installation simplicity construction conventional parabolic assembly precision continuous surface lens collapsed onto flat basis or plane practical aspect compressing lens surface power plano surface requires finite prism pitch slope angle component made flatter deeper provide choice of f/D ratios Collect solar energy Harness power from the sun lens surface consisting of concentric series of simple lens sections thin lens short focal length large diameter used spotlights Fresnel series ideal compact lightweight tungsten Fresnel spotlights small studios grid height support large weight double convex lens surface curvature gives focusing power surface curvature thick lens in sections maintaining focal length fraction weight Multiple Thinner flatter Conventional continuous Modular solar concentrating dish dish reflector concentrating solar flux uniformly target plane solar cell array comprising plurality concentric concave reflective surface elements arranged symmetrically axial position forward parabolic reference dish vertex spaced target plane distance equal to the focal length dish reflector concentrating moderate solar flux uniformly target plane solar cell array dish stepped reflective surface characterized plurality ring-like about a common axis segment concave spherical configuration two-axis solar tracker apparatus multiple dish-shaped monolithic reflectors for concentrating sunlight dish-shaped monolithic reflectors co-axially aligned in an array supported moveable frame elevation structure two-axis tracker control means following the movement of the sun across the sky prior art solar reflector economical production techniques single-piece mold dish stamping technique reflector dish plurality of reflective elements surfaces tailored flux level uniform profile Substrate Detects Amplify Beam style sun pointing Sun vector Pointer crosshair Laser cut crosshairs Telescope crosshairs presents a visual representation of sun beam masking plate sun beam Visualise sun sensor operation Crosshairs in an Illuminated reticle crosshair target Green crosshair Bullseye Crosshairs taget type mechanical Pointing scope Solarscope Reticle means Eyepiece Sauter control Solar Tracking System Design GPS and Astronomical Equations Soot particles Tracking accuracy assessment concentrator solar photovoltaic system Gebaudemanagement Programming parameterisation via PC Control engineering libraries Time and calendar function Data recording microSDHC card Predictive control based on meteorological forecast data Mechanical rail guide mechanical path slide on a rail Leonardo parabolic compass Energy safety Diminishing sunlight on solar receiver optimal tracking neuro-controller for nonlinear dynamic systems neural network electromagnetic calorimeter Solar Reforming Heat recuperation Double-sided CdS and CdSe Quantum dot QD solar water heater collector thermal energy performance of circulating pipe Co-sensitized ZnO Nanowire Arrays Photoelectrochemical Hydrogen Generation Electromagnetic Radiation EMR Matter Interactions Remote Sensing Energy in Electromagnetic Waves Remote Sensing from Air and Space Imagery Survey Monocrystalline Polycrystalline Gallium Arsenide GaAs Emitter wrap-though cells Amorphous silicon Solar energy harvesting nanotechnology Supercapacitors Emitter wrap-though cells Copper indium diselenide (CIS) or copper indium gallium diselenide (CIGS) Quantum wells Smart coatings electrochromic gadgets thermochromic fenestrations Carbon nanotubes carbon fullerenes Nanowires proportional-integral-derivative controller Free-Greenius renewable energy systems hourly plant performance simulations power plant modelling solar receiver design and analysis Urban Scale Solar Energy Computer-aided-synthesis Discrete Descriptor Control System pneumatic control system solar concentrated CSP thermodynamic research store thermal energy concentrated solar power systems absorption chillers regulate power production user demand dispatchability integrated thermoelectric power thermal cycle machinery hybrid systems renewable energy sources available locally arid lands desert areas disused areas Solar Energy Research tracking the sun green alternative solar smart system polar sundial Sun Position synchronization Energy Security Renewable Energy concentrating solar solar power Solar Research SunPos algorithm Microsoft Windows, Macintosh, iOS, MS-DOS, Android, Palm OS, Unix/Linux actuator automation azimuth elevation Pursued the sun tracker alignment encoder handling PLC mechatronic drives automation CPU microprocessor microcontroller syntax battery calculated camera carbon footprint closed-loop cloud cogeneration components computed concentrated solar power configuration control system DC motor devices Mobility platform mobile dynamic platform dynamic space frame diagram self-alignment algorithm sun tracker field test open loop sun tracking ephemeris tracking Dobson thermal Dobson Spectrophotometer enea thermal emission robotics and automation Solar Motor Sun-Tracer Solar Positioner module 3D CAD Model Parts Motors E-Learning Drive Selection Motion Control Thermal Behavior Publications solar Forecasting solar energy Demand Management solar Acquisition Single-Axis solar tracker embedded positioner time controlled astronomical algorithm sun tracking solar connectors mil-spec motor connectors parts military specification IP-65 Water-Dust IP Resistant enclosure watertight IP-55 custom configured saved CAD file 3D part model translated into 2D outline drawing download CAD file formats brushed DC brushless DC motor gearhead encoder motor controller application panneaux solaires Crouzet Premium hybrid power plant high-value dispatchable power On-orbit calculated UVS Solar Viewer boresight direction solar incidence angle angle between surface normal and apparent positions of the sun point Boresight-Intersection Average boresight spectrum solar Dynamo-electric machines TOP alignment proven Tested middle boresight position digital camera Error analysis accuracy Mirror slope error mrad Inherently aligns mirrors receiver measurements near center of mirrors alignment Proof slanted receiver image mirror Field crew install micromechanics Electrostatic relays dynamo-electric generators or motors Electrostatic generators motors clutches holding devices Linear rotary motors positioners actuators Travelling wave motor Vibration wave motor Micro-electro-mechanical system slope error measurement tool cavity solar absorber MicroStation Dimension Driven Design Geometric Optics micros one man crew motorized parabolic slider Solar Parabolic Trough Collectors four system configurations parabolic trough and linear Fresnel focus sunlight in a linear fashion whereas dish engines and power towers central receivers focus sunlight to a point fluidized-bed particle receiver direct supercritical carbon-dioxide s-CO2 receiver high-temperature thermal receiver for power tower fossil boiler technology Advanced solar receiver coatings heliostats characterizing refining advanced coatings to increase solar absorption decrease emissivity increase receiver efficiency High-temperature solar-selective coatings Solar Power Integrated Layout and Optimization performance layout requirements ordered arrays quantum dots self-assembled electrochemical techniques Central Falling particle receiver tower Integrated dual axis slew Tracking Racking Solar Power System Tidal Turbine Counterweight Drilled Piles Mooring Counterweights Choose Best Foundation Solar Tracker Foundation Options Download Center Solartracking Systeme Movie Solartracking Systeme Photovoltaikanlagen Solarenergiespeicher Nachf\"uhrsysteme Photovoltaik Solar Tracker mit nachgef\"uhrten Photovoltaikmodulen folgen dem Lauf der Sonne Nachteile deshalb wesentlich effizienter als starre oder astronomisch gesteuerte Anlagen Der Wirkungsgrad einer Solaranlage hängt entscheidend davon viel Energie SunTracer krugloe parabolicheskoe zerkalo Solar Nachf\"uhrungssystem Solar Tracker Solarmodule Anzahl der gesteuerten Achsen solar sensor controlled tracking systems zweiachsigen astronomisch gesteuerten Nachf\"uhrsysteme Effizienzsteigerungen Solaranlagen Solar Tracking System Using ATmega Arduino solar meter Arduino controller arduino solar tracking Arduino Solar Tracker search brightest light source sun Arduino Solar Tracking Robot arduino board Arduino Solar Tracker with ServoMotor Electro Schematics servomotor LDRs resistors rotate solar panel Sun Arduino Solar Tracker Solar Tracker Circuit Diagram Arduino Mobile Sun Tracking Solar Power arrangement Arduino orient face solar panel 2 Axis Solar Tracker Dual Axis Solar Tracker using Arduino align solar panel towards higher density of Sun light Dual Axis Solar Tracker OpenSource Classroom Arduino 2-DOF Sun Tracker LDRs Track Light Source Voltage Divider monitor Solar Open Source Arduino Sun Tracking Heliostat Control Program Arduino Platform Differential Gap Control Arduino Powered 2 Axis Solar Tracker Project Arduino Controlled dual axis Solar Tracker Arduino Duemilanove upgraded atmega328 controls linear actuators 24V DC motors arduino uno Solar Tracker Code limit steppers double axis solar tracker Motor-shield V2 bipolar stepper motors Solar SmartSurfaces Kinematics Solar Rotators Solar Equipment Rotation Fuzzy control solar tracker Arduino Uno Stepper motor arduino-solar-tracking Arduino Sun Google Code code.google.com arduino solar tracking downloads Aeroquad Shield Arduino Pro Mini standard servo Arduino dual axis solar tracker Arduino MEGA 2560 Arduino Relay Circuit Solar Tracker Motor Control Parts Relay Shield Arduino Controlled Sun Tracking Solar Panel Arduino Kits Boards Shields solar tracking arduino solar tracker project arduino sun tracking arduino solar tracker code sun tracking solar arduino solar cell arduino sun tracker code 2 axis solar tracker Helionomics Motorized Screw Jacks Field proven Rugged embedded systems Tactical Solar Tracker Power Charging Solutions Rugged Solar Panels non-bending panel back pouch Portable Easy Transport Storage Automatica PhotoBioLib Rugged design rugged solar charger rugged solar panels ruggedized solar concentrator mirror panels Opposed Piston engine efficiency OP engines Diesel Turbo gas and dual-fuel power generation solutions PV-T Collector Development intelligent positioner Metal panels topped with thin PV laminates conceal solar thermal system underneath pan tilt roll accessories Hub Sprockets Plain Bore Sprockets Servo Sprockets Chain Aluminum Hub Mount Sprocket Plastic Chain Channel Sprockets Tower of gears sprocket pulley belt chain Servo Accessories Motors Accessories Servo Controllers Motor Controllers Transmitters Pan/Tilt/Roll Accessories Camera Accessories Robot Accessories Channel Brackets Shafting Tubing Hubs Couplers Adaptors Bearings Bushings Gears Wheels Tires Fasteners Hardware Batteries Power Supplies Wire Connectors Electronics Tools Project Center Anodized Aluminum Reflectors Actuators Servoactuators Electro hydraulic actuator uninterruptible power supply UPS Solar radiation spectrum spectral response thermopile Graphing Libraries Scientific Data Plotting Software high-level library visualization solar user data IT energy Meteorology Automatic Precise Positioning motorized solar tracker Solar concentrator photovoltaics tracking accuracy CPV tracker vibration optical measurement light from our sun energy management and building automation system video to pc tracking technique Sun Finder Transfer function matrix linear singular descriptive system fundamental matrix hybrid solar micro-CHP system household sector Adaptive Sun Tracking algorithm maximizing Incident Energy maximization Sun's Position to High Accuracy tracking algorithms sun tracking trade off between accuracy and complexity Solar Tracking Application Sun tracking algorithm calculates solar azimuth and zenith angles of the sun Pinhole Sensor pinhole camera without lenses pinhole four-quadrant detector 4-detector tracking methodology complementary tracking techniques flights astro bodies Sun java sun-pos.m sun-position.m File Exchange Matlab MathWorks matlabcentral Reda Andreas solar position algorithm solar radiation Energy Production Solar Power Simulink modeling harness solar energy analyzing performance Tracking Algorithm Solar Inverter cleantech innovation entrepreneurship Pixie pixy camera sun tracking Microcontroller Arduino pixy cam track motion daylight conditions CMUcam Pixymon Track points video using matlab Kanade-Lucas-Tomasi KLT algorithms point tracker object tracks source code Object Tracking Particle Filter Based Self-Adaptive Multi-Features Fusion Particle filter based tracker Mean shift based tracker Deformable articulable object tracker Appearance learning based tracker Advanced appearance model based tracker micro-CCHP micro combined cooling, heating and power system thermal management controller Direct Absorption Solar Thermal Collectors Thermoelectric Materials Solar Thermoelectric Generators Tri-Segmented Parabolic Trough Solar Thermoelectric Receiver Tube Multi-Component Energy Conversion amplifying effect natural convection power generation thermogalvanic cells greenius thermal modelling Bioelectronics software development Biorobotics electronic device machine tool profile tracking mobile robot perception computer science atmospheric thermo-physics sun tracker Lightweight Design Construction Atmospheric Photochemistry Kinetics Postdoctoral Scientist Smart Building Research Atmospheric Remote Sensing integrative energy photo-physics astrophysics atmospheric science Optical analysis deviations concentrating photovoltaics central receiver flux homogenizer Online short-term heat load forecasting single family houses Computer Vision System Toolbox video tracking algorithm Camera Calibration Track points video using Kanade-Lucas-Tomasi algorithm vision point-tracking feature-tracking algorithm Motion Tracking in Image Sequences video sequences tracked object Matlab code motion tracking algorithm object tracking matlab object tracking using matlab matlab centroid tracking matlab code for image tracking object tracking code object detection and tracking project report moving object tracking matlab code download Motion Tracking Kalman Filter Matlab Code track moving object from live cam meanshift camshift algorithm track moving object maximum photovoltaic powertracking perturb observe-algorithm matlab simulink Incremental Visual Tracking Real-time Compressive Tracking online tracking algorithm Matlab toolbox for particle tracking Target Tracking Matlab Computer Vision System Toolbox MathWorks Electromagnetic Actuated Conveyance System Contactless Sensing Orgone energy Orgone box oracs Orgonics Orgone machine Orgone accumulator Natural energy Ether energy Etheric energy Thermodynamic properties Solar nanofluids colloid science Nanoparticles improve solar collection efficiency photovoltaic efficiency enhancement low-dimensional structures Thermal conductivity lubrication characteristics nanofluids aggregation interfacial thermal resistance thermal conductivity nanocomposites colloidal nanofluids Membrane electro-catalyst materials fuel cell technology Dynamic positioning simulation thrust optimization Sliding-Mode Control design control Nanoparticle supported catalysts are assumed to be the most auspicious materials for catalysis in fuel cells solid-gas-suspensions direct absorption concentrated solar radiation Direct-Absorption Solar Thermal Collectors direct absorption receiver concept motion tracking algorithm object tracking matlab centroid tracking matlab code for image tracking object tracking code object detection tracking report moving object tracking matlab code download Parrot teleprompter DSLR camera SunAir Solar Power Controller Board Tracker Phone Charger Arduino Raspberry Pi Open Source Drivers Dual WatchDog Timer SPOT Solar Panel Orientation Toolbox hybrid electromagnetic suspension system EMS linear synchronous motor finite element analysis method dispersion of forces design reduces distortion and strain modules Aerodynamic shape minimizes load tracker adverse weather conditions frame hot dip galvanized absorption algorithms arguments azimuth Chile cloudy compiler data day Dislin Distributed revision control elevation energy Fortran get_command_argument gfortran Git Github graph Graphics irradiance Lab Languages linux mac make makefile matlab measure National Renewable Energy Laboratory nrel Open source Photodiode piranometer plot position python Renewable energy rsr satellite scattering solar Solar energy Solar power solar radiation solar spectrum South America spa sun sunny Tambo Real thermopile tracker United States USM solar wavelength production methane heat bioethanol sugarcane bagasse solar biorefinery motorized sun tracker aggregation of distributed energy resources energy demand response load control transponder Multi-Objective Optimization Performance Power Energy HPC Kernels Regional analysis building distributed energy CO2 abatement tracking comparison slew drive solar panel tracking device solar panel sun tracking device solar panel slew drives Anidolic daylighting systems fast track programs tracking solar wall ventilation trombe wall Images and video processing istracking pan-tilt-zoom PTZ cameras Discrete digital control system Model predictive control Dual-axis biaxial Slewing Drive with motor and gearbox for solar tracking video2pc pointing sensors fibre-coupled CPV Concentrating Photo voltaic linear collector EPS-tenerife sun tracking control unit tracking computer mocam sundog sun tracking control video 2 pc parabolic dish modal testing resonant effects elastic structure support mast Concrete Strip Footing Ballasted detached solution pre-cast pour job-site concrete footings solar tracker foundation footing Gravel Pan foundations landfill brown field installations residential agricultural solar project load distribution feature tracker anchored gravel pans float top soil pans filled materials sand coral cemented calcareous sand recycled aggregates concrete brick glass asphalt gravel gravel pans ship tracker mounting hardware Ramming Posts Attached solution foundation four ramming posts Solar collector design stiff sandwich panels aluminum dishes inflated umbrella-type membrane configurations Sunflower concentrator high-efficiency collector long-term consistent accuracy new configuration Pactruss backup structure object lifting jack hywire technology hy wire electrical mechanical mechatronic hand Mechanical Dust Collector Moterized Garage Door Energetic environmental economic aspects hybrid renewable energy system Techno-economic analysis autonomous hybrid photovoltaic diesel battery system Energy for Sustainable Development stand-alone residential photovoltaic thermal power system multivariate qualitative model APEX ASAP ReflectorCAD Engineering ASAP chromaticity analysis Solar Dish Field System Model Spacing Optimization Acyclic Recyclic Information Flow Oildyne electro-dynamic actuator Dynamic Fluid Products Solar Tracker Kit Dual Axis Solar Tracking Kit DIY Solar Tracking Kit Solar Tracker Rapid Control Prototyping RCP code controller compiled linked run real-time target system Hardware-in-the-Loop simulation hardware software developed in parallel System integration embedded codes completed hardware rework software redesign workaround development correction errors less expensive embedded software against real-time dynamic environment robust position control Electro-hydraulic Actuator Sliding Mode Control Radial Basis Function Sliding Mode Control

control algorithms tracking electro-hydraulic actuators sliding mode Point-to-point trajectory tracking with discrete sliding mode control electro- hydraulic actuator system position control electro-hydraulic servo Pneumatics Fittings Cylinders Valves humanoid bot joint swivel motion control technologies precision-engineered solution mobile industrial aerospace climate control electromechanical filtration fluid gas handling hydraulics pneumatics process control sealing shielding Air Preparation Dryers Cylinders Actuators Fittings Gas Generators Hose Piping Tubing and T-slot Framing Hose Piping Tubing T-slot Framing Motors Drives Controller Power Take Off Drive System Pump Refrigeration Air Conditioning Regulator Flow Control Thermal Power Management Valves motorized Miter Gearbox Bevel Gear Jack Worm Screw Jack Acme Screw Jack Cubic Screw Jack Worm Screw Jack Machine Screw Jack Bearing Supertechnology Ultra-High Speed turbine Moter System motarized screw jack solar power satellite Sensor pan/tilt kit Servos Arduino 2-axis servo solar tracker prototyping sun motion tracking solar motion tracing Pan and Tilt Kit Black Anodized sun tracking satellite tracking moon tracking algorithm source code download moon tracking algorithm source code software Antenna dish Position Decoding Target Location Target Tracking Antenna Dish Control Housekeeping PC Programs for the IBM PC and compatibles running MS-DOS Windows Programs for the IBM PC and compatibles running Microsoft Windows Linux Programs for the IBM PC and compatibles running Linux Macintosh Programs for the Apple Macintosh Java Programs in Java for any machine with Java installed Psion Programs for the Psion HP Programs for the Hewlett-Packard HP-48 family of programmable calculators TRS-80 Model 100 Programs for the Tandy TRS-80 Model 100, 102, and 200, and compatibles including the WP-2 and NEC PC-8201A Source Code Programs in source code form, suitable for compiling and running on a wide variety of computers Firmware Firmware updates for various hardware devices Spreadsheets Spreadsheet files in popular formats Nova for Windows Fast accurate real-time tracking Earth-orbiting satellites Full-color 3-D maps built-in autotracking for turning az/el antenna dish Control antenna dish with computer joystick audio tracking algorithm object tracking algorithm tracking algorithm matlab tracking algorithm opencv Sun Moon Lunar Phase Algorithm PyEphem bug tracker source code repository C compiler pip Python installer tool ephem ephemeris Energy Simulation eQUEST gbXML Generative Design Google Earth Google Maps Green Building Studio Green Roof Hardware Human–Computer Interaction IES IES VE-Ware IES Virtual Environment IFC Interoperability KML LEED Lighting Design Living Building Challenge Mac OS X Materials Maxwell Render Open Source OpenStudio Parametric Design Passive House Performance Driven Geometry Photoshop Plugins Podcast Renewable Energy Revit Revit Tools Rhino Scripting Scripts Simulation SketchUp Solar Analysis Solar Energy Sustainable Design TED Tensile Tutorial Urban Planning User Community Vancouver Vertical Farming Video Vray Weather Data web-based 3ds Max 4D 2030 Challenge ArchiCAD Architectural Animation AutoCAD Autodesk Bicycles Biomimicry Carbon Footprint CASCADIA Climate Analysis Climate Change Cradle To Cradle Daylight Simulation Demeter Design Performance Viewer EcoDesigner Ecotect Embodied Energy energy Energy Efficiency EnergyPlus 3D Modelling Architecture Building Performance Analysis Design Environment GIS Visualisation System Simulation in Buildings Autodesk geometry Calculating reference DNI NREL ISHARE data Concentrating Solar Power Desalination Plant Independent Solar Thermal Desalination System Solar Water Detoxification Disinfection System Electronically Scanned Arrays Matlab Modeling Simulation Trnsys Modelica enabled Rapid Prototyping 2 DOF Pan Tilt Robot Joint Servos Solar foundation solar tracker mast solar tracker pedestal foundation solar no concrete foundation solar tracker without concrete foundation Solar metal foundation solar tracker footpiece Plans for Home-Built Parabolic-Type Reflector position-encoder Optical linear encoders Optical rotary (angle) encoders Magnetic encoders Resolute absolute encoder system Laser encoders Ultra high vacuum (UHV) optical encoders Accessories for optical encoders Encoder product configurator Exhibitions and conferences Atom miniature encoder system solar dynamo radiant energy collecting converting device array slat-like concave reflective elements elongated receiver axis of rotation cantilever beam plurality telescopically-interconnected cylindrical members free end joined spherical joint beam able to rotate joint in three degrees of freedom protracting retracting telescopically rudimentary System pulley springs cantilever beam move in three dimensions form architectural space able to move and change its shape architectural spaces form a building change shape design adapts to changes in surrounding environment Hydroformed space frame pair of laterally spaced longitudinally extending side rail structures laterally spaced upright structures joints lower ends side rail structures Space frame joint construction Space frame apparatus Split joint construction parabolic reflector dish ladder frame Structural beam Die-formed sheet metal structure dish joining plastic panels to aluminum space frames Adjustable cable guide assembly Structural beam process for producing Method for manufacturing Method manufacturing dish body frame assembly Structural composite body panels dish collector space frame assembly Rivet nut machinable head tubular members Reinforced section Side panel module Expandable space-frame double-layer space frame Strut system solar mirror frame Solar concentrator focal system Concentrating solar energy collector assembling large space structures Connection element composite material dish Lightweight truss joint connection carbon fibres Linear Fresnel solar array drives Movable support armature dynamo curved reflector Carrier solar energy reflector element Matrix solar dish Space frame connection node arrangement Torque transfer trough collector modules composite collector module groups stabilizing operation Electro-hydraulic solar dish panel carrier adjusting device remote angle mapping process solar array Solar automatic overturning Telemetry telemetric Solar tracker Device control using Telephone keyboard DTMF decoder IC signals sun-chasing platform device PV-T Collector hybrid photovoltaic/thermal PV/T air heating collector compound parabolic concentrator CPC Etendue Acceptance angle Concentrated photovoltaics Concentrated solar power Solid-state lighting Lighting Anidolic lighting Hamiltonian optics Winston cone Nonimaging optics focons focusing cones nonimaging concentrators applied solar energy concentration optics Parabolico-thoric focons calculate first derivative DCV cyclic voltamograms CV map a country solar radiation calculation procedure microclimates modelling PV array Matlab microgeneration technologies domestic scale low carbon heating condensing boilers biomass boilers room heaters air source ground source heat pumps solar photovoltaic panels flat plate evacuated tube solar thermal panels micro-wind combined heat and power Stirling engines internal combustion engines fuel cells microgeneration industry Solar Augmentation Using Parabolic Dish Trough Photovoltaics Electric vehicles Solar fuels Concentrated solar power Solar economy Helionomics Energy efficiency new technologies achieve maximum irradiance illuminance pattern receiver target movements inhomogeneities optical axis concentrating sunlight onto receiver cylindrical light collectors trough-like reflecting wall light channels shape concentrate radiant energy phase space conservation concentrating radiation tube receiver solar-thermal photovoltaic applications Sustainable Energy Communities Insular Ecologically Sensitive Areas Electrical switching drive systems solar-to-hydrogen Receiver Design Receiver Size Receiver Heat Loss Receiver Size Optimization Prototype Parabolic Troughs Performance Prototype Trough Prototype Parabolic Dishes Shenandoah Dish JPL PDC1 Concentrator Concepts Fixed-Mirror Solar Collector FMSC Moving Reflector Stationary Receiver SLATS Fixed-Mirror Distributed Focus FMDF spherical bowl Simultaneous Multiple Surfaces design method Electronic Sensor Systems Electrical Information Engineering Optical Lenses Achromatic Lenses Aspheric Lenses Plano Convex Lenses Double Convex Lenses Plano Concave Lenses Double Concave Lenses IR Lenses UV Lenses Cylinder Lenses Ball or Condenser Lenses Fresnel Lenses Lens Kits Optical Mirrors Windows Diffusers Optical Filters Polarizers Prisms Beamsplitters Diffraction Gratings Optics Assemblies Fiber Optics Infrared Optics Ultraviolet Optics Laser Optics Defense Optics Elastic opto-thermo-mechanical actuation defocus the system clean the reflective elements Structure Articulation System Solar Collectors spatial clustering Wii sensor bar positioning get accurate pointer thermodynamic concentration solar power station Intelligent solar tracking concentrated solar cooling, heating and power CSCHP system analyzed exergy method sun powers Thermo Dynamic Solar Pump Free-form lenticular optical elements Sun-Pumped cw Watt Laser Polymorphic component telescopic beam connects two ends arranged circle around central point rotated horizontally vertically about controller ends protracted retracted move free ends closer to further from central point covering triangle object shape transforming various shapes telescopic structural beam radiant energy collecting and converting device having at least one array of slat-like concave reflective elements and an elongated receiver Access to Energy bio-gas Conference consulting Containerized Demonstration sites design electric golf carts energy audit energy efficiency energy metering energy monitoring feasibility studies grid-tied ground-mounted heat hybrid hydro-power industrial Interns LEDs Lightbox mini-grid News off-grid project managment PV plant renewables Research Rooftop Rural Savings small scale IPP Solar PV Solar Thermal steam tariff tracker Training waste to energy Access To Energy Solar Thermal Differential Controller energy efficiency energy metering energy monitoring AKKUtrack akkutrac accutrack accutrak B-Spline Curve Parabola 3D parabolic solar parabolic B-spline solar parabolic surface design B-spline Continuous b-spline surfaces Geometry Construction Caustic Images Continuous b-spline surfaces parabolic concentrators for solar cells meshes operate C2 continuous B- spline surfaces positioning parabolic dish trough Optical design fabrication Concentrators Optics one-dimensional grating conical B-spline modal Graded index planar waveguide solar concentrator Nonparabolic solar concentrators parabola concentrator profile trough parabolic shape integral design mirror profile design arc-spline solar dish trough concentrator concept designer machine construction Programming system integration HMI design AC motor drives Solar power system biometric access system Low-Profile Solar Concentrator Dish Autonomous Self-Tracking web2CAD Trace Parts Hot water storage rollable foldable collector units collapse employing tracking means direction- finders for determining the direction from which sunlight electromagnetic waves are being received solar tracking systems control of position or direction Calibration means Methods for initial positioning of solar concentrators or solar receivers Control arrangements Control of position for tracking responsive to temperature responsive to wind controlling transmission of solar radiation Solar heat systems greenhouses distillation by solar energy devices for producing mechanical power from solar energy central heat systems using heat solar energy domestic hot-water supply systems using solar energy air-conditioning systems using solar energy refrigeration machines, plants or systems using solar energy drying solid materials or objects by radiation from the sun direction determined interferometric type transmitting antenna array vectorial combination of signals derived from differently oriented antennae boresight solar heat collectors ultrasonic distance measurement Mechanical vibration generators Adjustable optical elements motorised lenses Oscillatory dynamo-electric generators Electrostatic motors generators Motors using thermal drive effects electric or magnetic perpetua mobilia continuous separate strokes actuators or positioners driven element movable along linear angular stroke limited stroke motors tracking Speed reducer planocentric gear arrangement Speed Size Turbine type Bearings Seals Frequency alternator Single stage Radial multi stage Axial multi stage Single stage Radial multi stage single stage Axial multi stage Gas Foil Magnetic Hydrodynamic oil Hydrostatic Adv labyrinth Dry lift off Permanent Magnet Wound Synchronous Gearbox Synchronous Shaft Configuration Single Shaft Visual Servoing Adaptive Control Access Control Active Control Attitude Control Automatic Control Chaos Control Climate Control Cognitive Control Coherent Control Congestion Control Control Charts Control Groups Control Orientation Control Project Control Systems Control Techniques Control Theory Control and Instrumentation Cost Control Digital Control Dynamics and Control Error Control Feedback Control Flight Control Flow Control Force Control Fuzzy Control Intelligent Control Internal Control Locus Of Control Loss Control Management Control Motion Control Motor Control Movement Control Neural Control Noise Control Nonlinear Control Optimal Control PID Control Pollution Control Postural control Process Control Quality Control Quantum Control Robot Control Robust Control Satellite Control Shape control Speed Control Stochastic Control Structural Control Symbolic Control Topology Control Traffic Control Vector Control Vehicle Control Vibration Control Active Vibration Control Advanced Control Systems Advanced Control Theory Air Pollution Control Air Quality Control Air Traffic Control Attribute Based Access Control Automatic Gain Control Case-Control Studies Control System Design Control Systems Engineering Distributed Control Systems Emerging Control Applications Error Control Coding Facility Regulation and Control Fault Tolerant Control Field Oriented Control Fractional-Order Control Fuzzy Logic Control Industrial Pollution Control Internal-External Control Media access control Medium Access Control Model Predictive Control Motor Learning and Motor Control Networked Control Systems Optimal Control Theory Power System Control Production Planning and Control Randomized Control Trials Real-Time Control Sliding Mode Control Statistical Process Control Statistical Quality Control Thermal Control System Extensible Access Control Markup Language Higher Order Sliding Mode Control Self-Sensing Control of Electrical Machines Controlled Environment Controlled Release Controlled Vocabulary Controller Design Controlling Controls Fractional Order Controllers HCI/CHI Input Devices - Controllers IT-Controlling Industrial Controls Programmable Logic Controllers Resistive Heat Controller Solar Storage Controller Voltage Controlled Oscillator controller area network Boresight adjustments made optical sight align the solar collector sights telecommunications radar engineering antenna boresight axis of maximum gain maximum radiated power reception directional parabolic dish antenna Image analysis software analyze images generate adjustment instructions Quality control alignment check magnetic attraction or repulsion Arrangement starting regulating braking controlling machines second machine electro-chemical actuators Actuators absorbing desorbing gas metalhydride Actuators difference osmotic pressure between fluids Actuators elements stretchable liquid rich in ions UV light salt solution electroactive polymers combination electrostrictive electrostatic micro-electro-mechanical resonators material piezo-electric electrostrictive magnetostrictive capacitor machines corona charging type Machines induction charging type Electric motors generators piezo-electric magnetostriction photonic troughs reflectors motorized solar tracking systems Aplanatic Solar Concentrator Structure graphene graphite crystal fullerene molecule graphene solar cells thin film composite Functional materials Graphene organic quantum dots organic solar cell Solar Tracking System Using Digital Solar Position Sensor Design Digital Solar Panel Automatic Tracking Robust Solar Position Sensor Tracking Systems Bug Tracker Power factor reactive power in solar systems phasor exergy balance for control volumes Energy transfer by mass Exergy analysis flat plate solar collector exergetic performance analysis analytical Rigid body planar movement Linear dynamics Rotational dynamics Angular momentum rigid body Kinematic drive Physics rotational motion mechanics Linear motion mechanics Ground mount solar Rotational kinetic energy angular momentum torque angular acceleration Torque movement of inertia circular motion movement rotational tracking dynamics Adiabatic Steam Turbine Adiabatic Control volumes compressor transient simulation combined cycle Electro-Pneumatic Positioners Kinetrol actuator Positioners operate pneumatic valve actuators position response friction histograms Flowserve Digital Positioner PV Thermal Solar Systems Solar Resource Knowledge Management Housing Renovation Solar Conservation Solar Thermal Cooling Air Conditioning Solar Heating Cooling Systems Performance Testing Solar Collectors Insolation Handbook Instrument Package Meteorological Information Solar Energy Application Solar Systems Using Evacuated Collectors Central Solar Heating Plants with Seasonal Storage Passive and Hybrid Solar Low Energy Buildings Active Solar Energy Systems Photovoltaic Buildings Polymeric Materials Solar Thermal Applications Net Zero Energy Solar Buildings Compact Solar Thermal Energy Storage Daylight Research Solar Radiation Pyranometry Studies Solar Materials RnD Passive Hybrid Solar Commercial Buildings Building Energy Analysis Design Tools Solar Applications Solar Low Energy Buildings Measuring Modeling Spectral Radiation Glazing Materials Solar Building Applications Solar Air Systems Solar Energy Building Renovation Daylight Buildings Optimization of Solar Energy Use in Large Buildings Solar Crop Drying Advanced Storage Concepts Solar Low Energy Buildings Solar Heat Industrial Processes Testing Validation Building Energy Simulation Tools Building Energy Analysis Tools Solar Assisted Air Conditioning Buildings Solar Combisystems Solar Sustainable Housing Solar Facade Components Autostart self-calibration Self diagnostics Predictive Maintenance communication protocols Intelligent Field Device Configurator common control system Fisher Rosemount AMS Delta-V Siemens SIMATIC PDM Yokogawa Honeywell ABB SMAR intelligent solar positioner power actuator Rotary Modules and Positioners Intelligent Charger Valve Positioner RF Marine Positioner Learning Robot iRVision Programmable Positioner Spreadsheet und Makro um eine Parabel von einem Gegebenen Fokus Zu berechnen Hoja de cálculo y Macro para Calcular una Parábola de un Foco Dado Planilha e Macro para Calcular uma Parábola de um Foco Dado Le tableur et Macro pour Calculer une Parabole d'un Foyer Donné Antenna parabolic dish Rotator Positioner Controller Automatic calibration Control software easy installation and calibration automated satellite solar tracking control optimal thermodynamics upperbound combined heat and power thermoeconomic optimization endoreversible solardriven heat engine thermodynamics irreversibility second law analysis exergy efficiency exergy resources entropy exergoeconomics thermoeconomics optimisation-environomics exergetic life cycle assessment regional and national exergy utilisation Parabolic trough concentrating solar power Power tower concentrating solar power molten salt direct steam Linear Fresnel concentrating solar power Dish-Stirling concentrating solar power Conventional thermal Solar water heating for residential or commercial buildings Large and small wind power Geothermal power and geothermal co-production Biomass power Developer Mobile Desktop Sensors Photoelectric sensors Inductive sensors Capacitive sensors Ultrasonic sensors Measurement sensors Pressure Vacuum sensors Encoders Safety light curtains Safety laser scanner Vision sensors Automation Logic controller Timers Control relays Solid-state relays Counters Temperature controllers Pneumatics Transmitter Touchpanels Laser markers Seeking the sun Program CD disk disc Skill solar Refrigeration Air-conditioning Active Tracking Algorithm Manual Tracking Algorithm Forward Reverse Rotation Control Panel Tracking-type Algorithm Azimuth Angle Tracking Algorithm Tracking-type Floating Photovoltaic System Parabolic Trough Satellite Dish Conversion Concentrator Catenary Chain Parabola dish deformation misalignment photovoltaic solar tracker structural Shock vibration isolation Plastic bearings Vibration monitoring Solar Plastic Bearings Lubrication maintenance free solar tracker compon igubal Spherical Bearings Vibration dampening iglide Clip Bearings Automatic Tracking Solar Dish Application case Solar tracking system solar tracking system for aligning a primary sunlight concentrator Control of position or direction Solar Tracker Tracking the Sun orbit Here comes the sun Track practice run practice sun sun visible intra-orbit angle south pole equator ascending node geodetic latitude earth nadir point altitude earth-to-sun unit vector in eci coordinates unit vector from tracker to sun reflection point center of the observation cell geodetic latitude (deg) east longitude (deg) boresight earth incidence angle (deg) boresight earth projection relative to clockwise from north (deg) boresight points sun vector earth incidence angle (deg) sun vector earth projection relative to clockwise from north (deg) sun vector points away from earth sun glint angle angle between the specular reflected boresight vector and the sun vector (deg) moon glint angle: angle between the specular reflected boresight vector and the moon vector (deg) declination latitude from where the specular galactic radiation originated (deg) ascension from where the specular galactic radiation originated (deg) geodetic latitudes of the four corners of the 3-db footprint east longitudes of the four corners of the 3-db footprint Optical alignment solar concentrator Precision Alignment Stage 6 axis positioning made simple satellite dish alignment software procedures collimator off-axis parabola linear or rotary motors dynamo-electric machines intermediate driving device Generators thermal kinetic energy converted into electrical energy ionisation fluid removal of charge Solar photovoltaic tracking astronomic control system Tracking type photovoltaic power generation system three-dimensional geomagnetic sensor solar Dish steering orienting Changing the direction of the antenna beam Motive power systems Image Analysis pattern recognition image processing reflector, director or active antenna Sun dragon tracker Kits Motorized Pan Tilt Heads and Systems Pans 360 degrees Continuous rotation either direction mechanical stop pan rotation direction Ready to use right out of the box pan and tilt at the same time making diagonal movements Accommodates load Tilts degrees total Pan and tilt Speed is continuously adjustable degrees per second Fastens tripod camera Move the camera up and down, right and left Operates batteries ptional 12 Volt DC or 120 240 Volt AC power supplies Accessories for Motorized Pan Tilt Systems Variable Speed Motorized Pan Tilt Systems Ultra Wide Speed Range Motorized Pan Tilt Systems Automatically Follows sun Motorize Pan Tilt Kit Motorized Pan Tilt Systems complete kits aplanat solar tubular receiver String Method Tubular Absorber Collimator Tubular Light Source Solar tracking system using periodic scan patterns Pattern follower Traveling markers Rotary markers X-Y positioner Gun positioner Turret positioner Barrel positioner Multi-direction positioner producing combined linear and rotary motion multi-direction positioners light radiation directly converted into electrical energy solar cells assemblies thereof Multi-marking Profile tracing Camera telemetric means Celestial Time computing gnomonic indicator sundial compass magnetic compass level or plumb gyroscope Multisight line Common viewpoint Relatively movable Angularly and rectilinearly separately adjustable Vertical and horizontal angle measurer Vertical angle gravity responsive indicating means pendulum distance finding feature Horizontal angle measurer Alignment device Railway track Self leveling tubular sighting means Rod or target Self computing type rod leveling or plumbing adjunct Extensible rod sections Reticle Adjustable calculation comparison direction or inclination Pendulum mounted or directed marker Radiant energy or electrically produced marking magnetic directional indicator Record movable to marking position Electrical telemetering to read-out Inclination and direction indications Indicator image projected on sensitized record photographic Thermally sensitive Gyromagnetic compass Electrical telemetering Differential disparity correction Gyroscopically controlled or stabilized Magnetic compass Geographic position indication latitude or longitude Plural gyroscopes reference platform Diverse indications Directive gyroscope stabilized auxiliary gyroscope Gyroscopic compass Spherical indicator Continuous gauging electric means Pivoted probe torque resulting from selectively controlling at least one solar array position Solar power generating apparatus solar tracking method collimator device narrow beam of particles waves directions motion aligned specific direction collimated parallel spatial cross section beam become smaller Discharge tubes thermionic generators naturally-occurring electricity lightning or static electricity Generation electric power conversion of infra-red radiation visible light ultraviolet light photovoltaic PV modules Electric motors thermal effects expansion contraction bodies due to heating cooling electrostatic chucks Apparatus devices using heat produced exothermal chemical reactions use of solar heat solar collectors production use of heat derived combustion Large-Payload 2-Axis Tracker Highly accurate automated open- and closed-loop tracking Optical Efficiency Test Loop Fully automated test loop measurements receiver heat loss Thin-Film Deposition advanced solar-selective and reflective coatings Ultra-Accelerated Outdoor Testing system simulates harmful effects long-term sun damage on outdoor products coatings and paints in months, rather than decades High-Flux Solar Furnace receiver collector high-temperature material coatings extreme solar environment Receiver Optical Test Stand analyze the steady-state off-sun thermal losses of receivers solar parabolic trough power plants reduce collector optical losses reduce receiver heat loss elevated temperatures Infrared Camera Solar Field Survey Thermal Scout identify analyze bad receiver tubes global positioning system infrared camera sophisticated software tracks and analyzes data in real time Receiver Characterization Laboratory Equipment to characterize line-focus receivers reduce collector optical losses reduce receiver heat loss at elevated temperatures Optical Characterization Turbo-machinery Particle Receiver Integrated Fluidized Bed heat exchange Concave Convex Spherical Mirrors Aspheric Parabolic Lenses Mirrors High Precision Toroidal Mirrors Miniature Reflective Beam Expanders Custom Optical Mounts Fast Focusing Mirrors for High Energy Physics Space Observation IR to X-ray Wavelengths Precision Interferometer Optics High Resolution FT-IR Highly Stable Mirror Mounts Mirror Control Off-Axis Parabolic Mirrors Universal Collimator Large Optics Large Diameter Reference Flats Mirrors Achromatic Beam Expanders Ultra Smooth Mirrors Custom Optical Prisms Thermomagnetic generators thermodynamic power generation Radiation pyrometers Thermometers thermo-electric thermomagnetic elements magnetography hydrostatic pressure permanent magnets perpetual motion solid state components Electrochemical current voltage generator magnetic attraction or repulsion Holding levitation device magnetic attraction repulsion electric or magnetic devices for holding work machine tools monorail vehicle propulsion or suspension sliding or levitation devices railway systems material handling conveyer electrostatic or magnetic gripper magnetic holders by air blast or suction bearings magnetic or electric supporting means relieving bearing loads dynamo-electric clutch brake electric furnaces simultaneous levitation and heating Modular Helix Heat Exchanger Mechanical Gearbox Indirect Drive Mag Gear magnetic coupling and reduction gear high speed rotational output power output drive conventional speed AC or DC generator CO_2 in Gas Turbines Altitude Instrument sun Solar position locator Curve and chart analysis Indexing and verniers X-Y motion Angular measurement Optical readout Angular position transducer Angle polysection Remote point locating Light direction Astronomical GEOMETRICAL INSTRUMENTS Simulating calculators Rotary marker Multi-marking Profile tracing Gyroscopically stabilized Horizontal angle measurer Multiple indicating means interconnected pantographic sun Course tracking Sight-line controlled Perspective view tracing Stereoscopic mapping Curved surface Single beam Pattern grading Structurally installed relation to feature Axle supported Railway rail spacing and inclination measurement in plural directions or of shape variable angle indication independent linear measurement angle or shape determination damper or governor sensor Magnetic viewing aid illuminator illumination director Spirit level electric illuminator preselected direction indicator protector or shock absorber Diverse directional indicator magnetic compass Line plumb and bubble level Magnetic field responsive Error indicator preventer compensator Error-producing-field minimizing Adjustable positioned permanent magnet Pivoted adjustment Electro-magnet or inductor flux valve Inductor rotated or vibrated Photoelectric pickoff Electrical contact pickoff Electrolytic liquid pickoff Resistance capacitance inductance pickoff Fluid jet or pressure pickoff Liquid buoyed magnetic needle Dip aligning needle Level plumb terrestrial gravitation responsive Electrically actuated signal or indicator Plural nonparallel axes plural orientation sensors compensation sensed quantity acceleration pulse or digital processing circuit component Fluent sensor light or radiant energy detecting circuit control element buoyant control element fluent material reactive circuit control element inductive Capacitive sensor resistive or contact circuit control element multiple circuit paths through conductive fluid light or radiant energy detecting circuit control element pendulum sensor reactive circuit control element inductive capacitive resistive or contact circuit control element indent level Indicator details Rotary base Triangulation solving trigonometric functions solar thermal heat systems are Supercritical CO_2 Turbines, Brayton Cycle systems and Solar-driven supercritical CO_2 Brayton Cycle systems Smart Solar Tracking System Optimal Power Generation Power Spectral Density matlab code Pole/Zero Plots on the Z-Plane Pixel Interpolation Phase Locked Loop matlab Fourier analysis phase amplitude analysis rectifier design in matlab Permanent Magnet Synchronous Motor Control code mean wind forces hemispherical solar collector Mechatronic solar System Design Laboratory Multibody Mechatronic System sun tracking Protected against falling drops of water condensation sprays of water splash water protection against dust ingress low hight pressure water jets immersion in water durable Solar-powered Rotisserie Solar Cooker Batteries Inverters Solar Collector Solar Concentrators Solar Do It Yourself Solar Evacuated Tubes Solar Glass And Glazing Greenhouses Grid Tie Solar Passive Solar Designs Solar Companies Solar Cooker Solar Cost and Rebates Solar Equipment Solar Heating Cooling Solar Homes Solar Panels Solar Pool Heaters Solar Water Heater motorized solar tracker positioner Thin Film Solar trial and error cogeneration system trigeneration triple-generation quad-generation poly-generation micro Combined Heat and Power CHP mCHP micro Combined Cooling Heating and Power CCHP CHCP mCCHP mCHCP system Micro system Block Solar District Heating Solar Heat for industrial processes Advanced storage concepts Open sorption processes solar tracking positioner design Handbook emulator emulation trnsys model modelica molten-salt heat transfer fluid thermocline system two-tank indirect thermal energy storage system phase-change materials Solar thermal electric power system Solar chemistry research Solar technologies applications Solar Heat for Industrial Processes SHIP Storage systems Two-tank direct Two-tank indirect Single-tank thermocline Molten-salt heat transfer fluid Storage media Concrete Phase-change materials miniature ceramic rotary motor Sky-vision Electro-optics Solar System iultra smooth parabolic, ellipsoidal, spherical and toroidal mirrors running and returning system for controlling motorized dish ADC Analog-to-Digital reflection principles parabolic antennas stepper motor servo motor controlled rotated parabolic concave hyperbolic Cassegrain reflector How to Install automatic mirror alignment controlled fusion Rotary rotary oscillatory motion Mobile-friendly patent application laser power meter beam profiler Aspheric Lenses optical filter precision optics using laser micro-machining compact spectrometers colour-corrected optical lenses in-situ re-optimisation process control optical thin films fluorophores Thermal Imaging Environmental Impact Landfill Site Near-field goniophotometry energy efficient luminaires solid state lighting imaging Thermal Solutions Thermal cameras FLIR standards Linux sensing and control motor controllers for aiming heliostat hard sun-tracking precision positioning reflectors pivotal role Instructions How to Construct Reflector Poynting antennas studio Line parabolic dish line satellite dish reflective material lining Reflective satellite dish reflective film Wooden pallet Solar Dynamics dissociating water overunity Simple G-code tool path generator excel program generator yaskawa encoder Slic3r G-code generator 3D printer tacho generator python CNC g-code generator Manual Pulse Generator numerical control NC programming language LinuxCNC G-Code sketchup gcode OpenCAM vectorial drawing files Machines Repository EMC quantum dot solar Nanocrystals Accelerators Electrodynamics Photovoltaics Motor-driven positioner regulation Software dongle motorized adjusters panel control systems Motorized lenses mirrors parabolic dish Energy storage Fuel Cells Clean Fossil Energy Mitigating impacts global energy demand Climate change prediction Energy Infrastructure reliability and security Greenhouse gas monitoring and measurement CO_2 capture and sequestration sonograms Parabola Parabolic antenna Parabolic trough Paraboloid Spherical reflector Toroidal reflector Solar furnace Solar cooker Rotating furnace Paraboloids how to construct cardboard type Paraboloids how to construct fibreglass type collapsible solar parabolic Pie shape petal solar reflector following the sun control networks electric actuators gearbox accesories motorised modulating full-turn turnkey Mechatronic sun tracker Control System Design for a Mechatronic Solar Tracker Audio Parabolic Solar Dome Super Polycarbonate Bowl arduino gcode gxf gcode centroiding algorithm sun tracker measure refinement sun image processing algorithm for sun sensors optimization highly dynamic sun trackers photovoltaic photophilic photocatalytic Sun Tzu active daylighting control systems closed-loop solar tracking open-loop solar tracking systems Measurement cloudiness influence UV radiation Carbon nanotube Ginger Solar oil production concentrating Solar agriculture Mushroom drying onion garlic drying Solar radiation absorbed ellipsoid Drying solar wood timber drying solar charcoal sun baking sun energy surveying Parabolic mirror Diocles Telescope PAR lamps axis of symmetry circular paraboloid energy classical antiquity curvature energy focal point lighting liquid mirror parabola parabolic microphone plane wave point source radio telescope radio sunlight electromagnetic wave reflecting mirror solar reflection reflective rotating furnace satellite dish solar cooker sound spherical aberration spherical reflector spherical wave vertex Radar equation Cassegrain reflector primary concave mirror secondary convex mirror .NET Reflector browser decompiler static analyzer Retro-reflector Corner reflector Parabolic reflector parabolas parabolae parabolic Parabolic mirror Paraboloid shape parabolic reflector Spherical aberration corrector plate Soft focus parabolic microphone retroreflector retroflector cataphote horn antenna microwave horn feed horn Dipole antenna solar tracking mechanics weather surveillance radar Doppler weather radar Pulse-Doppler radar solar thermal dephlegmator solar powered ammonia water Diffusion Absorption Cooling Machine Solar Energy Applications Dwellings Hybrid solar fridge Absorber Heat Recovery solar thermal power rock-bed storage rock-bed thermal energy storage Sustainable building Perspex Fabrication solar parabolic dish composite material aluminium dish turn a flat sheet into a parabolic dish Satellite Dish Solar Cooker Parabolic Dish Mirror Paraboloid DIY Reflector Huge Parabolic Mirror Solar Power Reflective Film Commercial Product Coordinate geometry Make own parabolic mirror off axis parabolic mirrors Confocal Paraboloidal Coordinates, Helmholtz Differential Equation Parabolic Coordinates, Parabolic Cylindrical Coordinates Conic Section Ellipse Hyperbola Parabola Catacaustic Parabola Evolute Parabola Inverse Curve Parabola Involute Parabola Negative Pedal Curve Parabola Pedal Curve Paraboloid Quadratic Curve Reflection Property Tschirnhausen Cubic Pedal Curve Welch Apodization Function Circular Segment Geometric Centroid Parabola strong crylic solar mirrors acrylic parabolic mirrors Fresnel lenses parabolic mirrors cooking making solar biochar solar soldering solar glass cutting glass solar water distillation Sun Bin online solar-chat Sun Wu concentrating Solar Thermal Qdot Probes solar quantum dot nanocrystal semiconductor material Power Plants Electricity Generation point-concentrating non-concentrating Power Plant Central Receiver Power Plant non-concentrating generation Dish/Stirling System point-concentrating Parabolic Trough Solar Chimney tap the sun dual-axis efficiency electrical electronic elevation angle encoder ensure equation example illustrated input installation interface irradiation mechanical microcontroller maximum power point Mppt solar tracking monitoring movement NREL open-loop control operation optical optimization output parabolic dish parameters Trimble Platform Gimbal photovoltaic power budget power conversion encyclopaedia Pursuing the sun remote satellite slew drive solar cells solar collector solar concentrator solar dish solar energy solar harvesting solar position algorithm solar power system solar radiation solar receiver solar reflector system solar resource solar thermal energy solar tracking applications solar tracking control solar tracking error solar tracking platform solar tracking system solar vector stand-alone stepper motor Stirling engine sun path sun position sun sensor sun tracking sun vector sunlight tracker solar Zig zag tracking Stepwise tracking Bang bang tracking control on-off programmable motor control trigeneration triple generation heat recovery solar polygeneration solar quadgeneration vision Wii remote weather station weather center wind Solar lighting Concentrated solar energy Fibre optic bundle solar simulation Matlab Simulink Matlab Simulink Modelica TRNSYS solar synthesis Energy analysis Efficiency Green buildings Efficient buildings automatic solar tracking system Twitter solar tracking system using microcontroller Micro-controller Digital Electronics Computing sun position solar tracking mechanism solar tracking system circuit diagram solar tracking system project solar tracking circuit solar navigation systems sun navigation systems Inertial navigation system solar tracker orientation and attitude measurements automatic dish positioner automatic camera positioner automatic telescope positioner thermal imaging tracking time controlled astronomical algorithms satellite positioner welding positioner CNC positioner CMUcam Open Source Programmable Embedded Color Vision Sensors CNC funtionality antenna positioner antenna steering electro-pneumatic solar actuation satellite positioner solar positioner sntenna positioning system solar positioning system robot solar positioner robotic positioning solar tracker kit DIY solar tracker electronics kit portable solar tracker Sun position Smartphone Sun chaser hybrid solar Meccano solar tracker Lego solar tracker antenna steering sun platform steering augmented Reality Sun path diagram app Facebook solarkraftwerk green energy clean development mechanism CDM carbon credits bankable environmental-consciousness kit stirling dish Net metering rapid prototyping welding CNC machinery Design Analysis COMSOL Matlab Labview Maple PSpice Mobile Studio Silicon Laboratories EES CAD SolidWorks Inventor NX Cadence OrCad PSpice Programming Matlab C Python ActionScript solar hybrid FFA firefly algorithm sun tracker smartgrid demand side control demand response scheduling solartechnology solartrak harness power of the sun solar flux DNI Air Mass Energy Use Intensity Life Cycle Energy Use Cost Renewable Energy Potential Annual Carbon Emissions Annual Energy Use Cost Energy Use Electricity Potential Energy Savings Monthly Heating Load Monthly Cooling Load Monthly Fuel Consumption Monthly Electricity Consumption Monthly Peak Demand Annual Wind Rose Monthly Design Data Annual Temperature Bins Diurnal Weather Averages Humidity C chipKIT DesignSpark PCB hardware MAX32 Microchip microprocessor programming language sun sensor software solar array tracker Sunseeker surface-mount design PICkit Autonomous power Electric decentralized autonomous energy system low-temperature Stirling engine transforms heat energy to mechanical and electrical energy developing country Millennium Villages rural area smallholding solar countryside solar farm isolated household autonomous power off-grid community island village eco estate remote island deep rural settlement rural power remote location isolated region mini grid solar farm solar farming sun energy rural environment rural community solar collector panels mounted support system Microchip Bluetooth Pay-as-you-go Electricity Lights solar stove spatial information KMZ file Google Earth ArcGIS Explorer Attribute table Excel Power Towers Dish Systems Trough Systems Ring Arrays Slat Arrays Fresnel Arrays Photovoltaics lamda sensor solar wood pellet boiler next energy sun new energy solar gasifier technology Azimuthal tracker Sun energy for free radar sun tracker IP address Instagram Allen Bradley MicroLogix controller Polarised Light Sun angle Sensor pixel tracker pixel resolution aiming at the sun differently angled polarizers polarised lenses patent multibody mechatronic solar tracking System energetic efficiency photovoltaic array mechatronic solar trackers Energy balance Fuzzy Logic Control FPGA Solar Tracking space frame System Solar Tracking Actuators Reliable Easy to Install Optimized for Drive Efficiency Solar Actuators Solar Tracking Jacks Mechatronics System Design solar tracking system stepper motor actuator load torque Mechatronics Dual Axis Solar Tracker Solar Tracking Servo System Mechatronic systems prototype servo motors Simulation dual-axis solar tracker improving performance Solar Tracking Photo-Voltaic System Solar Modules Disaster Prevention Salt Mist Test Multi-Purpose Solar Powershelter Slums peri urban autonomous solar power solar synthesis solar photosynthesis water photooxidation Sunway Smart String Box Parallel string box serial communication system integrated remote control Buck/Boost Inverting Controller Solar Energy Technologies Photovoltaic Systems Producing electricity directly from sunlight Solar Hot Water Heating water with solar energy Solar Drives Solar Electronics solar XGB Controller i3H Control Center Jaguar Inverters iSmart V3 i3 Range i3C PCB Terminals Power Supplies Din Terminals Temperature Controllers Limit Switches DC Isolators C4 Motor Circuit Breakers QB Sensors Signal Conditioning Cam Switches Miniature Circuit Breakers Solar Connectors Solar Electricity using sun's heat produce electricity Passive Solar Heating Daylighting Solar energy to heat and light buildings Solar Process Space Heating and Cooling Industrial commercial uses sun's heat solar blanching solar drying rehydration inverter computation power factor calculation invertor solar power triangle YouTube pursuit of the sun Fibonacci Numbers golden mean solar tracking automation Mathematical calculations String lists and buffer processing Logic module programming Date and time functions Control Engineering modules Digital Signal Processing Solar Heating Solar Ventilation Solar Air Conditioning Building automation Network and communication functions Measurement and Sensor Technology Device drivers digital peripherals Robotic Arm Object Tracking Pixy Camera Pixy Pet Robot Adafruit Learning System Pixy camera powerful image processing capabilities track objects color Pixy Robot code ObjectTracking Pixy Camera Brewer–Dobson circulation energy-system simulation optimization tools BALMOREL EMPS MESSAGE MiniCAM PERSEUS RAMSES WILMAR Planning Tool National energy-system tools 4see AEOLIUS E4Cast EMCAS EMINENT EnergyPLAN ENPEP-BALANCE GTMax IKARUS INFORSE Invert LEAP MARKAL/TIMES Mesap PlaNet MODEST NEMS ORCED PRIMES ProdRisk SimREN SIVAEL STREAM UniSyD3.0 WASP Island energy-system tools H2RES Local community or single project energy-system tools BCHP Screening Tool COMPOSE energyPRO ETEM MODEST HOMER HYDROGEMS TRNSYS RETScreen Mechatronics Solar Tracking Sun's Energy Solar Energy Profile Solar Radiation Map Solar Radiation Spectrum Solar Insolation Crystalline Silicon Solar Cells Thin Film Solar Cells Solar Efficiency Limits Sun Tracker Array Solar Inverters Micro Inverters Space Based Solar Power SunBall SolarCube Solar Smoker solar oven solar furnace Solar-Aided Water Splitting tapthesun illuminated daytime solar function software function Solaris Simatic HMI PVSS Simatic WinCC open architecture Intel IAMT Profibus module Profinet controller Dezentralized Automation COMOS solar automation SINVERT Siemens Logo Harvesting trough Concentrated Solar Power Single Axis Tracking Parabolic Trough Solar Trackers Facing the Sun free energy generator solar Dual Axis Electronic Compass Garmin Gps Maximum Power Output Precise Accuracy Proper Position Rs232 Rs485 Signals Solar Array Solar Panels Solar Tracker Back of Panel Boost Solar Power Liquid Air Energy Storage Flow Batteries Compressed Air Energy Storage Thermal Energy Storage Electric Energy Storage Intelligent Solar Tracker Robot solar assessment solar Surveillance WiMAX Resource Allocation Algorithm Solar Energy Municipal Heating System thin film modules Angle of Attack Sensor DFDR Inertial Accelerometer Fuel Compensator Fuel Flow Transmitter Fuel Quantity Probe Liquid Level Sensor Position Transducer Pressure Transducer Reservoir Tank Switches System Harnesses Temperature Sensors Total Air Temperature Sensors Transient Suppression Units solar tracker single axis tracker Linear Actuator parabolic trough tiny tracker csp satellite actuator driver solar heat solar electronics LOGO Solar Tracking Levelized Cost of Energy LCoE Solar Tracking System Video Processing Micro-controller embedded smart-camera machine vision camera sun tracker LabView simulations model demonstration Labview DSP module CompactRIO developer suite signal conditioning power-train control smart metering chronological tracker sun synchronous tracking Thin-film solar tracker Collimating Sensor Radiation Observing system orbital tracking automatic solar tracker in the Solar Radiation Observing System solar tracker automatic all-weather high precision two control modes orbit tracking mode sensor tracking mode Orbital tracker mechanical solid state solar tracker Biaxial tracking systems tandem single axis tracker system Process heat process steam solar boiler Solar Tracker interface Labview Solar Tunnel Drier, Concentrating Power Systems Solar Street-Lighting System Gas Water Heaters Solar Lanterns Dual Axis Solar Tracker Rv Solar Battery Charger Rv Solar Panel Kit Buck/Boost Inverting Controller starfish sun pi Synchronous automatic tracking to sun without electric power High tracking precision of portable solar water boiler time-based control sunlight intensity comparison space-time synchronization SunFlower Tracker 2-Axis Tracking System Follows the Sun from Sunrise to Sunset Available in single and double axis Dual Axis Azimuth Elevation Tracking Geographical coordinates of the SunFlower Tracker Integrated Trackers Interface Computer Control System Motor protection High precision circuitry prevent detect overloads Single axis backtracking solar development solar farm construction planning Tracker Target sun Satellites GPS Communication Single-axis solar tracking system photovoltaic solar array power tracking device PV array azimuth angle sun high-precision tracking PV park patented Optical design Wind Power Pilot Plant Solar Power Hydro Power Engine Power Power Systems Energy Storage Water Pumping Efficient Lighting Conservation high radiative flux solar furnace clean energy jobs Solar Desalination Saltwater Brackish water briny water brine Solar Path visualization path sun across sky Solar Boilers Chillers Radiant Heat Exchangers Gasification Parabolic Systems Parking Canopies Tracking Systems Consulting Services Wind Energy Rankine Turbines Anaerobic Digesters PLC Control Data Logger Geothermal Solar Water Management sun path Orthographic projection solar Waldram diagram sun energy solar Sankey diagram Shadowing Control Modelling Case studies Acoustic Laser thermoacoustic engine biogas digester PV Panel Shading Parabolic dish fabrication Solar Cube sensor Auto tracker Welding positioner Led lighting CNC turntable solar tracker Solar position motion compensation and stabilization Dynamic positioning Solar tracking structure motion monitoring Orientation and attitude Steering a Dish Antenna PCB design Parabolic dish material ska dish AC Disconnects DC Disconnects AC Drives Circuit Protection Solar Enclosures Motor Control PLC Power Distribution Power Supplies Pneumatic solar FTP server Solarbot Car tracking 3D printer parabolic parabolic dish 3D printer code snippets pixie camera solar tracker pixy camera sun tracker video camera solar webcam solar wiimote camera PIXY Smart Vision Sensor video processing Open Vision Control Tracking Software Home Solar Power solar pay as you go solar Sim card raspberrypi program code snippets raspberry pi solar tracker Solar position SDK Solpos SDK OpenGeo-Suite SDK Sky dome Parametric shading analysis Solar radiation analysis Sunlight rays Solar Thermal Energy Storage Power generation storage Steering a Dish Antenna electrical infrastructure for housing developments and residential property as green field eco development Green property Eco Country estate Green development Green property concept Eco villages solar cube sensor solar training models Labview Solstation course of the sun in the sky climatology of solar radiation seasons and orography Line-focusing Point-focusing technology diurnal circle apparent path followed by the sun due to the earth's rotation on its axis solar radiation models GIS solar atmospheric models Animation of Sun Path and Solar Position Animation Altitude is the vertical angle Design, construction and testing of a self-tracking solar concentrating reflector Point focus parabolic dish Stirling system variable stroke variable angle swashplate variable stroke kinematic Stirling engine KSE FPSE Stirling Thermal Motors direct illumination receiver kleinmotoren curvature element fluid-structure interaction finite solar collector photovoltaic panel tracker maximum power point tracking MPPT tracking Sun Contour Projector System Two-Stage Travelling Wave Thermoacoustic engine Video camera sun tracker iTrack Script reference SDK engine Serial Parallel port Robotic arm Motion tracking Head tracking Hand tracking motion controller SDK physical geography geospatial methods solar environment interaction geospatial technologies GIS Remote Sensing Cartography small-scale wind turbines and solar assisted anaerobic digester biogas digester solar assisted airconditioning solar assisted heating solar thermal salt storage Solar Tracker Printed Circuit Board PCB Design Software Orbit of the sun Sunrays, lights rays Grid-tie Solar angle calculator Solar position plugin Wolfram language Xbee processor Sun position appletHtml, javascript PHP dynamic C Python ArcGIS Calculate Solar Energy real time aiming solar receiver dish rotary encoder FTDI drivers Data Matrix Positioning System Position Guided Vision Inductive Positioning Systems a prototype of automatic; feasibility design presented methodology microcontroller photo resistor photovoltaic cell solar tracker ensures solar tracking stepper motor This book details Automatic Solar Tracking Automatic Sun Tracking System, Solar-Tracker Automatic Sun Tracker System tracking Design construction automatic solar tracking system Intelligent tracking system sutomatic sun tracker solar responsive design solar responsive sun following Solar Tracker Position Control generate ephemerides solar-system bodies Planetary Calculation Engine Ephemeris calculates planet positions Delphic Oracle uses the Moshier ephemeris online software toolbox Astrology Astronomy Graphic Ephemeris Comic Almanack Web-based Expert System AstroSurf Pivot Platform Google Geo Developers Sun Surveyor sourceforge github agriculture architecture bathymetry population csv data visualization dbf DEM ecology ecophysiology ecotect fabrication geodesic GIS grasshopper housing hydroponics incident solar interior landscape matlab minimal surface phytoremediation psychrometrics python qgis rhinoscript solar panel stereographic projection sustainability thin film topography urban design urban planning weather data weather maps solar assisted seawater desalination Solar garden geconcentreerde zonne-energie High-Concentration photovoltaic PV Systems HCPV photoreceptor sensors mechanical sunflower optics photonics Klimatotvirni factors solar panel backtracking control Google Earth Bing Maps API Virtual Earth New energy inventions Parabolic materials SketchUp File Download SketchUp download sketch Overunity automatic positioner solar tracking powered 2 axis tracker github solar tracker sun tracker code Propeller Parabolic solar reflector Solar farm solar village DIY Solar Tracking Device 2-axis servo solar tracker Arduino sketch embedded c code Header file for a solar tracker atmega Circuits Telematics circuit Az/El Telescope Mounts Alt Azimuth Mounts Flat plate collector Modular solar tracking Photovoltaic tracker Arduino Sun Harvester Shield Chronological tracker Picaxe solar tracker Solar robotics Microprocessor controlled solar tracking Tracking solar concentrator Equations for Solar Tracking solar tracker based on motorized rotating mirrors solar tracking circuit solar tracking system using microcontroller solar tracking system circuit diagram Solar photochemistry Align with the sun Mechanical solar tracking system Self powered solar tracking Solar panel tracking Solar tracking tree Solar water splitting Particle Mechanics solar hydrogen oxygen electrolysis Crossbeam Fission and thermal oxidisers using concentrated sunlight keyring atom complete mechatronic system Actuator bearing solutions for solar tracking High Concentrator Low Concentrator Solar Electric Applications Luminescent Solar Concentrators Holographic Solar Concentrators Spectrum Splitting Concentrators High Concentration Optics Organic Photonics PV CPV module bandgaps Predict position of sun Software algorithms predicting position of the sun Intelligent solar tracking Solar tracking artificial intelligence Robotic solar tracking Weather modelling Siemens TG Smartgrid systems Totally integrated automation Universal tracker controller Multi-axis Solar harvesting, Astronomy, Satellite tracking Ray tracing, concentrating solar power software Satellite-derived solar resource maps Solar Resource Assessment estimating direct normal irradiance cloud cover index solar irradiance model estimates mapping global illuminance from satellite data Correlation models estimation diffuse fraction global illuminance from satellite data Daylight availability model global diffuse horizontal illuminance irradiance sky modeling validation daylight availability illuminance irradiance on horizontal plane evaluation global diffuse luminous efficacy all sky conditions tropical climate humid climate Correlation model satellite data compute Cloud Fractional Coverage Intelligent solar tracking Solar tracking artificial intelligence Robotic solar tracking Real time tracking GPS coordinates Software to top list Free download Low limited budget Model electronics Sun tracing system Sun ray tracing software sun tracing software Sun tracing software algorithm program Sun pointing Computerized solar tracking Ground path images Mapping silhouette on the sky d sun tracking Mobile tracking mobile tracing torrent serial crack keygen active downloads crackserial FullReleases cellphone tracing Low budget solution sunposition computer software solar position algorithm trace program Sun's Daily Path Across the Sky mechatronic platform solar tracking tracing the sun Tracing the path of the Sun Tracing The Sun Sonnet-Tracing The Sun Follow the sun sun following software follow the sun software development Calculation of sun's position in the sky tracing the sun sun track and trace tracking the sun across the sky tracking the sun automatic sun tracking system sun tracking system project sun tracking solar panel project sun tracking sensor sun tracking solar panel ppt The Tracking Solar Cooker Solar Cooking Solar Panel Tracking Systems Ship power system, satellite system Edged on silhouette of sky Angle Sensitive tracking Dynamic tracing Proliferation of the Sun Solar rotation Sky scan-sky scanner Visualize sun path in sky Elevation angle declination angle Sun path projections Sun produces a daily solar arc projection sun in sky Sun and sky Orbital path Sun projection software Profile of sun in sky Solar disk, plane in sky Sun's current position Smart Remote Microgrids Autonomous power distributed energy systems Radiotelescope Satellite tracking Following celestial bodies Global Climate Energy Project Processor code Orbit of the sun Sunrays, lights rays Grid-tie Solar angle calculator Solar position plugin Wolfram language Xbee processor Sun position applet Html javascript PHP dynamic C Python ArcGIS Meridional Altitude Simulator Declination Ranges Sidereal time Synodic time Simulator Ecliptic Simulator Union Seasons Demonstrator Azimuth/Altitude Demonstrator Daylight Simulator Obliquity Simulator Ecliptic Zodiac Simulator Longitude Latitude Demonstrator Celestial Equatorial Demonstrator Paths of the Sun Sun Motions Sun Motions Demonstrator Sun Rays Simulator Sun Position on Horizon Big Dipper 3D Seasons Simulator Coordinate Systems Comparison Daylight Hours Explorer Antipodes Explorer Sidereal Time and Hour Angle Demonstrator Celestial and Horizon Systems Comparison Sidereal and Solar Time Simulator Climate Change Impact Demography Dynamics GIS Remote Sensing Generate solar path tracking algorithm generator control positioning monitor safety devices measure wind speed process alarms remote control Environmentally Responsive Solar Sun Parametric Tools Terrestrial Solar Radiation Solar Radiation at the Earth's Surface Atmospheric Effects Air Mass Motion of the Sun Solar Time Declination Angle Elevation Angle Azimuth Angle The Sun's Position Solar energy solutions SRF All Sky Camera Solar Radiation and Photonic Sensors Photovoltaic Evaluation Systems Heat Flux Sensors and Thermal Conductivity Testers Meteorological Sensors and Devices Sun Position Calculator Sun's Position to High Accuracy Solar Radiation on a Tilted Surface Arbitrary Orientation and Tilt Calculation of Solar Insolation Solar Radiation Data Measurement of Solar Radiation Analysis of Solar Irradiance Data Sets Typical Meteorological Year Data TMY Making Use of TMY Data Average Solar Radiation Isoflux Contour Plots

Sunshine Hour Data Cloud Cover Data PN Junction Solar Cell Operation Design of Silicon Cells Manufacturing Si Cells Modules and Arrays PV Characterization Material Properties Solar Photovoltaics solar irradiation solar panel angle solar power solar power calculations green automation eco power meter controller sun position games Microsoft PC Xbox PlayStation Nintendo Wii Windows Games VLC activeX plugin VB.NET Sun position Visual Basic VB.NET AGSatTrack iSAT Interactive Satellite Viewer ISSTracker J-Pass J-Track OnTrack Real-Time Satellite Tracking with Google Maps seeAsat CyOrbitView BINARY SPACE Classic ASP.Net C\# Visual Studio TFS JQuery Telerik Kendo Microsoft SQL Server MVC, Angular js Inject Javascript OOP MVC WebAPI Dependency Injection ServiceBus Angular MV framework HTML, CSS Database SQL Oracle PL SQL Microsoft Visual Studio .NET code C\# XML MVC Web Forms Entity Framework MS Enterprise SOA Java J2EE XML WebSphere WebLogic Application Server Spring Hibernate Web services SOAP REST concepts WSO2 ESB Developer Studio Carbon platform Application Server Core Java J2EE EJB MDB JAX-WS JAX-RS MVC Spring Struts Maven Jenkins SVN Selenium MS SQL server Stored procedures PL/SQL MS BI stack SSAS SSIS T-SQL stored procedures MDX multidimensional cubes Sunpower Tracking the sun Solar energy radiant light heat from the sun harnessed solar heating solar photovoltaics solar thermal electricity solar architecture artificial photosynthesis MOLAP and ROLAP UNIX admin Webspher Weblogic JBoss Cobol Fortran Abacus Mule XPath expressions functions XSLT Mule ESB SOAP REST API web-based Cold Fusion SQL server Java J2EE KShell Perl Oracle Exadata WebSphere Exadata SmartStream Windows MS Office MS Visio ER Studio Data Architect Visual Studio Relational Database SSIS Assembler REXX COBOL PL1 XML SAS MXG HTML CRplus BMC CONTROL-M CICS TS IMS DB2 Linux Unix Windows PHP Dash Board Creation PL SQL Dynamic SQL T-SQL Oracle forms SQL Server SSRS SSIS SSAS SDLC Agile Waterfall PVCS SDLC Teams Dimensional Modeling Data Modeling Jaspersoft Creating dashboard filter IBM zSeries HMC Processor Interface SYSPLEX Adobe InDesign Adobe InCopy QuarkXPress with ID2Q XTension Adobe Debut .lrv file Peak Power Tracking Buck Solar Charger Maximizer solar magneto hydro dynamic power generation solar trackers dual axis sun trackers single axis sun trackers spare parts and accessories linear motors actuators solar positioners external din rail heliostats solar panels solar mirrors solar inverters ground screws monitoring systems software turning parts pcb boards solar accessories rs485 accessories can bus accessories cable Pan and Tilt Kit with Servos Robot Kit Robotic Arm Bioloid Humanoid Robot Kit Quadruped Hexapod Robot Kit Robot Turret sun tracker Robot Kits Robot Parts BIM (revit) EnergyPlus Energy-PLAN Convection Natural convection Cavities Temperature Solar energy Coupling Facilities OSA Networking Interface ICC Integrated Console Controller FICON Fiber connectivity to peripheral devices DASD Storage Flash Copy ATL VTL Storage z/OS anti-virus Operating System z/OS z/AWARE BCP JES2 IOCP HCD RMF SMF DFSMS DFHSM DFDSS FDR SDSF DFSORT SMPE TSO CA-MIMS ISPF PDF RACF SVC Dumps OMEGAMON TMON VTAM SNA TCP/IP OSPF TCP/IP Routing Protocol VIPA FTP File Transfer z/OS PS PO PDS PDS/E z/FS VSAM/E Oscat Solar Position Algorithm s7-1200 Siemens Step 7 library SUN POS Block Sun Position Solar tracking Design Development SunTracking mechanism sun tracking mechanism solar automatic electronic control position solar parabolic solar cooker automatic two axes sun following calculation optimal position auto sun tracking Auto-Tracking Solar Power System follow the different position sun perpendicular light axis sunlight in the movement of tracking sun Solar Tracking Controller Pixy camera Made for video music games Sun Tsu sun tsze the rising sun negotiate sun position sun journal fast track download cracked full code crack download avoid warez keygen iso torrent full crack direct download ddl free key new latest serial no cd release Sun microsystems track electricity download standard component library overview solar dynamo solar hot water heating inverter solar heatpump solar powered farming Properties of Light Energy of Photon Photon Flux Spectral Irradiance Radiant Power Density Blackbody Radiation screenshot Sun Solar Radiation in Space Solar Radiation Outside the Earth's Atmosphere Solar Radiation at the Earth Surface Atmospheric Effects Air Mass Motion of the Sun Solar Time Declination Angle Elevation Angle Azimuth Angle The Sun Position Sun Position Calculator Sun's Position to High Accuracy Solar Radiation on a Tilted Surface Arbitrary Orientation and Tilt Calculation of Solar Insolation Measurement of Solar Radiation Analysis of Solar Irradiance Data Sets Typical Meteorological Year Data (TMY) Making Use of TMY Data Average Solar Radiation Isoflux Contour Plots Sunshine Hour Data Cloud Cover Data Sun Harvesting Electronics nano material nano composites photosynthesis organic solar cells iPhone, iPad, iPod Touch NI USB signal streaming OEM version LabVIEW LabWindows/CVI Measurement Studio Visual Studio .NET NI-DAQmx driver software NI LabVIEW SignalExpress LE interactive data-logging software cURL libcurl SourceForge download Debian Ubuntu Fedora Core Suse Mandriva Tiny Core BSD Mac OS X Windows Sun Harvester Driver Board sun path artificial leaf emulate sunflower solar tracking Supercapacitor graphene solar thermal storage Organic Solar Cells Dry run test wii remote wiimote Bluetooth Borland Delphi Windows XP Professional SP2 BlueSoleil Nintendo AVR microcontroller solar tracking GlovePIE BlueTunes Wii Key Virtual Drum Kit WiiMedia WMD image processing software camera footage shots Active sun tracking platform mobility slewing drive VFD variable frequency drive brush less DC motor mechatronic transducer design hydraulic tracking stepsize tracking resolution bandwidth deadband window Hex file firmware Doppler location controller southern hemisphere control northern hemisphere PIC tracker shield motor shield Arduino LEGO block meccano set K'NEX building set sun tracking animation solar tracker animation motions of the sun simulator PC MS-DOS Windows Microsoft Windows Linux Macintosh Apple Macintosh Java Psion HP-48 TRS-80 WP-2 and NEC PC-8201A Source Code Programs in source code Firmware Spreadsheet files popular formats I2C bus converter shield Arduino Telemecanique solar windmill solar power windmill sun tracker temperature difference solar energy storage mechanism Thermal Pneumatic Tracking for Solar Energy Thermal self regulating window cryocooler Liquefaction of gases Liquid air Liquifying Air solar air conditioning Rural electrification Solar electrification Energy kiosk Distributed generation Thermosyphin phase change material Thermosyphon storage energy carrier Solar desalination Tubular solar battery CAD drawing design Stand-alone Grid connected Solar plasma AEG Bateman waste heat waste to heat waste to energy Telemechanik Shareware Freeware Solar Tracking Software SMS Eiffel ABL ABAP Python Objective-C PHP JavaScrips Gambas Clarion Java Clipper Perl Vala Ajax Oz Visual FaxPro Ruby C\# Visual Basic Harbour Magik PHP5 Visual FoxPro VBNET Perl Fortran 77 and ANSI C UBasic SPICE Kernel Solar Panel Sun Position Tracking .Net development, Java J2EE Java 2 Enterprise Edition J2ME, PHP Development, C C++ Python Android Application Game Development Ipad Iphone App development Solar Tracking Vehicle Tracking Mobile Tracking Merlin Gerin sun tracker control astronomy program real-time Alt/Az astro library WebGeocalc A GUI Interface SPICE Geometry Calculator Solar Resource Models and Tools Renewable Resource Data Center Bird Clear Sky Model clear sky direct beam hemispherical diffuse total hemispherical solar radiation Bird Simple Spectral Model DISC Model direct beam irradiance PVWatts estimates the electricity production Calculator System Advisor Model (SAM) Simple Model of the Atmospheric Radiative Transfer of Sunshine (SMARTS) Solar and Moon Position Algorithm (SAMPA) Solar Position Algorithm (SPA) SPA calculate solar position Solar Position and Intensity (SOLPOS) Solar Path Calculator spectral mismatch calculator Autodesk project design file Ecotect Analysis Sunrise and Sunset Calculator Download NASA Sunrise Calculator Sunrise Sunset Times NOAA Sunrise and Sunset Calculator Sunrise Calendar App for Windows Modicon Watts Up rail electrification linear alternator Android Projects Cloud Computing Electronics Projects Engineering/Diploma/Bsc-IT/Msc-IT Projects Games Hardware Projects iOS Projects IT Projects J2me Projects Maths Calculations Mini Projects NS2/NS3 Projects Software installation GPS Software Vehicle Tracking Mobile Tracking dynamic positioner active platform positioning platform dynamic tracking pedestal active mobility platform tracker telescope drive firmware Mathematics of a Sunflower Energy Climate Change Cool Earth Solar Power Grid operation Photovoltaics Solar Modeling Steps Irradiance and Weather Incident Irradiance Transposition of irradiance into direct and diffuse components Translation of irradiance to the Plane-of-Array Shading, Soiling, and Reflection Losses Evaluation loss irradiance shading soiling reflection losses Cell Temperature Calculation cell temperature irradiance ambient air temperature wind speed Module Output Calculation IV curve irradiance temperature conditions DC and Mismatch Losses DC array mismatch wiring DC to DC Max Power Point Tracking Adjusting DC voltage maximize output power array DC to AC Conversion conversion losses inverter AC Losses AC losses utility meter Modeling Steps Outline Irradiance Weather Sun Position Solar Position Algorithm (SPA) Simple models Sandia code Irradiance and Insolation Extraterrestrial radiation Air Mass Direct Normal Irradiance DISC Model DIRINT Model Global Horizontal Irradiance Diffuse Horizontal Irradiance Spectral Content Standard Spectrum Satellite Derived Data Weather Observations Air Temperature Wind Speed and Direction Precipitation Air Pressure Irradiance Data Sources for Performance Modeling National Solar Radiation Database Typical Meteorological Years Site-Specific Data Measure Correlate Predict Irradiance Modeling Uncertainty and Variability Characterization of Irradiance Variability Interannual variability Short-term variability Spatial variability Clear Sky Irradiance models Incident Irradiance Array Orientation Fixed tilt Single Axis Tracking 1-Axis Horizontal Roll 1-Axis Tilted Roll 1-Axis Equatorial Two-Axis Tracking 2-Axis Azimuth-Elevation 2-Axis Polar 2-Axis Tilt-Roll Array Orientation Errors Effect of Array Tilt Errors Effect of Array Azimuth Errors Plane of Array Irradiance Measuring POA Irradiance Calculating POA Irradiance POA Beam Angle of Incidence POA Ground Reflected Albedo POA Sky Diffuse Isotropic Sky Diffuse Model Simple Sandia Sky Diffuse Model Hay and Davies Sky Diffuse Model Reindl Sky Diffuse Model Perez Sky Diffuse Model Concentrators POA Irradiance Uncertainty and Validation Shading, Soiling, and Reflection Losses Shading Far Shading Near Shading Soiling and Snow Soil Monitoring Studies Snow Effects Incident Angle Reflection Losses Physical Model of IAM ASHRAE Model Martin and Ruiz IAM Model Soiling effects on Incident Angle Losses Sandia Model Cell Temperature Definitions and Overview Module Temperature Thermocouple Voc method Sandia Module Temperature Model Faiman Module Temperature Model Transient Module Temperature Model Cell temperature Sandia Cell Temperature Model PVsyst Cell Temperature Model Transient Cell Temperature Models Module IV Curve Definitions and Overview Effective Irradiance Spectral Mismatch Single Diode Equivalent Circuit Models De Soto Five-Parameter Module Model PVsyst Module Model Point-value models Sandia PV Array Performance Model Loss Factor Model PVWatts Improvements PVWatts DC Mismatch Losses Mismatch Losses DC Wiring Losses DC Component Health Module IV Curves String IV Curves String Mismatch Losses Array IV Curves Array Mismatch Losses DC Wiring Losses Uncertainty and Validation Studies Maximum Power Point Tracking Array Utilization MPPT Voltage MPPT Efficiency MPPT Algorithms Uncertainty and Validation DC to AC Conversion Inverter Efficiency CEC Inverter Test Protocol Operating Temperature Sandia Inverter Model Driesse Inverter Model Inverter Saturation Loss of Grid Advanced Inverter Features Power Factor Control Uncertainty and Validation AC Losses AC Wiring Losses Transformer Losses PV Systems Operations and Maintenance Availability Failure Mode and Rates PV System Output Definitions and Overview PV System Monitoring Monitoring Equipment Data Filtering Data Filling PV Performance Metrics Performance Ratio Performance Index Annual Yield portable handhelp ipad ipad apps iPhone iphone apps ipod apps solar apps solar ipad apps solar iphone apps solar ipod apps Solar Panel Suitability Checker Solar Panels Suitability Checker Solar Panels solar smartphone apps solar energy Notebook tablet PDA personal digital assistant Analysis of shade Installation trackers Analysis topographical contours anemometer and data recorder communication monitoring digital wind speed displays Sun Source Of EnergySolar Photovoltaics solar irradiation, solar panel angle, solar power, solar power calculations Microsoft ASP.Net Sql Server Visual Basics Visual C\# Visual Basics PHP/MySQL Core PHP Cake PHP Zend Symfony Web Design/Graphics Design Adobe Flash Adobe PhotoShop CSS HTML/XHTML XML Open Source Drupal Joomla Magento Wordpress Rich Internet Application Adobe AIR Adobe FLEX AJAX Microsoft Silverlight Mobile Application Development Iphone Application Php Mysql ASP.Net with C\# Open Source Technologies Web Designing Arduino Motor Controller Circuit Matlab Arduino Php Lcds Xbees Tactical Texting Bau Energiebau Solarstromsysteme solar coffee brewing concentratore solare caffe Solar Energy Winemaking Carbonization Recycling Reclamation Green initiative solar clean development mechanism tesla solar tracker system racking system GPU programming concept PLC General purpose computing graphics processing unit GPGPU GPGP GP2U thermo solar thermal solar position sensor sun angle sensor potentiometer solar artificial photosynthesis plant Bioreactor lighting Biofilm Thermophilic solar Photosynthetic Organisms species strain carbon capture sequestration Concentrated solar Research support guide Guide to Solar system developers Community of practice Mobile device support Sun tracking glass louvre installation Sun tracking glass window louvre Solar irrigation The Solar Tracker Tracking the Sun orbit Solar Parabolic Collectors Solar instrumentation and control Solar farm inverter monitoring and control industrial aggregated solar farm Solar Air pollution control equipment Webinar Unbundling Multi-task manager and notification system Workflow application Mosaic platform Solar power lifecycle analysis Carbon footprint monitoring environmental impact reporting Managing solar tracking devices locating sun in sky Sun position offset Jump-pad webtop sun tracker Solar Portal On demand sun position public cloud pay for use sky-drive Solar monitoring metrics Solar measurement indicators Solar assessment analytics dual axis solar tracking system dual axis sun tracking solar systems solar sun tracking solar systems solar tracking system solar tracking system solar solutions solar panel tracking systems sun tracking solar system solar tracking system manufacturer solar tracking system actuator solar tracking system tracking download solar position algorithm dual axis solar tracker dual axis solar tracker application of dual axis solar tracker system dual axis sun tracking system dual axis solar tracking system two axis solar tracking system radar tracking system solar tracking system with two axis working model of dual axis sun tracking system automatic sun tracking system experience automatic sun tracking system sun tracking mechanism sun tracking solar system sun tracking solar panels sun tracking arduino sun tracking project sun tracking sensor sun tracking algorithm sun tracking device tracking solar tracking heater motor drive PHOTOVOLTAIC SOLAR ELECTRICITY DESIGN TOOLS PV Software calculator Free Solar photovoltaic software Online free photovoltaic software Professional photovoltaic softwares and calculator Online Professional photovoltaic softwares and calculator Software tools from inverter manufacturers DC and AC voltage drop and energy losses calculator Sun position calculation sun time Financial analysis PV systems Solar photovoltaic applications smartphone and tablet PV apps Principle and ressources calculate output power of PV systems Solar radiation databases Solar Thermal software Free Solar thermal software Professional solar thermal software Micro Urban Solar Integrated Concentrators panoramic type solar tracking sensor quadrangular table lateral photosensitive elements Collar sensor Sun Tracking Field Robotics Panoramic imaging camera essentially always sees sun Omron Stafsjos Helukabel Abacus Burkert Bytes Mitsubishi electric system drive unit eurodrive bevel helical gear unit SEW cooling Mechanical electronic sun tracking Electro-pneumatics Variable speed servo actuator drive embedded intelligent Solar tracking Industrial firewall modular rackmount computer Scada Process visualisation Climate change control corrosion test hmi touch screen Rugged housing encapsulation housing Kinetic scada telemetry Inductive sensors modulus modbus serial link satellite radio modem satel radio Optical fibre cabling object pattern recognition Intelligent image processing position detection automatic tracking optimized orientation correction vision system camera portable analyzer gas dust flow power transmission cable energy logging and reporting Movidrive movitrac moxa Easy to Install Solar Tracking Actuators Ansys Comsol Quality control facilities large optical reflectors ENEA Joule Heating simulation ABAQUS CAE interface heat generation transient electrical-thermal analysis HETVAL subroutine heating electrical current .inp file .tmp file .trn file Linearizing a electromechanical control system Motor Gear box stiffness PWM contoller position control problem simulink simscape H Bridge controlled PWM load inertia automated PID Tuning PID tuning tool box system identification GUI solar tracking mooc Solar-gel-batteries STATCOM Dynamic reactive power compensation Solar resource assessment Solar dashboard Monitoring Plant control automation and grid integration Networked solar tracking networking Solar powered motor solar vfd Solar tracking manufacturers in the world Navigating towards the sun Solar platform navigator Sun pinpoint solar technology Mil-spec grease lubrication Advanced brush and brushless motion control solutions for a wide range of industrial automation applications, including factory automation renewable energy production door automation sun protection medical devices and laboratory equipment. System solutions are based on brushless DC servo motors/brush-type DC motors integrated power logic controllers planetary worm gearboxes encoders brakes Electro-mechanical Motor control solar tracker AC Batteries AC Motors Alkaline Batteries Alternative Energy Storage Methods Authentication and Identification Battery Applications Battery Comparison Chart Battery Life Battery Management Systems BMS Battery Pack Design Battery Performance Characteristics Battery Power Demand Management Battery Protection Methods Battery Quotation Battery Relability Battery Safety Battery Standards Battery Storage Battery Testing Battery Timeline Battery Types Benefits of Custom Battery Packs Brushless DC and Reluctance Motors Buying Batteries Carbon Footprints Cell Balancing Cell Chemistries Cell Construction Charger Specification Checklist Chargers and Charging Charger Quotation Request Common Battery Case Sizes Communications Buses Communications Satellites Conversion Table DC Motors Direct Energy

Conversion (AMTEC) Discovery of the Elements Electric Machines Electric Vehicle Charging Infrastructure Electrical Energy Electricity Demand Electricity from Biofuels Electricity from Fossil Fuels Electrochemical Energy Generation Electromagnetic Radiation Radio Waves Energy Efficiency Energy Resources Energy Conversion and Heat Engines Flow Batteries Fuel Cell Comparison Chart Fuel Cells Gas Turbine Power Generators Generators Geothermal Power Generation Going Solar Grid Scale Gratzel Cell High Power Batteries High Temperature Batteries History of Batteries (and other things) How to Specify Batteries Hybrid Power Generation Plants Hydroelectric Power Generation Hydrogen Power Instructions for Using Batteries Lead Acid Batteries Leclanch\'e Cells Lithium Battery Lithium Cell Failures Lithium Primary Batteries Lithium Secondary Batteries Low Power Batteries MagnetoHydroDynamic MHD Electricity Generation Motor Controls Nickel Cadmium NiCad Batteries Nickel Hydrogen Batteries Nickel Iron NiFe Batteries Nickel Metal Hydride NiMH Batteries Nickel Zinc Batteries Piston Engined Power Generators Primary Batteries Recycling Redox Batteries Reserve Batteries Satellite Technologies Secondary Batteries Semiconductor Batteries Silver Oxide Silver Zinc Batteries Small Scale Electricity Generation Software Configurable Battery Solar Batteries Solar Power Generation Special Purpose Motors State of Charge SOC Determination State of Health SOH Determination Steam Turbine Power Generators Stirling Engine Power Generator Supercapacitors Thermal Batteries Thermal Management Thermoelectricity Generators Traction Batteries Typical Cylindrical Cells High Power Cells Prismatic Cells Uninterruptible Power Supplies UPS V2G Energy Transfer Water Activated Batteries Zebra Batteries Zinc Air Batteries CMS experiment CERN LHC Super critical co2 brayton hexapod positioners OTDR receiver from Discovery Semiconductors automatic manual gain control Acoustic micro-imaging system linear motor Mobile-friendly Standing Positioner With Tray Automatic Emulation Direct Shear Apparatus Motorized Reflector Telescopes Solar Desalination System D.C. Speed Control System Apparatus Beam Deflectors Beam Positioning and Motion Control Air Bearing motor automatic relay motor control relay mould positioner multi-feed parabolic reflector antenna multi-functional box-type solar sunlight Acquisition Antenna Reflector Optics Interchangeable Feeds Positioner Wave Series Led Illumination Constant Current Control system Tri-Band Motorized FlyAway Antenna System Controllers Auto-Acquisition antenna azimuth position control system Datasheet antenna azimuth position control system circuit and application motorized cable drive system Dish Stowed Position Antenna Dish Clearance Envelope Top View Positioner Travel Rates Elevation Comprehensive substitution iPad sensor Origami-based solar cells increase efficiency Solenoid Valve Hydronorma Hydraulic Pump and Chiller System Turret Head Positioner Current Control system Tri-Band Motorized Fly-Away Antenna System Controllers Auto-Acquisition Motor control light and automatic adjustment apparatus Solar Cooker Satellite Dish Satellite dish solar cooker Motor-driven dish Mounting Pattern on Truck Azimuth Axis Antenna Noise Temperature clear sky reduce installation time and costs Control System motorized drive system no electronics Positioner Travel Rates Elevation Azimuth Polarization Valorisation Informations generales Outils informatiques et ressources Solar Geometry Meteosat Library Clear Sky Library Heliosat HelioClim SoDa Atlas solaire PACA Albedo du sol DataForWind Impacts PV Impacts eolien offshore Impacts filieres energetiques Webservice-energy catalog Chemical Engineering Data Analysis Environmental Fluid Mechanics Matlab Basics spettrofotometriche eseguite ad incidenza normale Calore ad alta temperatura dall-energia solare inseguimento solare inseguitore solare energia termica sole seguito posizionatore motorizzato energia rinnovabile Renewable Energy Technologies Concentrated Solar Power Controllo automatico Satellite tracking Oggetto di monitoraggio Smart Grid solari Sun monitoraggio energia solare Stirling microgrids Efficienza Energetica Exergia Analisi energetici gratuity Como construir tu propia parabolica Definitivo Cocina Solar inseguimento solare, inseguitore solare, energia termica, sole seguito, posizionatore motorizzato PALABRAS CLAVE aireacion bancos de baterias carga de la batería ecuacion de Bernoulli filtros bio-arena biomasa perforaciones filtros de cubo bomba centrifuga la desinfeccion quimica tratamiento quimico del agua compostaje concretas ecuacion de continuidad baterias de ciclo profundo desalinizadoras bombas de desplazamiento la distribucion red la filtracion la ecuacion de flujo la perdida por friccion el flujo por gravedad aguas grises aguas subterraneas bombas de mano humanure curva IV letrinas las baterias de plomo acido bombas mecanizadas flujo natural fotovoltaica tuberias redes de bombeo el agua de lluvia filtracion rapida de hormigon armado tanque de embalse el numero de Reynolds bomba de mecate bombas rotativas perforacion rota lodos filtros de desbaste filtros de arena sedimentacion filtros lentos de arena la irradiacion solar angulo del panel solar paneles solares wireing panel solar energia solar solar calculos de potencia sistemas de energaa solar bombeo de agua solar tratamiento de agua solar hojas de calculo tanque de agua de manantial agua de manantial de tapping perforacion martillo de piedra bombas sumergibles de la encuesta aseo aseos tratamiento de agua ultravioleta dureza del agua bombas de agua sistemas de agua pozo de agua estufa de lena rastreador solar seguimento solar seguidor solar automatico de seguimiento solar Una guia sobre la forma de calcular la cantidad de energía solar que incide sobre un plano inclinado en cualquier latitud La inclusion de una seccion sobre la astronomía solar El Sol como fuente de energia Astronomía Solar La energía solar llega a la superficie de la Tierra Solar Calculos de irradiacion

% Отслеживание ВС путь солнца Контур солнце Вс трекер Солнечная трекер солнечной системы слежения

% 太陽能跟踪器 Tàiyángnéng gēnzōng qì 聚光太陽能發電 Jù guāng tàiyángnéng fādiàn

Patent Classes G05D 3/105

Abstract for Google Translate in Spanish
Este libro detalla Solar-seguimiento automático, Sun-Seguimiento-Systems, Solar-Trackers y Sun Tracker Sistemas. Un seguidor solar automático inteligente es un dispositivo que orienta una carga útil hacia el sol. Tal computarizado dispositivo de seguimiento solar programable incluye principios de seguimiento solar, sistemas de seguimiento solar, así como microcontroladores, microprocesadores y / o basadas control de seguimiento solar PC para orientar reflectores solares, lentes solares, paneles fotovoltaicos u otras configuraciones ópticas hacia el sol. Estructuras espaciales motorizados y sistemas cinemáticos garantizan una dinámica de movimientos y emplean la técnica de accionamiento y engranajes principios para dirigir configuraciones ópticas como mangin,,, o Cassegrain colectores de energía solar parabólico cónicas para enfrentar el sol y seguir el movimiento de contorno sol continuamente.

En el aprovechamiento de la energía del sol a través de un seguidor solar o sistema de seguimiento solar práctica, los sistemas de automatización, control de energía renovables requieren un software de seguimiento solar automático y algoritmos de posición solar para llevar a cabo el control dinámico de movimiento con la arquitectura de automatización de control, placas de circuitos y hardware. Sistema en el eje de seguimiento al sol, como los sistemas de seguidores solares de altitud-azimut doble eje o de varios ejes utilizan un algoritmo de seguimiento del sol o el trazado de rayos sensores o software para garantizar el paso del sol por el cielo se traza con la alta precisión en aplicaciones de seguidores solares automatizadas , a la derecha a través de solsticio de verano, equinoccio solar y el solsticio de invierno. Un algoritmo de alta precisión calculadora de la posición del sol o la posición del sol utiliza una rutina de programa de software para alinear el seguidor solar con el sol y es un componente importante en el diseño y construcción de un sistema de seguimiento solar automático.

De sol trazando perspectiva del software, el soneto Tracing El Sol tiene un significado literal. Dentro del contexto de la pista sol y rastrear, este libro explica ese camino diario del sol a través del cielo está dirigida por principios relativamente sencillos, y si agarrado / entendido, entonces es relativamente fácil de rastrear el sol con sol siguiente software. Software informático para el seguimiento de la posición del sol el sol están disponibles como código fuente abierto, las fuentes que se mencionan en este libro. Irónicamente hubo incluso un sistema llamado sol cazador, dice que ha sido un sistema posicionador solar conocido por perseguir el sol durante todo el día.

Utilizando ecuaciones solares en un circuito electrónico para el seguimiento solar automático es muy sencillo, incluso si usted es un principiante, pero las ecuaciones matemáticas solares está por encima complica por expertos académicos y profesores en los libros de texto, artículos de revistas y sitios de Internet. En términos de aficiones solares, académicos, estudiantes y aficionado está mirando programas electrónicos de seguimiento o PC solares para seguimiento solar generalmente se superan por la gran cantidad de recursos materiales y de Internet científicos, lo que deja a muchos desarrolladores en frustración cuando búsqueda de fuente simple de seguimiento solar experimental -Código por sus sistemas de seguimiento solar en el eje. Este folleto va a simplificar la búsqueda de las fórmulas de seguimiento solar místicos para su tracker innovación sol y ayudarle a desarrollar su propio controlador de seguimiento solar autónoma.

Al dirigir el colector solar directamente al sol, una cosecha solar medio o dispositivo puede aprovechar la luz solar o calor térmico. Con el fin de realizar el seguimiento del sol como la tierra gira (o como el sol se mueve a través del cielo) la ayuda de fórmulas de ángulo del sol, las fórmulas del ángulo solar o procedimientos de seguimiento solar es necesaria para el cálculo de la posición del sol en el cielo. Software Sistema automático de seguimiento solar incluye algoritmos para el cálculo de ángulos de azimut altitud solares necesarios para seguir el sol a través del cielo. En el uso de la longitud, latitud coordenadas GPS de la ubicación seguidor solar, el seguimiento de herramientas de software de estos sol apoya precisión de seguimiento solar mediante la determinación de la altitud-azimut solar coordenadas de la trayectoria del sol en altitud-acimut seguimiento en el lugar de seguimiento, usando ciertas fórmulas del ángulo del sol en cálculos vectoriales sol. En lugar de seguir el software de sol, un sensor de seguimiento solar tal como un sensor de sol o cámara web o una cámara de vídeo con el sol basado en visión siguiente software de procesamiento de imágenes también puede ser utilizado para determinar la posición del sol ópticamente. Tales dispositivos de retroalimentación ópticos se utilizan a menudo en sistemas de seguimiento de paneles solares y sistemas de seguimiento plato.

Sol de seguimiento dinámico también se utiliza en el levantamiento solar, analizador de DNI y sistemas solares topografía que construyen mapas solares Infografía con resplandor solar, irradiancia y modelos DNI para GIS (sistema de información geográfica). De esta manera los métodos geoespaciales en interacción solar / entorno hace uso el uso de las tecnologías geoespaciales (SIG, Teledetección y Cartografía).

Los datos climáticos y los datos de la estación meteorológica o de centros de tiempo, así como las consultas de los servidores cielo y sistemas de bases de recursos solares (es decir, en DB2, Sybase, Oracle, SQL, MySQL) también pueden estar asociados con los mapas solares SIG. En tales sistemas de modelado de recursos solares, un piranómetro o solarímetro se utiliza normalmente, además de medir dispersa la radiación dispersa, directa e indirecta, y reflectante para una ubicación geográfica particular. Análisis La luz solar es importante en la fotografía con flash donde la iluminación fotográfica son importantes para los fotógrafos. Sistemas GIS son utilizados por los arquitectos que añaden applets sombra del sol para estudiar sombreado arquitectónico o análisis de sol sombra, cálculos de flujo solar, modelado óptico o para llevar a cabo la modelización del clima. Estos sistemas a menudo emplean un mecanismo operado computadora tipo telescopio con trazado de rayos de software programa como un navegador solar o sol trazador que determina la posición y la intensidad solar.

El propósito de este manual es ayudar a los desarrolladores de seguimiento y rastreo de código fuente adecuada y algoritmos de seguimiento solar para su aplicación, ya sea un aficionado, científico, técnico o ingeniero. Muchos sol de código abierto siguiendo y seguimiento de los algoritmos y de código fuente para los programas de seguimiento solar y módulos están disponibles gratuitamente para descargar en el Internet hoy. Algunos kits de seguimiento solar de propiedad y los controladores de seguimiento solar incluyen un kit de desarrollo de software SDK por sus atributos de la API de interfaz de programación de aplicaciones (guijarros). Widget bibliotecas, conjuntos de herramientas de widgets, GUI toolkit y bibliotecas UX con elementos de control gráficos están también disponibles para construir la interfaz gráfica de usuario (GUI) para su seguimiento solar o programa de supervisión de la energía solar.

La biblioteca solar utilizado por las calculadoras de posición solares, software de simulación solar y calculadoras solares contorno incluye código de programa de la máquina para el controlador de hardware solar que son software programado en microcontroladores, controladores lógicos programables PLC, matrices de puertas programables, procesador Arduino procesador o PIC. Seguimiento solar basado en PC también es alta en la demanda utilizando C ++, VB Visual Basic, así como MS Windows, Linux y Apple Mac sistemas operativos basados en tablas de rutas sol en Matlab, Excel. Algunos libros y páginas de Internet utilizan otros términos, tales como: la calculadora de ángulo del sol, calculadora de la posición del sol o la calculadora de ángulo solar. Como se ha dicho, como código de software calcular el ángulo de azimut solar, el ángulo de altitud solar, ángulo de elevación solar o el ángulo cenital solar (ángulo solar Zenith simplemente se hace referencia desde el plano vertical, el espejo del ángulo de elevación medida desde el nivel horizontal o plano de tierra) . Código de software similares también se utiliza en aplicaciones Calculadora solares o las aplicaciones Calculadora de energía solar para iOS y Android dispositivos smartphone. La mayoría de estas aplicaciones móviles solares smartphones mostrarás la senda sol y sol-ángulos para cualquier lugar y la fecha en un período de 24 horas. Algunos smartphones incluyen características de la realidad en la que se puede ver físicamente y mirar la trayectoria solar a través de la cámara del teléfono celular o cámara de un teléfono móvil en la localización GPS específico de su teléfono aumentados.

En el entorno de programación de computadoras y procesamiento de señales digitales (DSP), (código libre / abierto) código del programa están disponibles para Gambas, VB, Net, Delphi, Python, C, C +, C ++, PHP, Swift, ADM, F, Flash , Basic, QBasic, GBasic, KBasic, lenguaje SIMPL, Ardilla, Solaris, el lenguaje ensamblador en sistemas operativos como MS Windows, Apple Mac, DOS, Unix o Linux OS. Algoritmos de software posición del sol en el cielo que predicen están comúnmente disponibles como plataformas gráficas de programación como Matlab (Mathworks), modelos de Simulink, applets de Java, TRNSYS simulaciones, aplicaciones del sistema Scada, Módulo LabVIEW, Beckhoff TwinCAT (Visual Studio), Siemens SPA, aplicaciones móviles y iPhone, Android o aplicaciones de la tableta de iOS, y así sucesivamente. Al mismo tiempo, el código de software de PLC para una amplia gama de tecnología de automatización de seguimiento al sol puede seguir el perfil de sol en el cielo para Siemens, HP, Panasonic, ABB, Allan Bradley, OMRON, SEW, Festo, Beckhoff, Rockwell, Schneider, Endress Hauser , Fudji eléctrica. Honeywell, Fuchs, Yokonawa o Muthibishi plataformas. Sun software proyección ruta también están disponibles para una amplia gama de placas madre de PC embebidos modulares IPC, PC industrial, PLC (controlador lógico programable) y PAC (Controlador de Automatización Programable), como el Siemens S7-1200 o Siemens Logo, Beckhoff IPC o una serie CX, OMRON PLC, ERCAM PLC, AC500plc ABB, National Instruments NI PXI o nI cRIO, procesador PIC, Intel 8051/8085, IBM (Cell, Power, Brain o una serie Truenorth), FPGA (Xilinx Altera Nios), Intel, Xeon, Atmel megaAVR , MPU, Arce, Teensy, MSP, XMOS, Xbee, ARM, Raspberry Pi, Eagle, Arduino o Arduino ATMega microcontrolador, con servo motor, motor paso a paso, PWM corriente continua DC ancho de pulso modulación (controlador actual) o corriente alterna AC SPS o IPC de frecuencia variable impulsa las unidades de motor VFD (variador de frecuencia también denominada, variador de velocidad, variador de frecuencia, unidad de micro motores inversores o) para electricidad, mecatrónica, neumática, o actuadores de seguimiento solar hidráulicos.

Los sistemas de control de control de movimiento arriba y robot incluyen puertos de interfaz analógicos o digitales en los procesadores para permitir ángulo de rastreador de control de realimentación de la orientación a través de uno o una combinación de sensor de ángulo o el codificador de ángulo, codificador de eje, el codificador de precisión, codificador óptico, codificador magnético, la dirección codificador, codificador de rotación, un codificador de chip, sensor de inclinación, sensor de inclinación, o el sensor de campo. Tenga en cuenta que la elevación o cenit ángulo del eje del seguidor puede medir utilizando un ángulo cerrado altitud, ángulo cerrado declinación, inclinación de ángulo cerrado, de ángulo cerrado de paso, o de ángulo cerrado vertical, cenit sensor de ángulo cerrado o inclinómetro. Del mismo modo el ángulo del eje de acimut del rastreador puede medir con un ángulo cerrado acimut, ángulo cerrado horizontal, o rollo sensor de ángulo cerrado. Sensores de chip integrado magnetómetro de tipo acelerómetro giroscopio angular también se pueden utilizar para calcular el desplazamiento. Otras opciones incluyen el uso de sistemas de imágenes térmicas, tales como una cámara termográfica Fluke, o sistemas de seguimiento o de la visión robótica basados solares que emplean seguimiento de la cara, la cabeza de seguimiento, rastreo de mano, seguimiento de los ojos y de los principios de seguimiento de coche en el seguimiento solar.

Con desatendida descentralizada rural, insulares, aisladas, o instalaciones de energía fuera de la red autónomas, control remoto, control, adquisición de datos, registro de datos digitales y equipos de medición y verificación en línea se convierte en crucial. Asiste al operador un control de supervisión para monitorear la eficiencia de los recursos energéticos renovables y sistemas remotos y proveer valiosa retroalimentación basado en la web en términos de CO2 y el mecanismo de desarrollo limpio (MDL) del informe. Un analizador de calidad de energía para el diagnóstico a través de Internet, Wi-Fi y conexiones de telefonía móvil celular es más valioso en primera línea de resolución de problemas y el mantenimiento predictivo, donde se requiere un análisis de diagnóstico rápido para detectar y prevenir los problemas de calidad de energía.

Aplicaciones seguidor solar cubren un amplio espectro de aplicaciones solares y aplicación asistido por energía solar, incluyendo la generación de energía solar concentrada, la desalinización solar, purificación de agua solar, generación de vapor solar, la generación de electricidad solar, calor de proceso industrial solar, almacenamiento de calor solar térmica, secadores de comida solares, bombeo de agua solar, la producción de hidrógeno a partir de metano o hidrógeno produciendo y oxígeno del agua (HHO) a través de la electrólisis. Muchos patentado o aparato solar no patentada incluye el seguimiento en el aparato solar para el generador solar eléctrico, desalinizador solar, motor de vapor solar, máquina de hielo solar, purificador de agua solar, refrigeración solar, refrigeración solar, cargador solar USB, carga del teléfono solar, carga solar portátil tracker, elaboración de café solar, cocina solar o medios que mueren solares. Su proyecto puede ser el próximo gran avance o patente, pero su invención está frenado por la frustración en la búsqueda para el seguidor solar que necesita para su aparato de energía solar, generador solar, robot seguidor solar, congelador solar, cocina solar, secador solar, bomba solar , congelador solar o proyecto secador solar. Ya sea que su diagrama de circuito electrónico solar incluye un diseño simplificado solar controlador en un proyecto de energía solar, kit de energía solar, kit manía solar, generador de vapor solar, sistema de agua caliente solar, máquina de hielo solar, desalinizador solar, paneles solares aficionados, afición robot, o si está desarrollando la electrónica profesional o hobby para una utilidad solar o central eléctrica solar micro escala para su propia granja solar o la agricultura solar, esta publicación puede ayudar a acelerar el desarrollo de la innovación de seguimiento solar.

Últimamente, poligeneración solar, trigeneración solar (solar generación triple), y la generación quad solar (añadiendo la entrega de vapor, líquido / combustible gaseoso, o la captura de calidad alimentaria CO $ _2 $) sistemas tienen necesidad de seguimiento solar automático. Estos sistemas se caracterizan por aumentos de eficiencia significativas en el rendimiento de energía como resultado de la integración y la reutilización de los residuos o el calor residual y son adecuados para centrales eléctricas solares compactos envasados micro que podrían ser fabricados y transportados en el kit de-forma y operan en un enchufe base juego -y. Sistemas de energía solar híbridos típicos incluyen micro compactos o envasados solares combinadas de calor y energía (CHP o mCHP) o micro solares combinados, refrigeración, sistemas (CCHP, CHPC, mCCHP o mCHPC) utilizados en la generación de energía distribuida de calefacción y energía. Estos sistemas a menudo se combinan en CSP solar concentrada y CPV configuraciones microrred inteligente para fuera de la red rural, isla o aislada microrred, minirrejilla y energía distribuida de sistemas de energía renovable. Algoritmos de seguimiento solar también se utilizan en el modelado de sistemas de trigeneración utilizando Matlab Simulink (Modelica o TRNSYS) plataforma, así como en la automatización y control de sistemas de energía renovable a través de análisis inteligente, multi-objetivo, las estrategias de control de aprendizaje y de optimización de control adaptativos.

Algoritmos de seguimiento solar también encuentran aplicación en el desarrollo de modelos solares para estudios nacionales o solares específicos de la localización, por ejemplo en términos de medición o análisis de las fluctuaciones de la radiación solar (es decir, la radiación directa y difusa) en un área en particular. DNI solar, la radiación solar y la información y los modelos atmosféricos de este modo se pueden integrar en un mapa solar, atlas solares o sistemas de información geográfica (SIG). Estos modelos permiten definir parámetros locales para regiones específicas que pueden ser valiosos en términos de la evaluación de los diferentes solar fotovoltaica en los sistemas CSP en plataformas de simulación y síntesis como Matlab y Simulink o en plataformas de algoritmos de optimización lineales o multi-objetivos como COMPOSE , EnergyPLAN o DER-CAM.

Un seguidor solar de doble eje y de un solo eje seguidor solar pueden usar un algoritmo del programa de seguimiento de sol o el sol rastreador para colocar un plato solar, panel solar del panel, campo de heliostatos, panel fotovoltaico, antena solar o nantenna solar infrarroja. Un concentrador solar auto-seguimiento realiza el seguimiento solar automático calculando el vector solar. Algoritmos posición solar (TwinCAT, SPA, o PSA Algoritmos) utilizan un algoritmo astronómico para calcular la posición del sol. Se utiliza algoritmos de software astronómicas y ecuaciones para el seguimiento solar en el cálculo de la posición del sol en el cielo para cada ubicación en la tierra en cualquier momento del día. Al igual que un telescopio solar óptico, los algoritmos posición puntitos solares del reflector solar en el sol y se mantiene en ellas la posición del sol para rastrear el sol a través del cielo como el sol que avanza a lo largo del día. Los sensores ópticos tales como fotodiodos, dependientes-resistencias de luz (LDR) o fotorresistores se utilizan como dispositivos de retroalimentación de precisión óptica. Últimamente también se incluyó una sección en el libro (con enlaces a código microprocesador) sobre cómo la cámara infrarroja PixArt Wii en el Wii Wiimote a distancia o se puede utilizar en aplicaciones de seguimiento solar infrarrojos.

Con el fin de aprovechar la energía gratuita del sol, algunos sistemas de posicionamiento solares automáticos utilizan unos medios ópticos para dirigir el dispositivo de seguimiento solar. Estas estrategias de seguimiento solar utilizan técnicas de seguimiento ópticos, como un medio de sensores de sol, a los rayos directos del sol sobre un sustrato de silicio o CMOS para determinar la coordenadas X e Y de la posición del sol. En un dispositivo MEMS solares sol-sensor, la luz solar incidente entra en el sensor de sol a través de un pequeño agujero de alfiler en una placa de máscara donde la luz se expone a un sustrato de silicio. En un seguimiento solar de procesamiento de imágenes cámara web o cámara y medios sol siguiente, objeto de seguimiento de software realiza el seguimiento de objetos en movimiento o varios métodos de seguimiento de objetos. En una técnica de seguimiento de objetos solar, software de procesamiento de imagen realiza el procesamiento matemático a la caja el contorno del disco solar aparente o sol blob en el marco de la imagen capturada, mientras que el sol-localización se realiza con un algoritmo de detección de bordes para determinar las coordenadas del vector solares.

Un sistema de posicionamiento automático ayudar a maximizar los rendimientos de las plantas de energía solar a través del control de seguimiento solar para aprovechar la energía del sol. En estos sistemas de energía renovable, el sistema de colocación de panel solar utiliza una técnica de seguimiento del sol y una calculadora ángulo solar en los paneles fotovoltaicos de posicionamiento en los sistemas fotovoltaicos y sistemas CPV de Concentración Fotovoltaica. Seguimiento automático en el eje solar en un sistema de seguimiento solar fotovoltaica puede ser de doble eje de seguimiento del sol o de un solo eje sol de seguimiento solar. Se sabe que un sistema de posicionamiento motorizado en un panel fotovoltaico aumento rastreador rendimiento energético y garantiza una mayor potencia de salida, incluso en una configuración de seguimiento solar de un solo eje. Otras aplicaciones como seguidor solar robótico o un sistema de seguimiento solar robótico utiliza robotica con la inteligencia artificial en la optimización del control de producción de la energía solar en la cosecha a través de un sistema de seguimiento de robótica.

Sistemas de posicionamiento automático en diseños de seguimiento solar también se utilizan en otros generadores de energía libre, tales como los sistemas de disco Stirling CSP térmica solar concentrada de energía y. El dispositivo de seguimiento solar en un colector solar en un concentrador solar o colector solar Tal realiza sobre el eje de seguimiento solar, un eje dual asistencias de seguidores solares para aprovechar la energía del sol a través de un colector solar óptico, que puede ser un espejo parabólico, parabólico reflector, lente de Fresnel o espejo matriz / matriz. Una antena parabólica o reflector está dinámicamente directrices con un sistema de transmisión o media unidad de giro de seguimiento solar. En el gobierno del plato hacia el sol, el actuador plato poder y medios de accionamiento en un sistema de disco parabólico ópticamente enfoca la energía del sol en el punto focal de una antena parabólica o un medio de concentración solar. Un motor de Stirling, tubo solar térmica, thermosyphin, cambio de fase del receptor de material PCM solar o una luz solar receptor de fibra óptica significa se encuentra en el punto focal del concentrador solar. La configuración del motor Stirling plato se conoce como un sistema de disco Stirling o un sistema de generación de energía Stirling. Sistemas de energía solar híbrida (utilizado en combinación con biogás, biocombustibles, gasolina, etanol, diesel, gas natural o PNG) utilizan una combinación de fuentes de energía para aprovechar y almacenar la energía solar en un medio de almacenamiento. Cualquier multitud de fuentes de energía se puede combinar con el uso de controladores y la energía almacenada en las baterías, material de cambio de fase, de almacenamiento de calor térmico, y en cogeneración forma convierte a la potencia requerida usando ciclos termodinámicos (orgánica ciclo de Rankin, Brayton, micro turbina, Stirling) con un inversor y el regulador de carga.

Abstract for Google Translate in German
Dieses Buch beschreibt die Solar-Tracking-Automatic, Sonne nachgeführte-Systems, die Solar-Tracker und Sun Tracker-Systeme. Eine intelligente automatische Solar-Tracker ist ein Gerät, das eine Nutzlast in Richtung der Sonne orientiert. Solche programmierbaren Computer basierten Solar-Tracking-Gerät beinhaltet Grundsätze der solare Nachführsysteme, Solar-Tracking-Systeme, als auch Mikrocontroller, Mikroprozessor und / oder PC-basierte Solarspursteuerung, um Solarreflektoren, Solarlinsen, Photovoltaik-Module oder andere optische Konfigurationen nach der Sonne orientieren. Motorisierte Space Frames und kinematische Systeme sicherzustellen, Bewegungsdynamik und beschäftigen Antriebstechnik und Getriebe Prinzipien, optische Konfigurationen wie Mangin, parabolisch, konisch oder Cassegrain Solarkollektoren, um die Sonne zu stellen und folgen der Sonne Bewegung Kontur kontinuierlich zu steuern.

In Nutzbarmachung von Energie von der Sonne durch eine Solartracker oder praktische Solar-Tracking-System, erneuerbare Energie Kontrolle der Automatisierungssysteme erfordern automatische Solar Tracking-Software und Solar Position Algorithmen, um dynamische Bewegungssteuerung mit Steuerautomatisierungsarchitektur, Leiterplatten-und Hardware zu erreichen. Auf der Achse Sonne-Tracking-System, wie die Höhen-Azimut-Doppelachsen-oder Multi-Achsen-Solar-Tracker-Systeme verwenden eine Sonnen Tracking-Algorithmus oder Ray-Tracing-Sensoren oder Software, um die Sonnendurchgang durch den Himmel gewährleistet ist, mit hoher Präzision in automatisierten Solar-Tracker-Anwendungen verfolgt bis hin Sommersonnenwende, Solar Tagundnachtgleiche und Wintersonnenwende. Eine hohe Präzision Sonnenposition Rechner oder die Sonnenposition Algorithmus verwendet eine Software-Routine, um die Solar-Tracker auf die Sonne ausrichten und ist ein wichtiger Bestandteil in der Entwicklung und Konstruktion einer automatischen Sonnen Tracking-System.

Von Sonne Tracing Softwareperspektive das Sonett Tracing Die Sonne ist eine wörtliche Bedeutung. Im Rahmen der Sonne Track-and-Trace, erklärt das Buch, das die Sonne im Tagesverlauf über den Himmel wird von relativ einfachen Prinzipien geleitet, und wenn begriffen / verstanden, dann ist es relativ einfach, die Sonne mit Sonnen folgende Software verfolgen. Sonnenposition Computersoftware für die Rückverfolgung der Sonne sind als Open-Source-Code zur Verfügung, Quellen, die in diesem Buch aufgeführt ist. Ironischerweise gab es sogar ein System namens Sonne Chaser, sagte ein Solarstellungssystem für die Jagd nach dem Sonne den ganzen Tag gekannt haben.

Mit Solar Gleichungen in einer elektronischen Schaltung für die automatische Nachführung ist ganz einfach, auch wenn Sie ein Anfänger, aber mathematische Gleichungen Solar werden von wissenschaftlichen Experten und Professoren in Text-Bücher, Zeitschriftenartikel und Internetseiten kompliziert. In Bezug auf die Solar Hobbys, Wissenschaftler, Studenten und Hobby-sucht bei Solar-Tracking Elektronik oder PC-Programme für solare Nachführsysteme sind in der Regel durch die schiere Menge an wissenschaftlichen Material-und Internet-Ressourcen, die viele Entwickler frustriert verlässt überwinden, wenn Suche nach einfachen experimentellen Solar-Tracking Quelle -Code für ihre auf der Achse Sonne-Tracking-Systeme. Diese Broschüre wird die Suche nach den mystischen Sonnen Tracking-Formeln für Ihre Sun Tracker Innovation vereinfachen und Ihnen helfen, Ihre eigene autonome Solar-Tracking-Controller zu entwickeln.

Durch die Ausrichtung der Solarkollektoren direkt in die Sonne, eine Solarernte bedeutet oder Gerät kann Sonnenlicht oder thermische Wärme zu nutzen. Um die Sonne als die Erde sich dreht verfolgen (oder, wie die Sonne über den Himmel bewegt) die Hilfe von Sonnenwinkel Formeln, Formeln oder Sonnenwinkel Sonnenverfolgungsverfahren wird bei der Berechnung der Sonnenposition am Himmel erforderlich. Automatische Sonnen Tracking-System-Software enthält Algorithmen für die Sonnenhöhe Azimutwinkel Berechnungen nach der Sonne über den Himmel erforderlich. Bei der Verwendung der Längengrad, Breitengrad GPS-Koordinaten der Solartracker Lage, diese Sonne-Tracking-Software-Tools unterstützt Präzision Solar-Tracking durch die Bestimmung der Sonnenhöhe-Azimut-Koordinaten für die Sonnenbahn in der Höhe-Azimut-Tracking auf den Tracker Lage, unter Verwendung bestimmter Sonnenwinkel Formeln in der Sonne Vektor-Berechnungen. Statt der Sonne folgen der Software, eine Sonnenverfolgungssensor wie einem Sonnensensor oder Webcam oder Videokamera mit Weitblick auf der Basis Sonnen folgenden Bildverarbeitungssoftware kann auch verwendet werden, um die Position der Sonne optisch zu bestimmen. Solche optischen Feedback-Geräte werden oft in Solarpanel-Tracking-Systeme und Geschirr Tracking-Systeme eingesetzt.

Dynamische Sonnenverfolgung wird auch in der Solar Vermessung, DNI-Analysator und Sonne Vermessungssysteme , Solarinfografiken Karten mit Solar Ausstrahlung, Bestrahlungsstärke und DNI Modelle für GIS (Geographisches Informationssystem) zu bauen verwendet. Auf diese Weise Geodaten Methoden auf Solar / Umwelt-Interaktion nutzt Einsatz von Geoinformatik (GIS, Fernerkundung, Kartographie und).
Klimadaten und Wetterstation oder Wetter Center-Daten sowie Anfragen von Servern Himmel und Sonnenressourcendatenbanksystemen (zB DB2, Sybase, Oracle, SQL, MySQL) können auch mit Solar GIS-Karten zugeordnet werden. In solchen Solarressourcenmodellierungssysteme wird ein Pyranometer oder Solari normalerweise zusätzlich verwendet werden, um direkte und indirekte, zerstreut, zerstreut, reflektierenden Strahlung für einen bestimmten geographischen Ort zu messen. Sonnenlicht-Analyse ist in der Blitzfotografie, wo Fotolampen sind wichtig für die Fotografen wichtig. GIS-Systeme werden von Architekten, die Sonne Schatten-Applets in den architektonischen Schattierung oder Sonne Schatten Analyse, Solarflussberechnungen, optische Modellierung studieren oder Wetter-Modellierung durchzuführen verwendet. Solche Systeme verwenden oft einen Computer-Teleskop Typ Mechanismus mit Ray-Tracing-Programm-Software als Solar Navigator oder Sonne-Tracer, der die Sonnenposition und Intensität bestimmt.

Der Zweck dieser Broschüre ist es, Entwicklern zu verfolgen und zu verfolgen geeignete Quelle-Code und Solar-Tracking-Algorithmen für ihre Anwendung, ob ein Bastler, Wissenschaftler, Techniker oder Ingenieur zu unterstützen. Viele Open-Source-Sonne nach und Tracking-Algorithmen und Sourcecode für solare Nachführsysteme Programme und Module sind frei verfügbar im Internet heute herunterladen. Bestimmte proprietäre Solar-Tracker-Kits und Solar-Tracking Controller enthalten ein Software Development Kit SDK für seine Application Programming Interface API Attribute (Pebble). Widget-Bibliotheken,-Widget Toolkits, GUI-Toolkit und UX-Bibliotheken mit grafischen Bedienelemente sind ebenfalls verfügbar, um die grafische Benutzerschnittstelle (GUI) für Ihre Solar-Tracking-oder Solarenergie-Überwachungsprogramm zu konstruieren.

Die Solar Bibliothek durch Sonnenposition Taschenrechner, Solarsimulationssoftware und Solartaschenrechner verwendet werden, umfassen Kontur Maschinenprogrammcode für die Solar Hardware-Controller, die in Micro-Controller programmiert, Speicherprogrammierbare Steuerungen SPS, Programmable Gate Arrays, Arduino-Prozessor oder PIC-Prozessor-Software sind. PC-basierten Solar-Tracking ist ebenfalls hoch in der Nachfrage mit C ++, Visual Basic VB, sowie MS Windows, Linux und Apple Mac Betriebssystemen für den Sonnenpfad Tabellen auf Matlab, Excel. Einige Bücher und Internetseiten verwenden andere Begriffe, wie zB: Sonnenwinkel Taschenrechner, Taschenrechner oder Sonnenstand Sonnenwinkel Rechner. Wie gesagt, solche Softwarecode errechnen Sonnenazimutwinkel, Sonnenhöhenwinkel, Sonnenhöhenwinkel oder der Sonnenzenitwinkel (Zenith Sonnenwinkel einfach von vertikalen Ebene referenziert, der Spiegel der Höhenwinkel von der Horizontalen oder der Masseebene Ebene gemessen) . Ähnliche Software-Code wird auch in Solar-Taschenrechner-Apps oder die Solarenergie Rechner Apps für iOS und Android Smartphones verwendet. Die meisten dieser Smartphone Solar mobile Apps zeigen die Sonnenbahn und Sonnenwinkel für jeden Ort und Datum über einen Zeitraum von 24 Stunden. Einige Smartphones gehören Augmented-Reality-Features, in dem Sie physisch sehen und schauen Sie sich die Solar Weg durch Ihre Handy-Kamera oder Handy-Kamera zu bestimmten GPS-Position des Telefons.

In der Computer-Programmierung und digitale Signalverarbeitung (DSP)-Umgebung (kostenlos / Open Source) Programm-Code für Gambas, VB, Net, Delphi, Python, C, C +, C verfügbar ++, PHP, Swift, ADM, F, Flash-, Basic, QBasic, GBasic, KBasic, SIMPL Sprache, Eichhörnchen, Solaris, Assembler auf Betriebssystemen wie MS Windows, Apple Mac, DOS, Unix-oder Linux-Betriebssystem. Software-Algorithmen Vorhersage Position der Sonne am Himmel sind allgemein als grafische Programmierplattformen wie Matlab (Mathworks), Simulink-Modelle, Java-Applets zur Verfügung, TRNSYS Simulationen, Scada-System-Apps, Labview-Modul, Beckhoff TwinCAT (Visual Studio), Siemens SpA Handy und iPhone-Apps, Android oder iOS Tablet-Apps, und so weiter. Zur gleichen Zeit, kann SPS-Software-Code für eine Reihe von Sonnen Tracking-Automatisierungstechnik das Profil der Sonne im Himmel für Siemens, HP, Panasonic, ABB, Allan Bradley, Omron, SEW, Festo, Beckhoff, Rockwell, Schneider, Endress Hauser folgen , Fudji elektrisch. Honeywell, Fuchs, Yokonawa oder Muthibishi Plattformen. Sun-Weg Projektionssoftware sind auch für eine Reihe von modularen Embedded IPC PC-Motherboards erhältlich, Industrie-PC, SPS (Speicherprogrammierbare Steuerung) und PAC (Programmable Automation Controller), wie die Siemens oder Siemens Logo S7-1200, Beckhoff IPC oder CX-Serie, OMRON PLC, Ercam PLC, AC500plc ABB, National Instruments NI PXI oder NI CompactRIO, PIC-Prozessor, Intel 8051/8085, IBM (Cell, Power und BRAIN oder Truenorth-Serie), FPGA (Xilinx Altera Nios), Intel, Xeon, Atmel megaAVR , MPU, Ahorn, Teensy, MSP, XMOS, Xbee, ARM, Raspberry Pi, Adler, Arduino oder Arduino Mikrocontroller AtMega, mit Servomotor , Schrittmotor, Gleichstrom DC Pulsweitenmodulation (PWM aktuellen Treiber) oder Wechselstrom AC SPS oder IPC Frequenzumrichter VFD Motorantriebe (auch als einstellbare Frequenzantrieb , Antrieb mit variabler Drehzahl, AC-Antrieb, Mikro-Antrieb oder mit Umrichter) für elektrische, Mechatronik, pneumatischer oder hydraulischer Antriebe solare Nachführsysteme.

Die obigen Bewegungssteuerung und Robotersteuerungen umfassen analoge oder digitale Schnittstellen Ports der Prozessoren, für Tracker Winkelorientierung Rückkopplungssteuerung durch ein oder eine Kombination von Winkel-Sensor oder Winkelencoder, Drehgeber, Encoder Präzision, optische Codierer, magnetische Encoder Richtung zu ermöglichen Encoder, Drehgeber-Chip-Encoder, Neigungssensor, Neigungssensor, Neigungssensor oder. Beachten Sie, dass Höhe oder Zenitwinkel Achse des Trackers kann unter Verwendung einer Höhe winkel, Deklination winkel, Neigung winkel, Pech winkel oder vertikale winkel, Zenit winkelSensor oder Neigungsmesser. Ebenso Azimutachse Winkel des Verfolgers mit einem Azimut winkel, horizontal winkel oder Walzenwinkelsensor gemessen werden. Chip integrierten Beschleunigungsmagnetowinkelsensoren Kreisel Typ kann auch verwendet werden, um eine Verschiebung zu berechnen. Weitere Optionen sind die Nutzung von Wärmebildsystemen wie einer Fluke Wärmebildkamera, oder Roboter oder Vision basiert Solar-Tracker-Systeme, die Gesichtserkennung, Head-Tracking-, Hand-Tracking, Eye-Tracking und Auto-Tracking-Prinzipien in Solar-Tracking eingesetzt werden.

Mit unbeaufsichtigt dezentralen ländlichen, insel, isoliert, oder autonomen Off-Grid-Stromanlagen, Fernsteuerung, Überwachung, Datenerfassung, digitale Datenaufzeichnung und Online-Messung und Überprüfung Ausrüstung wird von entscheidender Bedeutung. Es unterstützt den Bediener mit Überwachungssteuerung, um die Effizienz der Fern erneuerbaren Energiequellen und Systeme zu überwachen und wertvolle Web-basierte Rückmeldung in Bezug auf die CO2-und Clean Development Mechanism (CDM) Berichterstattung. Ein Netzqualitätsanalysator für Diagnose über Internet, WLAN und Mobilfunkverbindungen ist das wertvollste in vorderster Front der Fehlersuche und vorausschauende Wartung, wo eine schnelle diagnostische Analyse ist erforderlich, um zu erkennen und Netzqualitätsprobleme zu vermeiden.

Solar-Tracker-Anwendungen decken ein breites Spektrum von Solaranwendungen und solar unterstützten Anwendung, einschließlich Concentrated Solar Power Generation, Solar Entsalzung, Solarwasseraufbereitung , solaren Dampferzeugung, Erzeugung von Solarstrom, Solar industrielle Prozesswärme, solarthermische Wärmespeicher, Solar Lebensmittel Trockner, Solarwasserpumpen, Wasserstofferzeugung aus Methan oder Herstellung von Wasserstoff und Sauerstoff aus Wasser (HHO), durch Elektrolyse. Viele patentierte oder nicht patentierte Solargerät gehören Verfolgung in Solargerät für Solarstromgenerator, Solar Entsalzungsanlage, Solardampfmaschine, Solar Eismaschine, Solarwasserfilter , solare Kühlung, solare Kühlung, USB Solar-Ladegerät, Solarlade Telefon, portable Solarlade tracker, Solar-Kaffees, Solar oder Solarkoch sterben bedeutet. Ihr Projekt kann der nächste Durchbruch oder Patent sein, aber Ihre Erfindung ist zurück von Frustration auf der Suche nach der Sonne-Tracker für Ihr Gerät benötigen solarbetriebene, Solargenerator, Solartracker Roboter, Solar Gefrierschrank, Solarkocher, Solartrockner, Solarpumpe gehalten , Solar Gefrierschrank, Trockner oder Solarprojekt. Egal, ob Ihre Solar elektronischen Schaltplan gehören eine vereinfachte Solarregler Design in einer Solarstromprojekt, Solarstrom -Set, Solar-Hobby Bausatz, Solar-Dampfgenerator, Solar-Warmwasseranlage , Solar Eismaschine, Solar Entsalzungsanlage, Hobby-Sonnenkollektoren, Hobby-Roboter, oder wenn Sie die Entwicklung professioneller oder Hobby-Elektronik für ein Solarprogramm oder Mikrosolarkraftwerk für die eigene Solarparks oder Solar Landwirtschaft sind, kann diese Publikation zur Beschleunigung der Entwicklung Ihrer Solar-Tracking Innovation.

In letzter Zeit, Solar Polygeneration, Solar-Kälte-Kopplung (Dreifachsolar Generation), und Solar Quad Generation (Hinzufügen Lieferung von Dampf, Flüssigkeit / gasförmigen Kraftstoff oder Capture Lebensmittelqualität CO $_2$) Systeme für die automatische Nachführung benötigen. Diese Systeme sind für erhebliche Effizienzsteigerungen bei der Energieausbeute als Ergebnis der Integration und Wiederverwendung von Abfällen oder Restwärme bekannt und eignen sich für kompakte Mikrosolarkraftwerke verpackt, die in Kit-Form hergestellt werden konnte und transportiert und arbeiten an einem Stecker -und Play-Basis. Typische Hybrid-Solarstromanlagen sind kompakt verpackt oder Solar Mikro-Kraft-Wärme-Kopplung (KWK oder Mikro-KWK) oder Solar Mikro-Kraft, Kühlung, Heizung und Strom (KWKK, KWKK, mCCHP oder mCHPC) Systemen in verteilten Stromerzeugung. Diese Systeme werden oft in konzentrierter Sonnen CSP und CPV Smart Microgrid-Konfigurationen für Off-Grid-Land, Insel oder isolierte Microgrid, Minigrid und verteilte Strom erneuerbaren Energiesystemen kombiniert. Solar-Tracking-Algorithmen auch in der Modellierung von Kraft-Wärme-Systeme mit Matlab Simulink (Modelica oder TRNSYS)-Plattform sowie in der Automatisierung und Steuerung von erneuerbaren Energiesystemen durch intelligente Analyse, Multi-Ziel, adaptive Lernkontrolle und Steueroptimierungsstrategien eingesetzt.

Anwendung bei der Entwicklung von Solar-Modelle für Land oder standortspezifischen Solar Studien, zum Beispiel in Bezug auf die Messung oder Analyse der Schwankungen der Sonnenstrahlung Solar-Tracking-Algorithmen finden auch (dh direkte und diffuse Strahlung) in einem bestimmten Bereich. Solar DNI, Sonneneinstrahlung und Luft Informationen und Modelle können so in eine Solarkarte , Solaratlas oder geografischen Informationssystemen (GIS) integriert werden. Solche Modelle können für die Definition von lokalen Parameter für bestimmte Regionen, die wertvolle in Bezug auf die Bewertung der verschiedenen Solar in Photovoltaik CSP-Systeme auf Simulation und Synthese-Plattformen wie Matlab und Simulink oder in linearer oder Mehrzieloptimierungsalgorithmus Plattformen wie komponieren kann , EnergyPLAN oder DER-CAM.

Ein Dual-Achsen-Solar-Tracker und einachsigen Solartracker kann eine Sonnen Tracker-Programm oder Sun Tracker-Algorithmus verwenden, um eine Solarschüssel, Solar-Panel-Array, Array Heliostaten, PV-Panel, Solar Antenne oder Infrarot-Solar nAntennenkabel positionieren. Ein selbst Tracking Solar-Konzentrator eine automatische Nachführung durch die Berechnung der Solar Vektor. Sonnenposition Algorithmen (TwinCAT, SPA, oder PSA-Algorithmen) verwenden einen astronomischen Algorithmus, um die Position der Sonne zu berechnen. Es verwendet astronomische Software-Algorithmen und Gleichungen zur Nachführung bei der Berechnung der Position Sonne am Himmel für jeden Ort auf der Erde zu jeder Tageszeit. Wie eine optische Sonnenteleskop, die Sonnenposition Algorithmus Pin-Punkte der Solarreflektor in die Sonne und Schlösser auf der Position der Sonne, die Sonne über den Himmel verfolgen, wie die Sonne den ganzen Tag fortschreitet. Optische Sensoren wie Photodioden sind lichtabhängig-Widerstände (LDR) oder Photowiderstände als optische Genauigkeit Feedback-Geräte verwendet. In letzter Zeit haben wir auch einen Abschnitt in dem Buch (mit Links zu Mikroprozessor-Code), wie die PixArt Wii Infrarot-Kamera in der Wii-Fernbedienung oder Wiimote kann in der Infrarot-Solar-Tracking-Anwendungen verwendet werden.

Um freie Energie von der Sonne zu ernten, einige automatische Positionierung Solarsysteme nutzen ein optisches Mittel, um die Solar-Tracking-Gerät richten. Diese Solar-Tracking-Strategien verwenden optische Tracking-Techniken, wie ein Sonnensensor Mittel, um die direkte Sonnenstrahlung auf einen Silizium-oder CMOS-Substrat, um das festzustellen, X und Y-Koordinaten der Position der Sonne. In einer Solar MEMS-Sensoreinrichtung Sonne, Sonneneinstrahlung in den Sonnensensor durch einen kleinen Pin-Loch in einem Maskenplatte, wo das Licht auf einem Silizium-Substrat ausgesetzt ist. In einem Web-Kamera oder eine Kamera die Bildverarbeitung Nachführung und Sonnen folgenden Mittel, Objekt-Tracking-Software führt Multi-Objekt-Tracking oder bewegten Objekt Tracking-Methoden. In einer Solarobjektverfolgungsverfahren, eine Bildverarbeitungssoftware mathematische Verarbeitung, um den Umriss der scheinbaren Sonnenscheibe oder Sonnen Blob in dem aufgenommenen Bild Rahmenkasten, während Sonnen Lokalisierung mit einem Kantenerkennungsalgorithmus durchgeführt, um die Solarvektorkoordinaten zu bestimmen.

Eine automatisierte Positionierungssystem zur Maximierung der Erträge von Solarkraftwerken durch solare Nachführsysteme steuern, um Energie Sonne nutzbar zu machen. In solchen erneuerbaren Energiesystemen, verwendet das Solarpanel Positionierungssystem ein Sonnenverfolgungstechniken und ein Solarrechner Winkel in der Positionierung PV-Module in Photovoltaik-Anlagen und Photovoltaik-CPV-Systeme konzentriert. Automatische Ein-Achsen-Nachführung in einer PV-Solar-Tracking-System kann zweiachsige Nachführung oder einachsige Nachführung Sonne sein. Es ist bekannt, dass ein motorisiertes Positionierungssystem in einem Photovoltaik-Panel-Tracker Erhöhung der Energieausbeute und sorgt für erhöhte Ausgangsleistung, auch in einer einzigen Achse Solar-Tracking-Konfiguration. Andere Anwendungen wie Roboter Solar-Tracker oder Roboter-Solar-Tracking-System verwendet robotica mit künstlicher Intelligenz in der Steuerungs Optimierung der Energieausbeute im Solarernte durch einen Roboter-Tracking-System.

Automatische Positionierung in Solar-Tracking-Designs sind auch in anderen freien Energieerzeuger, wie konzentrierte solarthermische Kraft CSP und Dish-Stirling-Systeme eingesetzt. Die Sonne-Tracking-Gerät in einem Sonnenkollektor in einem Solar-Konzentrator-oder Sonnenkollektor solches führt auf der Achse Solar-Tracking, eine zweiachsige Solar-Tracker hilft, Energie von der Sonne durch ein optisches Solarkollektor nutzen, die einen parabolischen Spiegel sein kann, parabolisch Reflektor, Fresnel-Linse oder Spiegel Array / Matrix. Eine Parabolantenne oder Reflektor wird dynamisch gelenkt mit einem Übertragungssystem oder Solar Tracking-Schwenktrieb bedeuten. Bei der Steuerung der Schüssel, um die Sonne stellen, die Macht Gericht Stellglied und Betätigungseinrichtung in einem Parabolspiegel System optisch fokussiert die Energie der Sonne auf der Brennpunkt einer Parabolantenne oder Solarkonzentrationsmittel. Ein Stirlingmotor, Solarwärmerohr, thermosyphin Solarphasenänderungsmaterial PCM-Empfänger oder ein Glasfaser Sonnenlicht Empfängermittel an dem Brennpunkt des Solarkonzentrators entfernt. Die Schale Stirlingmotorkonfiguration wird als eine Schale Stirling-System oder Stirling-Energieerzeugungssystem bezeichnet. Hybrid-Solarstromanlagen (in Kombination mit Biogas, Biokraftstoff, Benzin, Ethanol, Diesel, Erdgas oder PNG verwendet wird) verwenden eine Kombination von Energiequellen zu nutzen und zu speichern Sonnenenergie in einem Speichermedium. Jede Menge Energiequellen kann durch den Einsatz von Controllern und der in den Batterien gespeicherten Energie, Phasenwechselmaterial, thermische Wärmespeicher kombiniert werden und in KWK-Formular, um die erforderliche Leistung unter Verwendung thermodynamischen Zyklen umgewandelt (organische Rankin, Brayton-Zyklus, Mikroturbine, Stirling) mit einem Wechselrichter und Laderegler.

Abstract for Google Translate in Portuguese
Este livro detalha automática Solar-Tracking, Sun-tracking-Systems, Solar-Trackers e Sistemas Sun Tracker. Um seguidor solar automático inteligente é um dispositivo que orienta uma carga para o sol. Tal baseado em computador dispositivo de seguimento solar programável inclui princípios de rastreamento solar, sistemas de seguimento solar, bem como microcontrolador, microprocessador e / ou PC com controle de seguimento solar orientação refletores solares, lentes solares, painéis fotovoltaicos ou outras configurações ópticas para o sol. Estruturas espaciais motorizados e sistemas cinemáticos assegurar a dinâmica de movimento e empregam tecnologia de acionamento e orientando os princípios para orientar configurações ópticas como mangin,, cônicas ou coletores de energia parabólicos Cassegrain solares para enfrentar o sol e seguem o contorno movimento sol continuamente.

No aproveitamento de energia a partir do sol através de um seguidor solar ou sistema de seguimento solar prático, sistemas de automação de controle de energia renováveis exigem software de seguimento solar automático e algoritmos de posição solares para realizar o controle de movimento dinâmico, com arquitetura de automação de controle, placas de circuitos e hardware. On-eixo sistema de rastreamento de sol, tais como os sistemas de seguidor solar altitude-azimute de eixo duplo ou multi-eixos usar um algoritmo de rastreamento sol ou rastreamento sensores ou software para garantir a passagem do Sol pelo céu ray é traçado com alta precisão em aplicações automatizadas seguidor solar , através do direito solstício de verão, equinócio solar e solstício de inverno. Um algoritmo de alta precisão calculadora posição do sol ou posição do sol usa uma rotina de programa de software para alinhar o seguidor solar ao sol e é um componente importante na concepção e construção de um sistema de seguimento solar automático.

De rastreamento sol perspectiva de software, o soneto traçando a Sun tem um significado literal. Dentro do contexto de sol track and trace, este livro explica que caminho diário do sol através do céu é dirigido por princípios relativamente simples, e se agarrou / entendido, então é relativamente fácil de rastrear o sol com sol seguinte software. Sun software de computador para rastrear a posição do sol estão disponíveis como código aberto, fontes que está listado neste livro. Ironicamente houve até um sistema chamado sol caçador, disse ter sido um sistema posicionador energia solar conhecida por perseguir o sol durante todo o dia.

Usando equações solares em um circuito eletrônico para seguimento solar automático é bastante simples, mesmo se você é um novato, mas equações matemáticas solares são mais complicados por especialistas acadêmicos e professores em livros-texto, artigos de revistas e sites na Internet. Em termos de passatempos solares, acadêmicos, estudantes e Hobbyist está olhando programas solares eletrônicos de rastreamento ou PC para seguimento solar são normalmente superado pelo grande volume de materiais e internet recursos científicos, o que deixa muitos desenvolvedores em frustração quando busca por simples fonte de seguimento solar experimental -Code para os seus sistemas de rastreamento de sol no eixo. Este folheto irá simplificar a busca das fórmulas místicas rastreamento sol para o seu sol inovação rastreador e ajudá-lo a desenvolver o seu próprio controlador autônomo seguimento solar.

Ao dirigir o coletor solar diretamente para o sol, a energia solar significa colheita ou dispositivo pode aproveitar a luz solar ou calor térmico. A fim de acompanhar o sol como a Terra gira (ou como o sol se move através do céu) a ajuda de fórmulas ângulo do sol, fórmulas ângulo solares ou procedimentos de seguimento solar é necessária para o cálculo da posição do sol no céu. Software sistema de rastreamento automático de sol inclui algoritmos para cálculos de ângulo altitude azimute solares necessários para seguir o sol no céu. Ao usar a longitude, latitude coordenadas GPS do local seguidor solar, ferramentas de monitoramento de software estes sol suporta seguimento solar precisão ao determinar a altitude-azimute solar de coordenadas para a trajetória do sol em altitude-azimute rastreamento no local rastreador, usando certas fórmulas ângulo do sol em cálculos vetoriais sol. Em vez de seguir o software sol, um sensor de rastreamento de sol, como um sensor solar ou webcam ou câmera de vídeo com o sol baseado em visão seguinte software de processamento de imagem também pode ser usado para determinar a posição do sol opticamente. Tais dispositivos de realimentação ópticos são freqüentemente usados em sistemas de rastreamento de painel solar e sistemas de rastreamento de prato.

Rastreamento sol dinâmico também é usado em levantamento solar, analisador DNI e sistemas solares levantamento que constroem infográficos mapas solares com brilho solar, irradiância e modelos DNI para GIS (sistema de informação geográfica). Desta forma, métodos geoespaciais sobre a interação solares / ambiente faz uso uso de tecnologias geoespaciais (GIS, sensoriamento remoto e cartografia).
Os dados climáticos e dados da estação meteorológica ou centro de tempo, bem como as consultas de servidores céu e sistemas de banco de recursos solares (ou seja, DB2, Sybase, Oracle, SQL, MySQL) também pode estar associada com mapas GIS solares. Em tais sistemas de modelagem de recursos solares, um pirômetro ou solarímetro é normalmente utilizado, além de medir dispersos, dispersos, radiação reflexivo direta e indireta, para uma determinada localização geográfica. Análise de luz solar é importante na fotografia com flash onde iluminação fotográfica são importantes para os fotógrafos. Sistemas GIS são utilizados por arquitetos que adicionar applets sombra do sol para estudar sombreamento arquitectónico ou análise de sol sombra, os cálculos de fluxo solar, modelagem óptica ou para realizar a modelagem de clima. Esses sistemas geralmente empregam um computador operado mecanismo tipo telescópio com ray tracing software programa como um navegador solares ou sol tracer que determina a posição solar e intensidade.

O objetivo deste livro é ajudar os desenvolvedores a rastrear e acompanhar código-fonte adequada e algoritmos de seguimento solar para a sua aplicação, seja um hobby, cientista, técnico ou engenheiro. Muitos sol open-source seguir e rastrear algoritmos e de código-fonte de programas de seguimento solar e módulos estão disponíveis gratuitamente para download na internet hoje. Alguns kits seguidor solar proprietários e controladores de seguimento solar incluem um kit de desenvolvimento de software SDK para seus atributos de programação de aplicativos (API de interface do seixo). Bibliotecas widget, toolkits de widgets, kit de ferramentas GUI e bibliotecas UX com elementos de controle gráficos também estão disponíveis para construir a interface gráfica do usuário (GUI) para o seu seguimento solar ou programa de monitoramento de energia solar.

A biblioteca solar, usado por calculadoras posição solar, software de simulação solar e calculadoras contorno solares incluem código de programa de computador para o controlador de hardware solar, que são software programado no micro-controladores, Controladores Lógicos Programáveis PLC, matrizes de portas programáveis, processador processador ou PIC Arduino. Seguimento solar baseado em PC também é alta na demanda usando C ++, Visual VB Basic, bem como MS Windows, Linux e Apple Mac sistemas operacionais baseados para tabelas caminho do sol em Matlab, Excel. Alguns livros e páginas da Internet utilizam outros termos, tais como: calculadora ângulo do sol, calculadora posição do sol ou calculadora ângulo solar. Como disse, esse código software calcular o ângulo solar, azimute, ângulo de altitude solar, ângulo de elevação do sol ou o ângulo zenital solar (Zenith ângulo solar é simplesmente referenciada do plano vertical, o espelho do ângulo de elevação medido a partir do nível horizontal ou plano de terra) . Código de software semelhante também é usado em aplicações da calculadora solares ou as aplicações da calculadora de energia solar para smartphones iOS e Android. A maioria desses aplicativos móveis solares smartphones mostrar o caminho sol e ângulos solares para qualquer local e data por um período de 24 horas. Alguns smartphones incluem aumentada características da realidade em que você pode ver fisicamente e olhar para o caminho solar através de sua câmera de telefone celular ou câmera de telefone celular em local específico do GPS do seu telefone.

No ambiente de programação de computadores e processamento de sinal digital (DSP), (free / open source) código do programa estão disponíveis para Gambas, VB, NET, Delphi, Python, C, C +, C ++, PHP, Swift, ADM, F, o Flash , Basic, QBasic, GBasic, KBasic, linguagem SIMPL, Esquilo, Solaris, a linguagem Assembly em sistemas operacionais como o MS Windows, Apple Mac, DOS, Unix ou Linux OS. Algoritmos de software posição do sol no céu prevendo são comumente disponíveis como plataformas gráficas de programação, como Matlab (Mathworks), modelos Simulink, applets Java, TRNSYS simulações, aplicativos do sistema Scada, Módulo LabVIEW, Beckhoff TwinCAT (Visual Studio), Siemens SPA, aplicativos para celular e iPhone, Android ou iOS tablet, e assim por diante. Ao mesmo tempo, o código de software PLC para uma gama de tecnologia de automação de monitoramento sol pode seguir o perfil do sol no céu para a Siemens, HP, Panasonic, ABB, Allan Bradley, OMRON, SEW, Festo, Beckhoff, Rockwell, Schneider, Endress Hauser , Fudji elétrica. Honeywell, Fuchs, Yokonawa, ou Muthibishi plataformas. Sun software projeção caminho também estão disponíveis para uma variedade de placas-mãe de PCs embarcados IPC modulares, PC Industrial, PLC (Controlador Lógico Programável) e PAC (Programmable Automation Controller), como a Siemens S7-1200 ou Siemens Logo, Beckhoff IPC ou série CX, OMRON PLC, Ercam PLC, AC500plc ABB, National Instruments NI PXI ou NI cRIO, processador PIC, Intel 8051/8085, a IBM (Cell, Poder, Brain ou série TrueNorth), FPGA (Xilinx Altera Nios), Intel, Xeon, Atmel megaAVR , MPU, Bordo, Teensy, MSP, XMOS, Xbee, ARM, Raspberry Pi, Eagle, Arduino ou Arduino Atmega microcontrolador, com servo motor, motor de passo, a corrente PWM direto DC modulação de largura de pulso (driver atual) ou corrente alternada AC SPS ou freqüência variável IPC As unidades motoras de CSC (unidade de frequência ajustável também denominado, unidade de velocidade variável, inversor de frequência, unidade de micro ou conversor) para elétrica, mecatrônica, pneumáticos, hidráulicos ou atuadores de seguimento solar.

Os sistemas de controle de controle de movimento acima e robô incluem analógico ou portas de interface digitais nos processadores para permitir ângulo rastreador de controle de feedback orientação através de um ou uma combinação de sensor de ângulo ou ângulo encoder, codificador de eixo, a precisão do encoder, codificador óptico, codificador magnético, direção encoder, encoder rotativo, o chip codificador, sensor de inclinação, sensor de inclinação, ou sensor campo. Note-se que a elevação ou zênite ângulo do eixo do rastreador pode medida usando um angle- altitude, declinação angle-, inclinação angle-, pitch angle-, ou angle- vertical, sensor de angle- zênite ou inclinômetro. Da mesma forma azimute ângulo do eixo do rastreador ser medida com um angle- azimute, angle- horizontal, ou sensor angle- roll. Sensores de ângulo de chip integrado acelerómetro magnetómetro giroscópio tipo também pode ser utilizado para calcular o deslocamento. Outras opções incluem o uso de sistemas de imagem térmica, tais como uma câmara termográfica Fluke, ou sistemas robóticos rastreador ou visão baseada solares que utilizam rastreamento de face, cabeça de monitoramento, rastreamento de lado, eye tracking e princípios de rastreamento de carro em rastreamento solar.

Com autônoma descentralizada rural, ilha, isolado, ou instalações de energia fora da rede autônomos, controle remoto, monitoramento, aquisição de dados, registro de dados digitais e equipamentos de medição e verificação on-line torna-se crucial. Ela auxilia o operador com controle de supervisão para monitorar a eficiência dos recursos energéticos renováveis e sistemas remotos e fornecer feedback valioso baseado na web em termos de CO2 e mecanismo de desenvolvimento limpo (MDL), elaboração de relatórios. Um analisador de qualidade de energia para diagnóstico através de internet, Wi-Fi e ligações móveis celulares é mais valioso na solução de problemas na linha de frente e de manutenção preditiva, onde a análise de diagnóstico rápido é necessário para detectar e evitar problemas de qualidade de energia.

Aplicações seguidor solar cobrem um amplo espectro de aplicações solares e aplicação solar assistida, incluindo a geração de energia solar concentrada, dessalinização solar, purificação de água solar, geração de vapor solar, geração de eletricidade solar, calor de processo industrial solar, armazenamento de calor solar térmica, secadores de comida solares, bombeamento de água solar, produção de hidrogênio a partir do metano ou a produção de hidrogênio e oxigênio da água (HHO), através de eletrólise. Muitos patenteado ou aparelho de energia solar não-patenteado incluem rastreamento no aparelho solar para gerador solar elétrico, dessalinizador solar, máquina a vapor solar, máquina de fazer gelo solar, purificador de água solar, refrigeração solar, refrigeração solar, USB carregador solar, carregamento de telefone solar, carregamento solar portátil rastreador, preparação de café solar, cozinha solar ou morrer significa solares. Seu projeto pode ser o próximo avanço ou patente, mas sua invenção é retido pela frustração na busca para o rastreador de sol que você precisa para o seu aparelho movido a energia solar, gerador solar, robô seguidor solar, congelador solar, fogão solar, secador solar, bomba solar , congelador solar, ou projeto de secador solar. Se o seu diagrama de circuito eletrônico energia solar incluem um projeto simplificado solar, controlador de um projeto de energia solar, kit de energia solar, kit passatempo solar, gerador de vapor solar, sistema de água quente solar, máquina de fazer gelo solar, dessalinizador solar, painéis solares hobby, passatempo robô, ou se você estiver desenvolvendo electrónica profissional ou hobby para um utilitário de energia solar ou gerador solar, micro escala para a sua própria fazenda solar ou agricultura solar, esta publicação pode ajudar a acelerar o desenvolvimento de sua inovação seguimento solar.

Ultimamente, poligeração solar, trigeração solar (geração triplo solar), e geração quad solar (adicionando entrega de vapor, líquido / combustível gasoso, ou captura de alimentos-grade CO_2) sistemas têm necessidade de seguimento solar automático. Estes sistemas são conhecidos por aumentos de eficiência significativos no rendimento de energia como resultado da integração e reutilização de resíduos ou de calor residual e são adequados para propulsores solares compactos embalados micro que poderiam ser fabricados e transportados em kit-forma e operam em um plug base jogo -and. Sistemas de energia híbrido solar típicas incluem micro compactas ou embalados solares combinadas de calor e energia (CHP ou Mchp) ou micro solares combinados, refrigeração, sistemas (CCHP, CHPC, mCCHP, ou mCHPC) utilizados na geração de energia distribuída aquecimento e energia. Estes sistemas são muitas vezes combinados em CSP solar concentrada e CPV configurações microgrid inteligente para fora da rede rural, ilha ou isolado microgrid, minigrid e sistemas de energias renováveis de energia distribuída. Algoritmos de seguimento solar também são usados na modelagem de sistemas de trigeração utilizando Matlab Simulink (Modelica ou TRNSYS) plataforma, bem como na automação e controle de sistemas de energias renováveis, através de análise inteligente, multi-objetivo, estratégias de controle de aprendizagem e de otimização de controle adaptativo.

Algoritmos de seguimento solar também encontrar aplicação no desenvolvimento de modelos solares para país ou estudos solares específicos de localização, por exemplo, em termos de medição ou análise das flutuações da radiação solar (ou seja, a radiação direta e difusa) em uma área particular. DNI Solar, radiação solar e informações atmosféricas e modelos podem, assim, ser integrados em um mapa solar, atlas solares ou sistemas de informação geográfica (SIG). Tais modelos permite definir os parâmetros locais de regiões específicas que podem ser valiosas em termos de avaliação de energia solar fotovoltaica em diferentes sistemas de CSP em plataformas de simulação e síntese, tais como Matlab e Simulink ou em plataformas lineares ou multi-objetivo do algoritmo de otimização, como COMPOR , EnergyPLAN ou DER-CAM.

Um seguidor solar de dois eixos e um único eixo seguidor solar pode usar um algoritmo do programa rastreador solar ou rastreador solar para posicionar um prato solar, painel solar painel, array heliostat, painel PV, antena solar ou a energia solar nantenna infravermelho. Um concentrador solar auto-monitoramento realiza seguimento solar automático calculando o vetor solar. Algoritmos de posição solar (TwinCAT, SPA, ou PSA Algoritmos) usam um algoritmo astronômico para calcular a posição do sol. Ele usa algoritmos de software de astronomia e suas equações para seguimento solar no cálculo da posição do sol no céu para cada local sobre a terra a qualquer hora do dia. Como um telescópio solar óptica, os solares algoritmo posição pin-points do refletor solar no sol e fechaduras para a posição do sol para acompanhar o sol no céu como o sol progride ao longo do dia. Sensores ópticos, como fotodiodos, luz-dependente resistências (LDR) ou fotorresistências são usados como dispositivos de realimentação de precisão óptica. Ultimamente nós também incluiu uma seção no livro (com links para código microprocessador) sobre como a câmera infravermelha Pixart Wii no Wii Wiimote remoto ou pode ser utilizado em aplicações de rastreamento solares infravermelhos.

A fim de coletar a energia livre do sol, alguns sistemas de posicionamento solares automáticos use meios ópticos para dirigir o dispositivo de rastreamento solar. Estas estratégias de seguimento solar usar técnicas de rastreamento ópticos, como um meio de sensores sol, aos raios solares diretos em um substrato de silício ou CMOS para determinar as coordenadas X e Y da posição do sol. Em um dispositivo MEMS solares sol-sensor, a luz solar incidente entre o sensor solar através de uma pequena pin-furo numa placa de máscara, onde a luz é exposto a um substrato de silício. Em uma web-câmera ou câmera de processamento de imagem sol rastreamento e dom seguinte forma, rastreamento de objetos software executa vários rastreamento de objetos em movimento ou métodos de rastreamento de objetos. Em uma técnica de seguimento de objectos solar, o software de processamento de imagem executa o processamento matemático para a caixa do contorno do disco solar aparente ou sol gota dentro do quadro da imagem captada, enquanto sol-localização é realizada com um algoritmo de detecção de borda para determinar as coordenadas do vetor solares.

Um sistema de posicionamento automatizado ajudar a maximizar os rendimentos de usinas de energia solar por meio de controle de seguimento solar para aproveitar a energia do sol. Em tais sistemas de energia renovável, o sistema de posicionamento do painel solar usa um sol técnicas de rastreamento e uma calculadora solar no ângulo painéis fotovoltaicos de posicionamento em sistemas fotovoltaicos e sistemas fotovoltaicos CPV concentrados. O controle automático no eixo solar, em um sistema de seguimento solar PV pode ser duplo eixo de rastreamento sol ou sol de eixo único de rastreamento solar. Sabe-se que um sistema de posicionamento motorizado em um aumento de rastreador de rendimento da energia do painel fotovoltaico e garante aumento de potência, mesmo em um eixo único de configuração de rastreamento solar. Outras aplicações como seguidor solar robótico ou sistema de seguimento solar robótico usa robotica com inteligência artificial na otimização do rendimento energético na colheita solar, controle através de um sistema de rastreamento de robótica.

Os sistemas automáticos de posicionamento em projetos de seguimento solar também são usados em outros geradores de energia livre, como concentrado CSP energia térmica solar e sistemas de Stirling prato. O dispositivo de rastreamento sol em um coletor solar em um concentrador solar ou coletor solar tal realiza no eixo de rastreamento solar, um eixo duplo assistências seguidor solar para aproveitar a energia do sol através de um coletor solar óptico, que pode ser um espelho parabólico, parabólica refletor, lente Fresnel ou espelho array / matriz. A antena parabólica ou refletor é dinamicamente dirigido usando um sistema de transmissão ou de carro matou seguimento solar dizer. Na condução do prato para enfrentar o sol, o actuador mecânico prato e meios de actuação em um sistema de antena parabólica opticamente concentra a energia do sol sobre o ponto focal de uma antena parabólica ou um meio de concentração de energia solar. Um motor Stirling, tubulação de calor solar, thermosyphin, mudança de fase receptor PCM material solar, ou a luz solar receptor de fibra óptica significa está localizado no ponto focal do concentrador solar. A configuração de prato motor Stirling é conhecido como um sistema de prato ou de Stirling Stirling sistema de geração de energia. Sistemas de energia solar híbrida (usados em combinação com o biogás, biocombustíveis, gasolina, etanol, diesel, gás natural ou PNG) usam uma combinação de fontes de energia para aproveitar e armazenar a energia solar em um meio de armazenamento. Qualquer variedade de fontes de energia podem ser combinadas por meio da utilização de controladores e a energia armazenada em baterias, de material de mudança de fase, o armazenamento de calor, e na forma de cogeração convertido para a potência necessária utilizando ciclos termodinâmicos (ciclo orgânico Rankin, Brayton, micro turbinas, Stirling) com um controlador inversor e carga.

Abstract for Google Translate in Russian
В этой книге подробно Автоматическая Solar-Tracking, ВС-Tracking-Systems, Solar-трекеры и ВС Tracker Systems. Интеллектуальный автоматический солнечной слежения является устройством, которое ориентирует полезную нагрузку к солнцу. Такое программируемый компьютер на основе солнечной устройство слежения включает принципы солнечной слежения, солнечных систем слежения, а также микроконтроллер, микропроцессор и / или ПК на базе управления солнечной отслеживания ориентироваться солнечных отражателей, солнечные линзы, фотоэлектрические панели или другие оптические конфигурации к ВС Моторизованные космические кадры и кинематические системы обеспечения динамики движения и использовать приводной техники и готовится принципы, чтобы направить оптические конфигурации, такие как Манжен, параболических, конических или Кассегрена солнечных коллекторов энергии, чтобы лицом к солнцу и следовать за солнцем контур движения непрерывно.

В обуздывать силу от солнца через солнечный трекер или практической солнечной системы слежения, системы возобновляемых контроля энергии автоматизации требуют автоматического солнечной отслеживания программного обеспечения и алгоритмов солнечные позиции для достижения динамического контроля движения с архитектуры автоматизации управления, печатных плат и аппаратных средств. На оси системы слежения ВС, таких как высота-азимут двойной оси или многоосевые солнечные системы трекер использовать алгоритм отслеживания солнце или трассировки лучей датчиков или программное обеспечение, чтобы обеспечить прохождение солнца по небу прослеживается с высокой точностью в автоматизированных приложений Солнечная Tracker , прямо через летнего солнцестояния, солнечного равноденствия и зимнего солнцестояния.Высокая точность позиции ВС калькулятор или положение солнца алгоритм использует процедуру по программному обеспечению для выравнивания солнечной трекер к солнцу и является важным компонентом в проектировании и строительстве автоматической системой солнечной слежения.

От солнца отслеживания точки зрения программного обеспечения, сонет Трассировка ВС имеет буквальное значение. В контексте ВС отслеживания и, эта книга объясняет, что ежедневно путь Солнца по небу направлен на относительно простых принципов, и если схватил / понял, то сравнительно легко проследить ВС с ВС следующее программное обеспечение. Вс положение программное обеспечение для отслеживания солнце доступны как с открытым исходным кодом, источники, перечисленные в этой книге. По иронии судьбы был даже система называется ВС охотник, как говорят, был Солнечная система позиционирования известен в погоне за солнцем в течение всего дня.

Использование солнечных уравнений в электронной схемы для автоматического солнечной отслеживания довольно просто, даже если вы новичок, но математические солнечные уравнения над осложняется академических экспертов и профессоров в учебниках, журнальных статей и интернет-сайтов. С точки зрения солнечных хобби, ученых, студентов и Hobbyist смотрит на программах солнечных отслеживания электроники или ПК для солнечной слежения обычно преодолевается огромного объема научных материалов и интернет-ресурсов, что оставляет много разработчиков в отчаяние, когда поиск простой экспериментальной солнечной источника слежения -кода для их на-оси солнцезащитных систем слежения. Эта брошюра будет упростить поиск самых мистических формул слежения ВС для вашего ВС трекера инноваций и помочь вам развить свой собственный автономный солнечный регулятор отслеживания.

Направив солнечный коллектор прямо на солнце, солнечная сбор средств или устройство может использовать солнечный свет или тепловой тепла. Для того, чтобы следить за солнцем, как Земля вращается (или как Солнце движется по небу) помощь ВС угловых формул, солнечные формулы угол или солнечные процедуры отслеживания требуется при расчете позиции солнца в небе. Автоматическая ВС система отслеживания программного обеспечения включает в себя алгоритмы для солнечных высота угла азимута вычислений, необходимых в следующем солнце по небу. При использовании широты и долготы GPS координаты солнечной месте трекера, это солнце отслеживания программных средств поддерживает точность солнечной отслеживание путем определения высоты солнца-азимут координаты траектории ВС в высотно-азимуту отслеживания на месте трекера, используя определенные формулы угол ВС в векторных вычислениях вС. Вместо того, чтобы следовать программного обеспечения ВС, датчик слежения за солнцем, таких как датчик солнца или веб-камеры или видеокамеры с видение ВС на основе следующего программного обеспечения для обработки изображений также может быть использован для определения положения солнца оптически. Такие устройства оптической обратной связи часто используются в солнечных системах слежения панели и системы слежения блюдо.

Динамическая трассировка ВС также используется в солнечной геодезию, DNI анализатора и ВС геодезия систем, которые строят солнечные Инфографика карты с солнечного сияния, излучения и DNI моделей для ГИС (Географическая информационная система). Таким образом геопространственных методов на солнечной / среды взаимодействия использует использования геопространственных технологий (ГИС, дистанционного зондирования, и картографии).
Климатические данные и данные Метеостанция или погода центр, а также запросы из неба серверов и солнечных систем баз данных ресурса (то есть на DB2, Sybase, Oracle, SQL, MySQL) также могут быть связаны с солнечными карт ГИС. В таких солнечных систем моделирования ресурсов, Пиранометр или solarimeter обычно используется в дополнение измерить прямое и косвенное, рассеянный, фрагментарной отражающий излучение для конкретного географического расположения. Анализ Солнечный свет является важным при съемке со вспышкой, где фотографическое освещение важны для фотографов. ГИС-системы используются архитекторами, которые добавляют ВС теневые апплеты для изучения архитектурного затенение или солнце тень анализ, солнечного потока вычислений, оптический моделирование или проводить моделирование погоды. Такие системы часто используют компьютерную работает механизм типа телескоп с трассировки лучей программное обеспечение программы как солнечный навигатора или ВС индикатора, определяющего солнечной положение и интенсивность.

Цель этой брошюры заключается в оказании помощи разработчикам трекинг подходящий исходный код и солнечные алгоритмы отслеживания их применения, будь то любитель, ученого, специалиста или инженера. Многие с открытым исходным кодом ВС следующее и отслеживания алгоритмы и исходный код для солнечных программ слежения и модули находятся в свободном доступе для скачивания в Интернете сегодня. Некоторые фирменные комплекты солнечных трекер и солнечные контроллеры отслеживания включают разработки программного обеспечения комплекта SDK для своих прикладного программирования атрибутов интерфейс API (Pebble). Виджет библиотеки, виджет инструментарии, GUI инструментарий и UX библиотеки с графическими элементами управления также доступны для построения графического интерфейса пользователя (GUI) для вашей солнечной отслеживания или солнечной программы мониторинга питания.

Солнечная библиотека используется солнечных калькуляторов положения, солнечной программного обеспечения для моделирования и солнечных калькуляторов контурных включают программный код машины для солнечной аппаратного контроллера, которые являются обеспечение запрограммировано в микроконтроллерах, Программируемые логические контроллеры PLC, программируемых вентильных матриц, Arduino процессор или PIC процессор. На основе солнечной отслеживания PC также высоким спросом, используя C ++, Visual Basic VB, а также MS Windows, Linux и Apple Mac на основе операционных систем для ВС пути столов на Matlab, Excel. Некоторые книги и интернет-веб-страниц использовать другие термины, такие как: Вс угла калькулятор, позиции ВС калькулятора или солнечной угла калькулятора. Как уже говорилось, такой код программного обеспечения расчета солнечного азимута, угла Солнца высоты, солнечной угол возвышения или угол солнечных Зенит (Zenith солнечной угол просто ссылаться из вертикальной плоскости, зеркало угла возвышения измеряется от горизонтальной или молотые плоскости уровня) . Похожие программное обеспечение код также используется в солнечных калькулятор приложений или солнечных Калькулятор мощности приложений для IOS и Android смартфонов. Большинство из этих смартфонов солнечных мобильных приложений показать путь солнца и солнечных углы для любого места и даты в течение 24-часового периода. Некоторые смартфоны включают дополненной реальности черты, в которых вы можете физически видеть и смотреть на солнечной пути через свой мобильный телефон камеры или камеры мобильного телефона на определенном месте GPS вашего телефона.

В компьютерного программирования и цифровой обработки сигналов (DSP) среды, (свободного / открытого источника) программный код доступны для Gambas, VB, NET, Delphi, Python, C, C +, C ++, PHP, Swift, ADM, F, Flash , Basic, QBasic, GBasic, KBasic, СИМПЛ язык, Белка, Solaris, язык Ассамблея на операционных системах, таких как MS Windows, Apple Mac, DOS, Unix или Linux. Программные алгоритмы прогнозирования положение солнца в небе обычно доступны в виде графических платформ программирования, таких как Matlab (Mathworks), Simulink моделей, апплеты, TRNSYS моделирования, системы Scada приложения, модуль LabVIEW, Beckhoff TwinCAT (Visual Studio), Siemens SPA, мобильные и IPhone Служб, Android или IOS планшетные приложения, и так далее. В то же время, программный код PLC для диапазона технологии солнце автоматизации слежения может следовать профиля ВС в небе для Siemens, HP, Panasonic, ABB, Аллан Брэдли, OMRON, шить, Festo, Beckhoff, Rockwell, Schneider, Endress Hauser , Fudji электрический. Honeywell, Фукс, Yokonawa или Muthibishi платформы. Вс проекция путь программное обеспечение также доступны для целого ряда модульных IPC встраиваемых плат персональных компьютеров, промышленных ПК, ПЛК (Программируемый логический контроллер) и PAC (Programmable Automation Controller), таких как Siemens S7-1200 или Siemens Logo, Beckhoff IPC или серии CX, OMRON PLC, Ercam PLC, AC500plc ABB, National Instruments NI PXI или NI Crio, PIC процессор, Intel 8051/8085, IBM (сотовый, мощность, Brain или серии TrueNorth), FPGA (Xilinx Altera Nios), Intel, Xeon, Atmel MegaAVR , MPU, Maple, Teensy, MSP, XMOS, Xbee, ARM, Raspberry Pi, Opел, Arduino или Arduino ATMEGA микроконтроллер, с мотором, шаговым двигателем, постоянного тока PWM DC широтно-импульсная модуляция (ток драйвера) или переменного тока AC SPS или переменной частоты IPC приводит электроприводы VFD (также называется регулируемой частоты, вариатора, привод переменного тока, микро-диска или преобразователь) для электрического, мехатроники, пневматическим или гидравлическим солнечных приводов слежения.

Системы контроля над управления движением робота и включают аналоговых или цифровых сопряжения портов на процессоры для обеспечения отслеживания угловой ориентации управления с обратной связью по одному или комбинации датчика угла поворота или угловой кодер, кругового датчика, точность датчика, оптического датчика, датчика магнитного направлении, кодер, вращения энкодера, чип кодера, датчик наклона, датчик наклона, или датчик шага. Обратите внимание, что высота или зенитный угол оси трекера может определить при помощи высоты угол-, склонения угол-, склонность угол-, шаг угол- или вертикальную угол-, зенит угол- датчика или угломера. Аналогично азимутальный угол ось трекера быть измерена с азимута угол-, горизонтальной угол-, или угловым датчиком крена. Чип, объединенный акселерометр магнитометр угловые датчики типа гироскопа также может быть использован для вычисления смещения. Другие варианты включают использование тепловизионных систем, таких как Fluke тепловизора, или роботов или видения на основе солнечных следящих систем, которые используют слежения за лицом, отслеживание головы, отслеживание рук, глаз отслеживания и принципы отслеживания автомобилей в солнечной отслеживания.

С автоматической децентрализованной сельской, остров, изолированный, или автономных энергетических установок автономных, пульт дистанционного управления, мониторинга, сбора данных, цифровой регистрации данных и онлайн-измерений и поверочного оборудования становится решающим. Это помогает оператору с диспетчерского управления для мониторинга эффективности удаленных возобновляемых ресурсов и источников энергии и предоставить ценную веб-обратную связь по CO2 и механизм чистого развития (МЧР) отчетности.Качества электроэнергии анализатор для диагностики через Интернет, WiFi и сотовой мобильной связи является наиболее ценным в прифронтовой неисправностей и профилактического обслуживания, где быстро диагностический анализ требуется для обнаружения и предотвращения проблем с качеством электроэнергии.

Солнечные приложения трекер охватывают широкий спектр солнечных систем и солнечной помогают, приложения, в том числе концентрированного солнечного производство электроэнергии, солнечной опреснения, солнечной очистки воды, солнечной паровой, солнечной генерации электроэнергии, солнечного тепла для промышленных процессов, солнечной хранения тепловой тепла, солнечных сушилок питания, солнечная откачки воды, производство водорода из метана или получения водорода и кислорода из воды (HHO) путем электролиза. Многие запатентованные или НЕПАТЕНТОВАННОЕ солнечной аппарат включают отслеживание в солнечной установки для солнечного электрогенератора, солнечной опреснитель, солнечной парового двигателя, солнечной льда, солнечной очиститель воды, солнечного охлаждения, солнечной охлаждения, USB солнечного зарядного устройства, солнечной зарядки телефона, портативного солнечного зарядного трекер, солнечная приготовление кофе, инсоляция или солнечные умирающие средства. Ваш проект может стать следующим прорывом или патент, но ваше изобретение сдерживается разочарования в поисках солнца трекера необходимого вам солнечной энергии устройства, солнечный генератор, солнечные трекер робота, солнечная морозильной, солнечная плита, солнечная сушилка, солнечная насоса , солнечная морозильник, или проект солнечной сушилки. Будь ваша солнечная схема электронная схема включения упрощенного солнечной дизайн контроллера в солнечной проекта электричество, солнечная комплект питания, солнечной комплект хобби, солнечный генератор пара, солнечную систему горячей воды, солнечной льда, солнечной опреснитель, любитель солнечных панелей, хобби робота, или если вы разрабатываете профессиональных или хобби электроники для солнечной полезности или микро масштабах солнечной силовой для самостоятельно солнечной ферме или солнечной хозяйство, эта публикация может помочь ускорить развитие вашей солнечной инноваций слежения.

В последнее время, солнечная polygeneration, солнечная тригенерация (солнечная тройной поколения), и солнечная генерация четырехъядерный (добавление доставку пара, жидкости / газообразного топлива, или захват пищевой CO_2) системы нуждаются для автоматической солнечной отслеживания. Эти системы известны значительным увеличением эффективности в энергетическом выходе в результате интеграции и повторного использования отходов или остаточного тепла и подходят для компактных упакованных микро солнечных электростанций, которые могут быть изготовлены и перевозимых в комплекте-форме и действуют на вилку -И игра основу. Типичные гибридные системы солнечной энергии: компактные или упакованные солнечные микро теплоэлектроцентрали (ТЭЦ или МЧП) или солнечные микро комбинированные, охлаждение, (CCHP, CHPC, mCCHP или mCHPC), которые используются в распределенной генерации электроэнергии отопление и власть. Эти системы часто сочетаются в концентрированной солнечной CSP и КНД конфигураций умный Microgrid для автономных сельских районов, острова или изолированной микросетку, minigrid и распределены энергетика Возобновляемые источники энергии систем. Солнечные алгоритмы слежения используются также при моделировании тригенерационных систем, использующих Matlab Simulink (Modelica или TRNSYS) платформы, а также в автоматизации и контроля систем возобновляемых источников энергии через интеллектуальный разбора, многоцелевой, адаптивных стратегий управления обучением и оптимизации управления.

Солнечные алгоритмы слежения также найти применение в разработке солнечных моделей для страны или местоположения конкретных солнечных исследований, например в плане измерения или анализа колебаний солнечной радиации (т.е. прямой и рассеянный солнечный) в определенной области. Солнечная DNI, солнечное излучение и атмосферные информация и модели могут таким образом быть интегрированы в солнечной карте, солнечных атласа или географических информационных систем (ГИС). Такие модели позволяет определять локальные параметры для конкретных регионов, которые могут быть ценным с точки зрения оценки различных солнечных фотоэлектрических в СКП систем на имитационных и синтеза платформ, таких как Matlab и Simulink или в линейных или нескольких объективных алгоритмов оптимизации платформ, таких как сочинять , EnergyPLAN или DER-CAM.

Двухосевой солнечной трекер и одноосевой солнечной трекер может использовать алгоритм программы ВС трекер или солнце трекер позиционировать солнечной блюдо, солнечных батарей панель, гелиотроп массива, PV панели, солнечные антенны или инфракрасного солнечного nantenna.Саморегулирующиеся солнечный концентратор выполняет автоматическую солнечной отслеживание путем вычисления солнечной вектор. Солнечные алгоритмы позиция (TwinCAT, SPA, или PSA Алгоритмы) использовать астрономическую алгоритм для расчета положения солнца. Он использует астрономические алгоритмы и уравнения программного обеспечения для солнечной слежения в расчете позиции солнца в небе для каждого места на земле в любое время суток. Как оптического солнечного телескопа, солнечные алгоритм положение пин-точки солнечного отражателя на солнце и замков на положение солнца, чтобы следовать за солнцем по небу, как солнце прогрессирует в течение дня. Оптические датчики, такие как фотодиоды, светозависимой-резисторы (LDR) или фоторезисторы используются в качестве устройств обратной связи оптический точности. В последнее время мы также включен раздел в книге (со ссылками на микропроцессорной кода) о том, как инфракрасная камера PixArt Wii в Wii Remote или Wiimote могут быть использованы в инфракрасных приложений солнечных слежения.

В целях освоения свободной энергии от солнца, некоторые автоматические системы солнечных позиционирования пользоваться оптическим устройством, чтобы направить солнечный устройство слежения. Эти солнечные стратегии отслеживания использовать методы оптического слежения, такие как средство датчика солнечного, прямых солнечных лучей на кремниевую или КМОП подложку для определения X и Y координаты положения солнца. В устройстве солнечных MEMS ВС-датчика, инцидент солнечный свет входит датчик солнечного через небольшой Pin-Hole в маске пластины, где свет подвергается кремниевой подложке. В обработки изображений слежения ВС веб-камеры или камеры и ВС следующие средства, объект программа отслеживания выполняет мульти слежения за объектом или движущихся методы объекта слежения. В солнечной техники отслеживания объекта, программное обеспечение для обработки изображения выполняет математическую обработку боксировать очертания видимого солнечного диска или ВС капля в захваченном кадре изображения, в то время как солнце-локализация выполняется с помощью алгоритма детектирования кромки для определения солнечные векторные координаты.

Автоматизированная система позиционирования помочь максимизировать выход солнечных электростанций через солнечной контроля слежения, чтобы использовать энергию солнца. В таких возобновляемых источников энергии, системы солнечных батарей позиционирования использует ВС методы отслеживания и солнечный угол калькулятор в позиционирования фотоэлектрических панелей в фотоэлектрических систем и концентрируют фотоэлектрических систем КНД. Автоматическая солнечной слежения в PV Солнечной системы слежения на оси может быть двухосевой отслеживания солнце или одноосный ВС солнечной отслеживания. Известно, что моторизованная система позиционирования в увеличение трекер выходом энергии фотоэлектрические панели и обеспечивает повышенную мощность, даже в конфигурации солнечных отслеживания одной оси. Другие приложения, такие как робота солнечной трекер или роботизированной Солнечной системы слежения использует Robotica с искусственным интеллектом в оптимизации управления энергетическим выходом в солнечных батарей через роботизированной системой слежения.

Автоматические системы позиционирования в солнечных конструкций слежения используются также в других свободной энергии генераторов, таких как концентрированной солнечной тепловой CSP питания и посудомоечных систем Стирлинга. Отслеживание ВС устройство в солнечном коллекторе в гелиоконцентратора или солнечного коллектора Такая а выполняет на-оси солнечной слежения, двойную ось солнечные помогает трекер, чтобы использовать энергию от солнца с помощью оптического солнечного коллектора, которые могут быть параболического зеркала, параболическая отражатель, линза Френеля или матрица / матрица.Параболические антенны или отражатель динамически управляемыми с помощью системы передачи или солнечной отслеживания нарастания езды имею в виду. В рулевое блюдо, чтобы лицом к солнцу, силовой привод блюдо и приведение означает в параболической системы блюдо оптически фокусируется энергию солнца в фокальной точке параболической блюдо или солнечных концентрирующих средств.Двигатель Стирлинга, солнечная тепловая труба, thermosyphin, солнечная изменение фазы приемника материалы PCM, или солнечный свет приемник волоконно-оптические средства находится в фокальной точке солнечного концентратора. Чашку конфигурации двигатель Стирлинга называют посудомоечной системы Стирлинга или Стирлинга системы производства электроэнергии. Гибридные солнечные электрические системы (используется в комбинации с биогаз, биотопливо, бензин, этанол, дизельное топливо, природный газ или PNG) использовать комбинацию источников энергии, чтобы использовать и хранить солнечную энергию на носителе данных. Любой множество источников энергии могут быть объединены за счет использования контроллеров и энергии, запасенной в батареях, материал с фазовым переходом, аккумулировани тепловой тепла, так и в виде комбинированного преобразуется в требуемой мощности с помощью термодинамических циклов (органический цикл Ранкина, Брайтона, микро-турбины, Стирлинг) с контроллером инвертора и заряда.

Abstract for Google Translate in Chinese

這本書詳細介紹了全自動太陽能跟踪，太陽跟踪系統的出現，太陽能跟踪器和太陽跟踪系統。智能全自動太陽能跟踪器是定向向著太陽的有效載荷設備。這種可編程計算機的太陽能跟踪裝置，包括太陽跟踪，太陽能跟踪系統，以及微控制器，微處理器和/或基於PC機的太陽跟踪控制，以定向太陽能反射器，太陽透鏡，光電板或其他光學配置朝向太陽的原理。機動空間框架和運動系統，確保運動動力學和採用的驅動技術和傳動原理引導光學配置，如曼金，拋物線，圓錐曲線，或卡塞格林式太陽能集熱器面向太陽，不斷跟隨太陽運動的輪廓。

從陽光透過太陽能跟踪器或實用的太陽能跟踪系統利用電力，可再生能源控制的自動化系統需要自動太陽跟踪軟件和太陽位置算法來實現控制與自動化架構，電路板和硬件的動態運動控制。上軸太陽跟踪系統，如高度，方位角雙軸或多軸太陽跟踪系統使用太陽跟踪算法或光線追踪傳感器或軟件，以確保通過天空中太陽的通道被跟踪的高精度的自動太陽跟踪器的應用，通過正確的夏至，春分太陽和冬至。一種高精度太陽位置計算器或太陽位置算法採用了一種軟件程序例程對齊的太陽跟踪器的陽光和是在一個自動太陽跟踪系統的設計和建設的重要組成部分。

從太陽跟踪軟件的角度來看，十四行詩跟踪太陽有一個字面意義。在太陽跟踪和追踪的背景下，這本書解釋說，在天空中太陽的日常路徑是通過相對簡單的原則導向的，如果掌握/了解的話，就比較容易追查以下軟件，太陽有太陽。是太陽位置的計算機軟件用於跟踪太陽作為開源代碼，列出在這本書的來源。諷刺的是還出現了系統，稱為太陽跟踪器，據說已經知道了追逐太陽全天太陽能定位系統。

在電子電路，自動跟踪太陽能利用太陽能公式很簡單，即使你是一個新手，但數學太陽能方程在複雜的學術專家，教授的教科書，期刊和互聯網網站。在太陽能愛好，學者，學生和雕塑家的看著太陽能跟踪太陽能跟踪電子裝置或電腦程序而言通常是由科學材料和網絡資源數量龐大，這讓不少開發商在挫折克服時尋求簡單的實驗性太陽能跟踪源-code它們對軸太陽跟踪系統。這本小冊子將簡化尋找神秘的太陽跟踪公式，你的太陽跟踪器的創新，並幫助您開發您自己的自治太陽能跟踪控制器。

直接指揮太陽能集熱器到太陽，太陽能收集裝置或設備可以利用太陽光或熱的熱量。為了跟踪太陽與地球旋轉（或隨著太陽在天空中移動）太陽角式的幫助下，太陽能角式或太陽跟踪程序中需要的在天空中太陽的位置的計算。自動太陽跟踪系統的軟件包括用於以下劃過天空，太陽需要的太陽高度方位角的計算算法。在使用經度，太陽能跟踪器位置的緯度GPS坐標，這些太陽跟踪軟件工具，支持精確的太陽跟踪通過測定太陽高度角，方位角坐標太陽軌跡的高度，方位角跟踪的跟踪器位置，使用特定的陽角公式在太陽矢量計算。而不是跟著太陽軟件，陽光跟踪傳感器，如太陽敏感器或網絡攝像機或視頻的攝像頭，基於視覺的陽光下圖像處理軟件也可以用於確定光學太陽的位置。這樣的光學反饋裝置通常用於在太陽能電池板跟踪系統和盤的跟踪系統。

動態跟踪太陽還應用於太陽能測量，DNI分析和建立與太陽的光芒，輻射和DNI模型的GIS（地理信息系統），太陽能的信息圖表地圖太陽測量系統。這樣的太陽能/環境的相互作用地理空間的方法是利用利用地理空間技術（地理信息系統，遙感和製圖）的。

氣候數據和氣象站或氣象中心的數據，以及來自天空的服務器和太陽能資源數據庫系統的查詢（即在DB2中，Sybase，甲骨文，SQL，MySQL的），也可以用太陽能GIS地圖相關聯。在這樣的太陽能資源建模的系統中，天空輻射計或solarimeter通常用於除了測量直接和間接的，分散的，分散的，反射的輻射對於特定的地理位置。日照分析是在閃光攝影的地方攝影燈光對攝影師很重要很重要。 GIS系統所使用的建築師誰加日影小程序，研究建築遮陽或日影分析，太陽通量計算，光造型或執行氣候建模。這種系統通常採用與光線跟踪程序軟件作為太陽能Navigator或太陽跟踪器，用於確定太陽位置和強度的計算機操作的望遠鏡類型的機制。

這本小冊子的目的是幫助開發者跟踪和追溯合適的源代碼和太陽能跟踪算法及其應用，無論是業餘愛好者，科學家，技術人員或工程師。許多開源的陽光下和跟踪算法及源代碼太陽能跟踪程序和模塊都可以免費獲得今天在互聯網上下載。某些專有的太陽能跟踪器套件和太陽能跟踪控制器包括一個軟件開發工具包SDK的應用編程接口（API）的屬性（卵石）。部件庫，小部件工具包的GUI工具包和UX庫，圖形化的控制元件也可用來構建圖形用戶界面（GUI），為您的太陽能跟踪或太陽能發電監測方案。

使用太陽位置計算器，太陽能仿真軟件和太陽能輪廓計算器太陽能庫包括用於太陽能硬件控制器，該控制器是可軟件編程到微控制器，可編程邏輯控制器PLC，可編程門陣列，Arduino的處理器或處理器的PIC機程序代碼。基於PC的太陽跟踪也很高，使用C++，Visual Basic中的VB，以及微軟的Windows，Linux和蘋果的Mac操作系統下對MATLAB，Excel的太陽路徑表的需求。一些書籍和互聯網網頁使用其它術語，如：太陽角度計算器，太陽位置計算器或太陽角度計算器。如所述，這樣的軟件代碼，計算出太陽能方位角，太陽高度角，太陽仰角或太陽天頂角（天頂太陽角度被簡單地從垂直平面中引用，仰角從水平或接地平面電平測量的反射鏡）。類似的軟件代碼也應用於太陽能計算器應用程序或為iOS和Android智能手機設備上的太陽能計算器應用程序。大多數智能手機太陽能移動應用程序的顯示太陽路徑和太陽角度的任何地點和日期在24小時內。一些智能手機，包括增強現實功能，您可以在其中看到身體，並期待在太陽能道路通過你的手機攝像頭或手機攝像頭在手機的特定GPS位置。

在計算機編程和數字信號處理（DSP）的環境中，（自由/開放源碼）程序代碼可用於Gambas的，VB，淨，德爾福，Python和C，C+，C++，PHP，雨燕，ADM，女，閃光，基本，QBasic中，GBasic，KBasic，SIMPL語言，松鼠，Solaris操作系統，對操作系統，如微軟Windows，蘋果的Mac，DOS，Unix或Linux操作系統的彙編語言。軟件算法預測太陽在天空中的位置通常是可以作為圖形化編程平台，如Matlab（Mathworks公司），Simulink模型，Java小程序，TRNSYS模擬，SCADA系統的應用程序中，LabVIEW模塊，倍福的TwinCAT（Visual Studio中），西門子SPA，手機和iPhone的應用程序，Android或iOS的平板電腦應用程序，等等。同時，為一系列的太陽跟踪自動化技術的PLC軟件代碼可以跟隨太陽的輪廓在天空西門子，惠普，松下，ABB，艾倫·布拉德利，歐姆龍，SEW，費斯托，倍福，羅克韋爾，施耐德，恩德斯豪斯，Fudji電。霍尼韋爾公司，福克斯，Yokonawa或Muthibishi平台。孫路投影軟件，也可用於各種模塊化嵌入式工控機PC主板，工控機，PLC（可編程邏輯控制器）和PAC（可編程自動化控制器），如西門子S7-1200或西門子LOGO，Beckhoff的工控機或CX系列，歐姆龍PLC，PLC Ercam，AC500plc ABB公司，美國國家儀器公司的NI PXI或NI的cRIO，PIC處理器，英特爾8085分之8051，IBM公司（電池，電源，智慧或Truenorth系列），FPGA（Xilinx公司Altera公司的Nios），英特爾®至強®，Atmel公司megaAVR，MPU，楓木，Teensy，MSP，XMOS，的XBee，ARM，樹莓丕，鷹，Arduino的或Arduino的ATMEGA微控制器，伺服電機，步進電機，直流直流脈衝寬度調製（PWM）（當前的驅動程序）或交流電AC SP或工控變頻驅動變頻馬達驅動器（也稱為可調頻率驅動，變速驅動器，變頻器，微型變頻器或逆變器驅動器）電氣，機電，氣動，液壓或太陽能跟踪執行機構。

上述運動控制和機器人控制系統包括處理器上模擬或數字接口的端口，以使跟踪角取向的反饋控制通過一個或角度傳感器或角度編碼器，旋轉編碼器，精密編碼器，光學編碼器，磁性編碼器，方向的組合編碼器，旋轉編碼器，片式編碼器，傾斜傳感器，傾斜傳感器，或音調傳感器。請注意，使用高度角型，赤緯角型，傾斜角型，俯仰角型或垂直角型，天頂角型傳感器或測斜儀跟踪的抬高或天頂軸角度可以測量的。同樣，跟踪器的方位軸角與方位角角型，橫向角型或卷角型傳感器進行測量。芯片集成加速度計磁強計陀螺式角度傳感器也可用於計算位移。其他選項包括使用熱成像系統，如福祿克熱像儀，或僱用人臉跟踪，頭部跟踪，專人跟踪，眼動追踪及汽車跟踪原理的太陽能跟踪機器人或基於視覺的太陽能跟踪系統。

隨著無人值守分散的農村，海島，隔離，或自主離網發電裝置，遠程控制，監控，數據採集，數字化數據採集和在線測量和驗證設備變得至關重要。它可以協助管理控制操作員監視的遠程可再生能源和系統的效率，並提供了在二氧化碳和清潔發展機制（CDM）的報告方面有價值的基於網絡的反饋。電能質量分析儀，通過網絡，WiFi和蜂窩移動鏈接的診斷是最有價值的一線故障診斷和預測性維護，需要快速的診斷分析，以檢測和防止電能質量的問題。

太陽能跟踪器的應用涵蓋了廣泛的太陽能應用和太陽能輔助應用，包括集中太陽能發電，太陽能海水淡化，太陽能水淨化，太陽能蒸汽發電，太陽能發電，太陽能產業過程中的熱量，太陽能熱儲熱，太陽能食品乾燥機的頻譜，太陽能水泵，產氫或甲烷生產氫氣和氧氣從水中（HHO）通過電解。許多專利或非專利太陽能設備包括跟踪太陽能發電機，太陽能海水淡化，太陽能蒸汽機，太陽能製冰機，太陽能淨水器，太陽能製冷，太陽能製冷，USB太陽能充電器，太陽能手機充電，便攜式太陽能充電的太陽能設備跟踪器，太陽能煮咖啡，太陽能烹飪或太陽能垂死的手段。你的項目可能會成為下一個突破或專利，但你的發明阻礙了挫折中尋找您需要為您的太陽能供電設備上的太陽跟踪器，太陽能發電機，太陽能跟踪機器人，太陽能冰箱，太陽能灶，太陽能乾燥，太陽能水泵，太陽能冰箱，太陽能或烘乾機項目。無論您的太陽能電子線路圖包括一個簡化的太陽能控制器設計的太陽能發電項目，太陽能配件，太陽能嗜好套件，太陽能蒸汽發生器，太陽能熱水系統，太陽能製冰機，太陽能海水淡化，業餘愛好者的太陽能電池板，愛好機器人，或如果你正在開發的專業或愛好電子的太陽能實用程序或微規模的太陽能發電廠為自己的太陽能發電場和太陽能耕作，本出版物可以幫助加快你的太陽跟踪創新的發展。

最近，太陽能多聯產，熱電冷三聯產太陽能（太陽能三重代），以及太陽能發電四（添加交付蒸汽，液體/氣體燃料，或捕捉的食品級二氧化碳$_2$的）系統已經需要自動太陽跟踪。這些系統是已知的顯著效率增加的能量產率，為整合的結果和再利用的廢物或殘餘的熱量，並適用於可能被製造和運輸的試劑盒的形式與一插頭操作緊湊封裝的微太陽能發電廠 - 和發揮的基礎。典型的混合型太陽能發電系統，包括壓縮或包裝太陽能微型熱電聯產（CHP或MCHP）或太陽能微合，製冷，供暖和電力（熱電冷聯產，CHPC，mCCHP或mCHPC）在分佈式發電系統中使用。這些系統經常被組合在集中的太陽能的CSP和CPV智能微電網配置為離網鄉村，島嶼或孤立微電網，minigrid和分佈式電源可再生能源系統。太陽跟踪算法也可用於利用Matlab Simulink中（Modelica的或TRNSYS）平台三聯產系統的建模以及在自動化和通過智能解析，多目標，自適應學習控制和控制的優化策略可再生能源系統的控制。

太陽能跟踪算法也發現在測量或太陽輻射的波動分析方面開發太陽能模型的國家或地區的特定太陽能電池的研究，例如應用程序（即直接和散射輻射）在一個特定的區域。太陽能DNI，太陽輻射和大氣的信息和模型因此可以集成到太陽能地圖，地圖集太陽能或地理信息系統（GIS）。這種模型允許定義本地參數，可能是有價值的另一個太陽能的仿真和合成平台，如Matlab和Simulink或在直鏈的或多目標優化算法的平台，如COMPOSE CSP系統的光伏評估方面的特定區域，EnergyPLAN或DER-CAM。

雙軸太陽能跟踪器和單軸太陽能跟踪器可使用太陽跟踪程序或太陽跟踪算法來定位的太陽能菜，太陽能電池面板陣列，定日鏡陣列，光伏電池板，太陽能天線或紅外太陽能nantenna。一個自跟踪太陽能聚光通過計算太陽向量執行自動太陽跟踪。太陽位置算法（TwinCAT軟件的SPA，或PSA算法）使用一個天文算法來計算太陽的位置。它採用天文軟件算法和方程中的天空中，為地球上的每個位置的太陽位置計算太陽能跟踪在一天的任何時間。像光學太陽望遠鏡，太陽位置算法星星點點的太陽能反射太陽和鎖定到太陽的位置來跟踪在天空中太陽的太陽的進行了一整天。光學傳感器，如光電二極管，光依賴 - 電阻（LDR）或光敏電阻被用作光學精度反饋裝置。最近，我們還包括在書中的一段（鏈接到微處理器代碼）如何在Wii遙控器或Wiimote的的原相Wii的紅外攝像機可以在紅外太陽跟踪應用程序中使用。

為了從太陽收穫自由能，一些太陽能自動定位系統使用的光學裝置，以引導太陽能跟踪裝置。這些太陽能跟踪策略，利用光學追踪技術，如陽光傳感器裝置，以陽光直接照射到矽CMOS基板，以確定X和太陽的位置的Y坐標。在太陽能MEMS太陽傳感器裝置，太陽光入射，通過在光暴露於矽襯底上的小針孔的掩膜板的太陽傳感器。在一個網絡攝像頭或攝像頭圖像處理跟踪太陽和陽光下的手段，對象跟踪軟件進行多目標跟踪和運動目標跟踪方法。在一個太陽能對象跟踪技術，圖像處理軟件進行數學處理框所捕獲的圖像幀中的表觀太陽能光盤或太陽斑點的輪廓，而太陽定位，進行與邊緣檢測算法來確定太陽能矢量坐標。

一個自動定位系統有助於最大限度地提高太陽能發電廠，通過太陽能跟踪控制產量，以利用太陽的能量。在這樣的可再生能源系統，太陽能電池板的定位系統採用太陽跟踪技術和太陽能計算器的角度定位在光伏電池板的光伏發電系統和聚光光伏CPV系統。在太陽能光伏跟踪系統自動對軸太陽跟踪可雙軸太陽跟踪和單軸太陽太陽跟踪。已知的是機動化的定位系統中的光電面板跟踪增加能量產率，並確保增加的功率輸出，即使在一個單一的軸太陽跟踪配置。其他應用，如機器人的太陽能跟踪器或機器人的太陽能跟踪系統採用robotica具有人工智能的太陽能收集能源產量的控制，通過優化機器人跟踪系統。

自動定位系統，可在太陽能跟踪設計也可用於其它自由能的發電機，諸如集中式太陽能熱發電CSP和菜斯特林系統。在太陽能聚光器或太陽能收集器的太陽能集熱器，太陽跟踪裝置這樣的執行對軸太陽跟踪，雙軸太陽能跟踪器有助於從陽光透過的光的太陽能集熱器利用能量，它可以是一個拋物面反射鏡，拋物面反射鏡，菲涅爾透鏡或反射鏡陣列/矩陣。拋物面反射器或動態轉向使用傳輸系統或太陽能跟踪迴轉驅動的意思。在轉向的菜要面對太陽，電源盤驅動器和驅動裝置的拋物面光學系統主要論點集中太陽的能量在一個拋物面天線或太陽能集中裝置的焦點。斯特林發動機，太陽能熱管，thermosyphin，太陽能相變材料PCM接收器或光纖的陽光接收裝置位於太陽能聚光的焦點。這道菜斯特林發動機的配置被稱為一個菜斯特林系統或斯特林發電系統。混合型太陽能發電系統（與沼氣，生物燃料，汽油，乙醇，柴油，天然氣或PNG組合使用），使用的電源的組合，以利用和在存儲介質中存儲的太陽能。任何大量能源可以通過使用控制器的並存儲在電池中的能量，相變材料，熱儲熱相結合，並在熱電聯產形式轉換為使用熱力循環所需要的功率（有機蘭金，布雷頓循環，微渦輪機，斯特林）與逆變器和充電控制器。

这本书详细介绍了全自动太阳能跟踪，太阳跟踪系统的出现，太阳能跟踪器和太阳跟踪系统。智能全自动太阳能跟踪器是**定向向着太阳的有效**载荷设备。这种可编程计算机的太阳能跟踪装置，包括太阳跟踪，太阳能跟踪系统，以及微控制器，微处理器和**/或基于PC机的太阳跟踪控制**，**以定向太阳能反射器**，**太阳透**镜，光电板或其他光学配置朝向太阳的原理。机动空间框架和运动系统，确保运动动力学和采用的驱动技术和传动原理引导光学配置，如曼金，抛物线，圆锥曲线，或卡塞格林式太阳能集热器面向太阳，不断跟随太阳运动的轮廓。

从阳光透过太阳能跟踪器或实用的太阳能跟踪系统利用电力，可再生能源控制的自动化系统需要自动太阳跟踪软件和太阳位置算法来实现控制与自动**化架构**，电路板和硬件的动态运动控制。上轴太阳跟踪系统，如高度，方位角双轴或多轴太阳跟踪系统使用太阳跟踪算法或光线追踪传感器或软件，以确保通过天空中太阳的通道被跟踪的高精度的自动太阳跟踪器的应用，通过正确的夏至，春分太阳和冬至。一种高精度太阳位置计算器或太阳位置算法采用了一种软件程序例程对齐的太阳跟踪器的阳光和是在一个自动太阳跟踪系统的设计和建设的重要组成部分。

从太阳跟踪软件的角度来看，十四行诗跟踪太阳有一个字面意义。在太阳跟踪和追踪的背景下，这本书解释说，在天空中太阳的日常路径是通过相对简单的原则导向**的**，**如果掌握/了解的**话，就比较容易追查以下软件，太阳有太阳。是太阳位置的计算机软件用于跟踪太阳作为开源代码，列出在这本书的来源。讽刺的是还出现了系统，称为太阳跟踪器，据说已经知道了追逐太阳全天太阳能定位系统。

在电子电路，自动跟踪太阳能利用太阳能公式很简单，即使你是一个新手，但数学太阳能方程在复杂的学术专家，教授的教科书，期刊和互联网网站。在太阳能爱好，学者，学生和雕塑家的看着太阳能跟踪太阳能跟踪电子装置或电脑程序而言通常是由科学材料和网络资源数量庞大，这让不少开发商在挫折克服时寻求简单的实验性太阳能跟踪源-code**它**们对轴太阳跟踪系统。这本小册子将简化寻找神秘的太阳跟踪公式，你的太阳跟踪器的创新，并帮助您开发您自己的自治太阳能跟踪控制器。

直接指挥太阳能集热器到太阳，太阳能收集装置或设备可以利用太阳光或热的热量。为了跟踪太阳与地球旋转（或随着太阳在天空中移动）太阳角式的帮助下，太阳能角式或太阳跟踪程序中需要的在天空中太阳的位置的计算。自动太阳跟踪系统的软件包括用于以下划过天空，太阳需要的太阳高度方位角的计算算法。在使用经度，太阳能跟踪器位置的纬度GPS**坐**标，这些太阳跟踪软件工具，支持精确的太阳跟踪通过测定太阳高度角，方位角坐标太阳轨迹的高度，方位角跟踪的跟踪器位置，使用特定的阳角公式在太阳矢量计算。而不是跟着太阳软件，阳光跟踪传感器，如太阳敏感器或网络摄像机或视频的摄像头，基于视觉的阳光下图像处理软件也可以用**于确定光学太阳的位置**。这样的光学反馈装置通常用于在太阳能电池板跟踪系统和盘的跟踪系统。

动态跟踪太阳还应用于太阳能测量，DNI**分析和建立与太阳的光芒**，辐射和DNI**模型的**GIS（**地理信息系**统），太阳能的信息图表地图太阳测量系统。这样的太阳能/环境的相互作用地理空间的方法是利用利用地理空间技术（地理信息系统，遥感和制图）的。
气候数据和气象站或气象中心的数据，**以及来自天空的服**务器和太阳能资源数据库系统的查询（即在DB2**中**，Sybase，**甲骨文**，SQL，MySQL**的**），**也可以用太阳能**GIS**地**图相关联。在这样**的太阳能**资源建模的系统中，天空辐射计或solarimeter**通常用于除了**测量直接和间接的，分散的，分散的，反射的辐射对于特定的地理位置。日照分析是在闪光摄影的地方摄影灯光对摄影师很重要很重要。 GIS**系**统所使用的建筑师谁加日影小程序，研究建筑遮阳或日影分析，太阳通量计算，光造型或执行气候建模。这种系统通常采用与光线跟踪程序软件作为太阳能Navigator**或太阳跟踪器**，**用于确定太阳位置和**强度的计算机操作的望远镜类型的机制。

这本小册子的目的是帮助开发者跟踪和追溯合适的源代码和太阳能跟踪算法及其应用，无论是业余爱好者，科学家，技术人员或工程师。许多开源的阳光下和跟踪算法及源代码太阳能跟踪程序和模块都可以免费获得今天在互联网上下载。某些专有的太阳能跟踪器套件和太阳能跟踪控制器包括一个软件开发工具包SDK**的**应用编程接口（API）**的属性**（**卵石**）。**部件**库，小部件工具包的GUI**工具包和**UX库，图形化的控制元件也可用来构建图形用户界面（GUI），为您的太阳能跟踪或太阳能发电监测方案。

使用太阳位置计算器，太阳能仿真软件和太阳能轮廓计算器太阳能库包括用于太阳能硬件控制器，该控制器是可软件编程到微控制器，可编程逻辑控**制器**PLC，**可**编程门阵列，Arduino**的**处理器或处理器的PIC**机程序代**码。基于PC**的太阳跟踪也很高**，**使用**C++，Visual Basic**中的**VB，**以及微**软的Windows，Linux**和苹果的**Mac**操作系**统下对MATLAB，Excel**的太阳路径表的需求。一些**书籍和互联网网页使用其它术语，如：太阳角度计算器，太阳位置计算器或太阳角度计算器。如所述，这样的软件代码，计算出太阳能方位角，太阳高度角，太阳仰角或太阳天顶角（天顶太阳角度被简单地从垂直平面中引用，仰角从水平或接地平面电平测量的反射镜）。类似的软件代码也应用于太阳能计算器应用程序或为iOS**和**Android**智能手机**设备上的太阳能计算器应用程序。大多数智能手机太阳能移动应用程序的显示太阳路径和太阳角度的任何地点和日期在24**小**时内。一些智能手机，包括增强现实功能，您可以在其中看到身体，并期待在太阳能道路通过你的手机摄像头或手机摄像头在手机的特定GPS**位置**。

在计算机编程和数字信号处理（DSP）**的**环境中，（自由/**开放源**码）程序代码可用于Gambas**的**，VB，净，德尔福，Python**和**C，C+，C++，PHP，**雨燕**，ADM，**女**，闪光，基本，QBasic**中**，GBasic，KBasic，SIMPL语言，松鼠，Solaris**操作系**统，对操作系统，如微软Windows，**苹果的**Mac，DOS，Unix**或**Linux**操作系**统的汇编语言。软件算法预测太阳在天空中的位置通常是可以作为图形化编程平台，如Matlab（Mathworks**公司**），Simulink**模型**，Java**小程序**，TRNSYS**模**拟，SCADA**系**统的应用程序中，LabVIEW**模**块，倍福的TwinCAT（Visual Studio**中**），**西**门子SPA，**手机和**iPhone**的**应用程序，Android**或**iOS**的平板**电脑应**用程序**，**等等。同**时，为一系列的太阳跟踪自动化技术的PLC软件代码可以跟随太阳的轮廓在天空西门子，惠普，松下，ABB，**艾伦·布拉德利**，**欧姆**龙，SEW，费斯托，倍福，罗克韦尔，施耐德，恩德斯豪斯，Fudji电。霍尼韦尔公司，福克斯，Yokonawa**或**Muthibishi**平台**。孙路投影软件，也可用于各种模块化嵌入式工控机PC**主板**，**工控机**，PLC（**可**编程逻辑控制器）和PAC（**可**编程自动化控制器），如西门子S7-1200**或西**门子LOGO，Beckhoff**的工控机或**CX**系列**，**欧姆**龙PLC，PLC Ercam，AC500plc ABB**公司**，**美国国家**仪器公司的NI PXI**或**NI**的**cRIO，PIC处理器，英特尔8085**分之**8051，IBM**公司**（电池，电源，智慧或Truenorth**系列**），FPGA（Xilinx**公司**Altera**公司的**Nios），**英特**尔®**至**强®，Atmel**公司**megaAVR，MPU，枫木，Teensy，MSP，XMOS，**的**XBee，ARM，树莓丕，鹰，Arduino**的或**Arduino**的**ATMEGA**微控制器**，**伺服**电机，步进电机，直流直流脉冲宽度调制（PWM）（**当前的**驱动程序）或交流电AC SP**或工控**变频驱动变频马达驱动器（也称为可调频率驱动，变速驱动器，变频器，微型变频器或逆变器驱动器）电气，机电，气动，液压或太阳能跟踪执行机构。

上述运动控制和机器人控制系统包括处理器上模拟或数字接口的端口，以使跟踪角取向的反馈控制通过一个或角度传感器或角度编码器，旋转编码器，精密编码器，光学编码器，磁性编码器，方向的组合编码器，旋转编码器，片式编码器，倾斜传感器，倾斜传感器，或音调传感器。请注意，使用高度角型，赤纬角型，倾斜角型，俯仰角型或垂直角型，天顶角型传感器或测斜仪跟踪的抬高或天顶轴角度可以测量的。同样，跟踪器的方位轴角与方位角角型，横向角型或卷角型传感器进行测量。芯片集成加速度计磁强计陀螺式角度传感器也可用于计算位移。其他选项包括使用热成像**系**统，如福禄克热像仪，或雇用人脸跟踪，头部跟踪，专人跟踪，眼动追踪及汽车跟踪原理的太阳能跟踪机器人或基于视觉的太阳能跟踪系统。

随着无人值守分散的农村，海岛，隔离，或自主离网发电装置，远程控制，监控，数据采集，数字化数据采集和在线测量和验证设备变得至关重要。它可以协助管理控制操作员监视的远程可再生能源和系统的效率，并提供了在二氧化碳和清洁发展机制（CDM）**的**报告方面有价值的基于网络的反馈。电能质量分析仪，通过网络，WiFi**和蜂**窝移动链接的诊断是最有价值的一线故障诊断和预测性维护，需要快速的诊断分析，以检测和防止电能质量的问题。

太阳能跟踪器的应用涵盖了广泛的太阳能应用和太阳能辅助应用，包括集中太阳能发电，太阳能海水淡化，太阳能水净化，太阳能蒸汽发电，太阳能发电，太阳能产业过程中的热量，太阳能热储热，太阳能食品干燥机的频谱，太阳能水泵，产氢或甲烷生产氢气和氧气从水中（HHO）**通**过电解。许多专利或非专利太阳能设备包括跟踪太阳能发电机，太阳能海水淡化，太阳能蒸汽机，太阳能制冰机，太阳能净水器，太阳能制冷，太阳能制冷，USB**太阳能充**电器，太阳能手机充电，便携式太阳能充电的太阳能设备跟踪器，太阳能煮咖啡，太阳能**烹**饪或太阳能垂死的手段。你的项目可能会成为下一个突破或专利，但你的发明阻碍了挫折中寻找您需要为您的太阳能供电设备上的太阳跟踪器，太阳能发电机，太阳能跟踪机器人，太阳能冰箱，太阳能灶，太阳能干燥，太阳能水泵，太阳能冰箱，太阳能或烘干机项目。无论您的太阳能电子线路图包括一个简化的太阳能控制器设计的太阳能发电项目，太阳能配件，太阳能嗜好套件，太阳能蒸汽发生器，太阳能热水系统，太阳能制冰机，太阳能海水淡化，业余爱好者的太阳能电池板，爱好机器人，或如果你正在开发的专业或爱好电子的太阳能实用程序或微规模的太阳能发电厂为**自己的太阳能**发电场和太阳能耕作，本出版物可以帮助加快你的**太阳跟踪**创新的发展。

最近，太阳能多联产，热电冷三联产太阳能（太阳能三重代），以及太阳能发电四（添加交付蒸汽，液体/**气体燃料，或捕捉的食品**级二氧化碳$_2$**的）系**统已经需要自动太阳跟踪。这些系统是已知的显著效率增加的能量产率，为整合的结果和再利用的废物或残余的热量，并适用于可能被制造和运输的试剂盒的形式与一插头操作紧凑封装的微太阳能发电厂 - **和**发挥的基础。典型的混合型太阳能发电系统，包括压缩或包装太阳能微型热电联产（CHP**或**MCHP）**或太阳能微合，制冷，供暖和**电力（热电冷联产，CHPC，mCCHP**或**mCHPC）**在分布式**发电系统中使用。这些系统经常被组合在集中的太阳能的CSP**和**CPV**智能微**电网配置为离网乡村，岛屿或孤立微电网，minigrid**和分布式**电源可再生能源系统。太阳跟踪算法也可用于利用Matlab Simulink**中**（Modelica**的或**TRNSYS）**平台三**联产系统的建模以及在自动化和通过智能解析，多目标，自适应学习控制和控制的优化策略可再生能源系统的控制。

太阳能跟踪算法也发现在测量或太阳辐射的波动分析方面开发太阳能模型的国家或地区**的特定太阳能**电池的研究，例如应用程序（即直接和散射辐射）在一个特定的区域。太阳能DNI，**太阳**辐射和大气的信息和模型因此可以集成到太阳能地图，地图集太阳能或地理信息系统（GIS）。这种模型允许定义本地参数，可能是有价值的另一个太阳能的仿真和合成平台，如Matlab**和**Simulink**或在直**链的或多目标优化算法的平台，如COMPOSE CSP**系**统的光伏评估方面的特定区域，EnergyPLAN**或**DER-CAM。

双轴太阳能跟踪器和单轴太阳能跟踪器可使用太阳跟踪程序或太阳跟踪算法来定位的太阳能菜，太阳能电池面板阵列，定日镜阵列，光伏电池板，太阳能天线或红外太阳能nantenna。**一个自跟踪太阳能聚光通**过计算太阳向量执行自动太阳跟踪。太阳位置算法（TwinCAT软件的SPA，**或**PSA**算法）使用一个天文算法来**计算太阳的位置。它采用天文软件算法和方程中的天空中，为地球上的每个位置的太阳位置计算太阳能跟踪在一天的任何时间。像光学太阳望远镜，太阳位置算法星星点点的太阳能反射太阳和锁定到太阳的位置来跟踪在天空中太阳的太阳的进行了**一整天。光学**传感器，如光电二极管，光依赖 - 电阻（LDR）**或光敏**电阻被用作光学精度反馈装置。最近，我们还包括在书中的一段（链接到微处理器代码）如何在Wii**遥控器或**Wiimote**的的原相**Wii**的**红外摄像机可以在红外太阳跟踪应用程序中使用。

为了从太阳收获自由能，一些太阳能自动定位系统使用的光学装置，以引导太阳能跟踪装置。这些太阳能跟踪策略，利用光学追踪技术，如阳光传感器装置，以阳光直接照射到硅CMOS**基板，以确定**X**和太阳的位置的**Y**坐**标。在太阳能MEMS**太阳**传感器装置，太阳光入射，通过在光暴露于硅衬底上的**小**针孔的掩膜板的太阳传感器。在一个网络摄像头或摄像头图像处理跟踪太阳和阳光下的手段，对象跟踪软件进行多目标跟踪和运动目标跟踪方法。在一个太阳能对象跟踪技术，图像处理软件进行数学处理框所捕获的图像帧中的表观太阳能光盘或太阳斑点的轮廓，而太阳定位，进行与边缘检测算法来确定太阳能矢量坐标。

一个自动定位系统有助于最大限度地提高太阳能发电厂，通过太阳能跟踪控制产量，以利用太阳的能量。在这样的可再生能源系统，太阳能电池板的定位系统采用太阳跟踪技术和太阳能计算器的角度定位在光伏电池板的光伏发电系统和聚光光伏CPV系统。在太阳能光伏跟踪系统自动对轴太阳跟踪可双轴太阳跟踪和单轴太阳太阳跟踪。已知的是机动化的定位系统中的光电面板跟踪增加能量产率，并确保增加的功率输出，即使在一个单一的轴太阳跟踪配置。其他应用，如机器人的太阳能跟踪器或机器人的太阳能跟踪系统采用robotica具有人工智能的太阳能收集能源产量的控制，通过优化机器人跟踪系统。

自动定位系统，可在太阳能跟踪设计也可用于其它自由能的发电机，诸如集中式太阳能热发电CSP和菜斯特林系统。在太阳能聚光器或太阳能收集器的太阳能集热器，太阳跟踪装置这样的执行对轴太阳跟踪，双轴太阳能跟踪器有助于从阳光透过的光的太阳能集热器利用能量，它可以是一个抛物面反射镜，抛物面反射镜，菲涅尔透镜或反射镜阵列/矩阵。抛物面反射器或动态转向使用传输系统或太阳能跟踪回转驱动的意思。在转向的菜要面对太阳，电源盘驱动器和驱动装置的抛物面光学系统主要论点集中太阳的能量在一个抛物面天线或太阳能集中装置的焦点。斯特林发动机，太阳能热管，thermosyphin，太阳能相变材料PCM接收器或光纤的阳光接收装置位于太阳能聚光的焦点。这道菜斯特林发动机的配置被称为一个菜斯特林系统或斯特林发电系统。混合型太阳能发电系统（与沼气，生物燃料，汽油，乙醇，柴油，天然气或PNG组合使用），使用的电源的组合，以利用和在存储介质中存储的太阳能。任何大量能源可以通过使用控制器的并存储在电池中的能量，相变材料，热储热相结合，并在热电联产形式转换为使用热力循环所需要的功率（有机兰金，布雷顿循环，微涡轮机，斯特林）与逆变器和充电控制器。

Abstract for Google Translate in Hebrew
מעקב של עקרונות כולל מבוסס מחשב תכנות כגון שמש מעקב מכשיר .השמש לעבר מטען שמכוון מכשיר הוא אינטליגנטי אוטומטי שמש גשש.שמש מעקב ומערכות עוקבים-Sun-מעקב-Systems, Solar ,אחר טומטיאו למעקב שמש מפרט זה ספר
דינמיקת להבטיח kinematic מערכות ממונעות חלל מסגרות .השמש לכיוון אחרות אופטיות תצורות או פוטו פנלי ,שמש עדשות ,שמש מחזירי להתמצא במחש מבוססת סולרי מעקב שליטת או / ו המיקרו ,מיקרו גם כמו ,שמש מעקב מערכות ,סולרי
ברציפות השמש תנועת מתאר קווי לפי השמש עם להתמודד כדי אריתסול אנרגיה Cassegrain ,חרוטי ,פרבולית אספנים או ,ן'מאנז כגון אופטיות תצורות לנווט עקרונות ותשלובת כונן בטכנולוגית ושימוש תנועה.

עם דינמית בתנועה השליטה את להשיג כדי שמש עמדת ואלגוריתמי מעקב סולרית אוטומטית תוכנה דורשות מתחדשות האנרגיה בקרת אוטומציה מערכות ,מעשית שמש מעקב מערכת או שמש גשש באמצעות מהשמש כוח ברתימת
השמש של המעבר להבטיח מנת על תוכנה או חיישנים התחקות קרן או שמש מעקב באלגוריתם להשתמש ציר רב או אזימוט-הגובה כפול ציר שמש גשש מערכות כגון הציר על שמש מעקב מערכת .וחומרה מעגלים ,שליטה אוטומציה רתארכיטקטו
לשמש השמש גשש ליישר כדי תוכנה שגרת משתמש שמש עמדת או גבוה דיוק ברמת שמש עמדת מחשבון אלגוריתם.החורף והיפוך שמש שוויון יום ,הקיץ היפוך דרך שרי , אוטומטיים שמש גשש ביישומי גבוה דיוק עם לייחס היא השמים דרך
אוטומטית שמש מעקב מערכת של והבנייה בעיצוב חשוב מרכיב ומהווה.

זה אז ,הבין / הבין ואם ,יחסית פשוטים עקרונות ידי על נוהלה היא השמים פני על השמש של היומית שדרכה מסביר הזה הספר ,שמש ועקבות מסלול במסגרת .מילולית משמעות ןסא איתור הסונטה את לו יש ,תוכנה פרספקטיבת התחקות משמש
שמש positioner מערכת היה שהוא אמר ,בשם מערכת שמש רודף אפילו היה אירוני באופן .זה בספר המופיע תמקורו ,פתוח מקור כקוד זמינות השמש לאיתור שמש עמדת מחשב תוכנת .תוכנה הבאה השמש עם השמש את לאתר יחסית קל
היום כל לאורך השמש אחרי לרודף ידועה.

של במונחים .אינטרנט ואתרי עת בכתבי מאמרים ,לימוד בספרי ומרצים אקדמיים מומחים ידי על מסובכות מעל מתמטיות שמש משוואות אבל ,טירון אתה אם גם ,פשוטה די היא אוטומטי שמש למעקב אלקטרוניים במעגלים שמש במשוואות שימוש
רבים למפתחים שמשאיר מה ,דעייםמ ואינטרנט חומריים משאבים של האדירה הכמות ידי על להתגבר כלל בדרך שמש למעקב סולריות מחשב או מעקב אלקטרוניקה תוכניות על מסתכלים של ותחביבים סטודנטים ,חוקרים ,סולריים תחביבים
סולרי אוטונומי משלך בקר לפתח לך ולעזור שלך השמש גשש לחדשנות המיסטיות שמש מעקב נוסחות אחר החיפוש את לפשט תהיה זו חוברת .המעקב שמש צירם על למערכות קוד שם שמש ניסיוני פשוט מעקב מקור אחר חיפוש כאשר בתסכול
מעקב.

,שמש זווית נוסחות של עזרתו את (השמים פני על נעה שהשמש כמו או) מסתובבת הארץ שכדור כפי השמש אחר לעקוב כדי .תרמי חום או השמש אור את לרתום יכול מכשיר או הפירוש שמש קציר ,השמש אל ישירות השמש ןאסף הפניית ידי על
,האורך בקווי בשימוש.השמים פני על השמש בעקבות הנדרשים הגובה אזימוט שמש זווית לחישובי אלגוריתמים כוללת אוטומטית שמש מעקב מערכת תוכנת .בשמיים השמש של עמדתה בחישוב נדרש שמש מעקב נהלי או שמש זווית נוסחות
שמש זווית בנוסחות שימוש ,הגשש במיקום מעקב אזימוט-בגובה השמש מסלול עבור ינטותקואורד שמש אזימוט-הגובה קביעת ידי על דיוק שמש במעקב תומכת תוכנה כלי מעקב אלה שמש ,השמש גשש מיקום של הרוחב קו GPS קואורדינטות
.אופטית השמש של המיקום תא לקבוע כדי להשתמש ניתן הבא החזון מבוססת שמש תמונת עיבוד תוכנת עם וידאו מצלמת או אינטרנט מצלמת או שמש חיישן כגון שמש מעקב חיישן ,שמש תוכנת לעקוב במקום גם .שמש וקטור מסוימותבחישובי
צלחת מעקב ומערכות סולארי פנל מעקב במערכות קרובות לעתים משמשים כגון אופטיים משוב מכשירי.

סביבה / שמש אינטראקציה על geospatial שיטות זו בדרך .(גיאוגרפית דעמי מערכת) GISל DNI ודגמי irradiance ,שמש זוהר עם שמש infographics מפות שבונות מדידות שמש ומערכות DNI מנתח ,שמש במדידות גם משמש דינמי שמש מעקב
בטכנולוגיות שימוש שימוש עושה geospatial (GIS, מרחוק חישה, וקרטוגרפיה).
דוגמנות במערכות.שמש GIS מפות עם קשורים להיות גם עשויים DB2, Sybase, Oracle, SQL, MySQL) על כלומר) שמש משאב נתונים מסדי ומערכות שמיים משרתי שאילתות גם כמו ,אוויר מזג במרכז או אוויר מזג תחנת ונתונים אקלים נתוני
.צלמים עבור חשובות היא צילום תאורת שבו מצילו בבזק חשוב הוא שמש אור ניתוח .מסוים גיאוגרפי למקום רעיוני ,,,ועקיפה ישירה קרינה התפזרה פזורות למדידה בנוסף כלל בדרך משמש solarimeter או pyranometer ,כזה שמש משאב
מחשב טלסקופ סוג מנגנון להעסיק קרובות לעתים זה מסוג מערכות .אוויר מזג דוגמנות לבצע או אופטית דוגמנות ,שמש שטף חישובי ,שמש צל ניתוח או אדריכלית הצללה ללמוד השמש צל יישומוני שיוסיפו אדריכלים ידי על משמשות GIS מערכות
ובעוצמה שמש עמדת את הקובע שמש נותב או שמש כנווט תוכנה התחקות קרן עם פעלמו.

ומודולים סולריות מעקב יותלתוכנ מקור וקוד אלגוריתמים ומעקב הבא רב פתוח קוד שמש .מהנדס או טכנאי ,מדען ,תחביבים אם ,שלהם ליישום שמש מעקב ואלגוריתמי מתאים מקור קוד את ולאתר לעקוב למפתחים לסייע היא זו חוברת מטרת
וספריות GUI כלים ערכת ,יישומון כלים ערכות ,יישומון ספריות .(Pebble) הממשק API יישומי תכנות לתכונותיו תוכנה פיתוח ערכת SDK כוללים שמש מעקב ובקרי שמש גשש קניינית מסוימות ערכות .כיום באינטרנט להורדה חופשי באופן זמינים
סולארית אנרגיה ניטור תכנית או שלכם השמש למעקב (GUI) הגרפי המשתמש ממשק את לבנות כדי גם זמינות גרפיים יטהשל אלמנטי עם UX.

מעבד ,לתכנות שער מערכי ,פלסטיני מחוקק למועצה בקרים ,רומיק בבקרי שתוכנה שתוכנה שמש חומרת בקר עבור מחשב תוכנת קוד כוללת שמש גובה ומחשבונים שמש סימולציה תוכנת ,עמדה שמש מחשבוני ידי על בשימוש הסולרית הספרייה
ודפי ספרים כמה .Matlab, Excel על שמש נתיב לשולחנות מבוססות הפעלה מערכות אפל של ומקינטוש לינוקס ,MS Windows גם כמו ,Visual Basic VB ,++ C באמצעות בביקוש גבוה גם הוא מחשב מבוסס סולרי מעקב .PIC Arduino או מעבד
זניט שמש זווית) שמש זנית זווית או שמש גובה זווית ,שמש גובה זווית ,אזימוט שמש זווית את לחשב כזו תוכנה קוד ,כאמור .שמש זווית מחשבון או שמש עמדת מחשבון ,זווית שמש מחשבון :כגון ,אחרים במונחים משתמשים באינטרנט אינטרנט
היישומים רוב .ואנדרואיד IOS חכם טלפון מכשירי עבור סולארית אנרגיה מחשבון יישומי או סולריים מחשבון ביישומי גם משמש דומה תוכנה קוד . (קרקע מטוס או אופקית מהרמה נמדד הגובה זווית של המראה ,אנכי ממישור הפניה פשוט היא
באמצעות סולארית הדרך על ומסתכל פיזי לראות יכול אתה שבה מציאות תכונות תוספת כוללים מסוימים חכמים טלפונים .שעה 24 תקופה פני על ומועד מקום לכל זוויות ושמש השמש נתיב את מראים אלה החכם הטלפון הסולריים הניידים
.שלכם הטלפון של הספציפי GPS במיקום ניידת בטלפון המצלמה או שלך המצלמה של הסלולרי הטלפון

אסמבלי השפה ,Solaris ,סנאי ,Simpl שפת QBasic, GBasic, KBasic ,יסוד , פלאש ,ADM, F ,סוויפט ,Python, C, C +, C ++, PHP ,דלפי ,נטו ,VB ,לגמבות זמין (פתוח קוד / פנויים) תוכנה קוד ,(DSP) דיגיטלי אותות ועיבוד מחשבים תכנות בסביבת
יישומוני ,Simulink מודלים ,(MathWorks) Matlab כגון תכנות גרפיות פלטפורמות בכינויו זמינים בשמיים השמש של מיקום חיזוי תוכנת אלגוריתמי .לינוקס הפעלה מערכת או יוניקס ,DOS ,אפל של MS Windows, Mac כגון הפעלה במערכות
אוטומציה טכנולוגיות של רחב מגוון עבור PLC תוכנת קוד ,במקביל .הלאה וכן ,iOS לוח יישומי או אנדרואיד ,פוןואיי ניידים יישומים ,SPA סימנס ,(Visual Studio) Labview, Beckhoff TwinCAT מודול ,SCADA מערכת יישומי ,סימולציות Java, TRNSYS
Muthibishi או Yokonawa, פוקס, Honeywell, Fudji. יחשמל , האוזר אנדרס ,שניידר ,רוקוול ,Festo, Beckhoff ,לתפור ,OMRON ,ברדלי אלן ,HP, Panasonic, ABB ,סימנס עבור בשמים שמש של הפרופיל אחר לעקוב יכול שמש מעקב
לוגו או סימנס S7-1200 כגון (Programmable Automation Controller) IPAC (Programmable Logic Controller) PLC ,מחשב התעשייה ,מודולרי מוטבע IPC מחשב אם לוחות של רחב מגוון עבור גם זמינה שמש נתיב הקרנת תוכנת .פלטפורמות
סימנס, Beckhoff IPC או סדרת CX, OMRON PLC, Ercam PLC, AC500plc ABB, מכשירים הלאומיים NI PXI או NI cRIO, מעבד PIC, אינטל 8051/8085, IBM (Cell, כוח סדרת Truenorth או מוח), FPGA (Nios Altera Xilinx), אינטל, Xeon, Atmel
תדירות או משתנה חשמלי זרם SPS AC או (נוכחי נהג) DC פולס הרוחב אפנון הנוכחי הישיר PWM ,צעד מנוע ,סרוו מנוע עם ,מיקרו Arduino AtMega או Arduino ,הנשר ,Pi פטל ,ARM, XBee, XMOS, MSP ,זערורי ,מייפל ,megaAVR , MPU
.הידראוליים שמש מעקב מפעילי או ,פנאומטי ,כטרוניות ,חשמל מכשירי עבור (מהפך כונן או מיקרו כונן ,AC כונן ,במהירות משתנה כונן ,גם המכונה בתדירות מתכוונן כונן) VFD מנוע כונני כונני IPC משתנה

,אופטי מקודד ,דיוק מקודד ,פיר מקודד ,זווית מקודד או זווית חיישן של שילוב או אחד באמצעות אורינטציה משוב גשש זווית שליטת לאפשר כדי המעבדים על דיגיטליות ממשק יציאות או אנלוגיות כוללות ורובוט לעיל השליטה תנועת בקרת מערכות
,האנכי angle- או המגרש angle- ,יהנטי angle- ,סירוב angle- ,גובה angle- באמצעות למדוד יכולה הגשש של שיא או הגובה ציר שזווית לב שים .המגרש חיישן או ,נטייה חיישן ,הטיה חיישן ,שבב מקודד ,סיבובי מקודד ,מקודד כיוון ,מגנטי מקודד
אפשרויות .עקירה לחשב כדי לשמש יכולים זווית גירוסקופ סוג התאוצה מגנטומטר משולבים שבב חיישני גם .רול angle- חיישן או ,האופקי angle- ,אזימוט angle- עם למדידה הגשש של אזימוט ציר זווית לכך בדומה .שיפוע מד או שיא angle- חיישן
.שמש במעקב מכונית מעקב ועקרונות עין מעקב ,מעקב יד ,ראש מעקב ,פנים אחר מעקב שמעסיקות גשש שמש המבוססות חזון או רובוטיות מערכות או ,תרמית פלוק תרמי כגון תרמית הדמיה במערכות שימוש כוללות חרותא

לפקח כדי פיקוח שליטת עם למפעיל מסייע זה .קריטי להיות הופך באינטרנט ואימות מדידה וציוד הדיגיטלי datalogging ,נתונים וניתוח איסוף ,ניטור ,רחוק שלט ,מייםאוטונו לרשת מחוץ חשמל מתקני או ,מבודד ,מבוזר אי ,כפרי השגחה ללא עם
יקר הוא ניידים סלולריים וקישורים WiFi ,אינטרנט באמצעות אבחון עבור חשמל איכות מנתח.(CDM) נקי פיתוח מנגנון חודיוו CO2 של במונחים ערך בעל אינטרנט מבוסס משוב ולספק ומערכות מתחדשים אנרגיה מרוחקים משאבים של היעילות על
.הכח באיכות בעיות ולמנוע לזהות כדי נדרש מהיר לאבחון ניתוח שבו ,חזויה ואחזקה חזית בקו בעיות בפתרון ביותר

תרמית חום אחסון ,שמש תעשייתי תהליך חום ,סולרי חשמל ייצור ,סולארי קיטור דור ,סולרית מים טיהור ,סולרית התפלה ,סולארית אנרגיה מרוכז דור כוללים ,שמש בסיוע ויישום סולאריים יישומים של רחב ספקטרום לכסות שמש גשש יישומי
,החשמלי סולארי לגנרטור סולרי במנגנון מעקב כוללים בפטנט מוגנים שאינם סולריים מכשירים או פטנט רבים .אלקטרוליזה באמצעות (HHO) ממים וחמצן הפקה מימן או מתאן מימן ייצור ,מים שמש שאיבת ,סולריים מזון מייבשי ,סולרי
הפרויקט .שמש גוסס אמצעי או סולרי בישול ,קפה שמש מתבשל ,גשש ניידת סולארית הטעינ ,סולרית טלפון טעינת ,USB סולארי מטען ,סולרי קירור ,סולרי קירור ,סולריים מים מטהרים ,שמש קרח יצרנית ,סולארי קיטור מנוע ,שמש desalinator

יותר יבשה ,שמש נורת ,שמש מקפיא ,שמש גשש רובוט ,סולארי גנרטור ,שלך השמש מופעל המכשיר עבור צריך שאתה השמש גשש אחר בחיפוש תסכול ידי על בחזרה מוחזקת שלך ההמצאה אבל ,פטנט או הבאה הדרך פריצת להיות עשוי שלך
מים מערכת ,סולארי קיטור מחולל ,שמש תחביב ערכת ,סולארית אנרגיה ערכת ,סולארי חשמל בפרויקט בקר שמש פשוט עיצוב כולל שלכם השמש אלקטרוניים המעגלים תרשים אם .סולרי מייבש פרויקט או ,שמש ,מקפיא שמש משאבת ,שמש
,שלו שמש חקלאות או סולארית חווה עבורך מיקרו מידה בקנה סולרית מנועה או שמש לשירות תחביב או מקצועית אלקטרוניקה מפתחים אתם אם או ,תחביב רובוט ,תחביבים סולאריים פנלים ,הסולרי desalinator ,שמש קרח יצרנית ,שמש חמה
.שלכם השמש מעקב חדשנות של הפיתוח את להאיץ לעזור עשוי זה פרסום

לעליות ידועות אלה מערכות .אוטומטי שמש למעקב שצריכות מערכות ($ 2_ לכידת מזון באיכות CO או ,גזים דלק / נוזל ,קיטור של מסירה הוספת) שמש מרובע ודור ,(שמש משולש דור) שמש trigeneration ,שמש polygeneration ,האחרון בזמן
מערכות .ואז- מחזה בסיס תקע על ולפעול בצורה בערכה ומועבר מיוצר להיות שיכול שמש מיקרו ארוז הקומפקטי powerplantsל ומתאימים שיורי בחום או בפסולת חוזר ושימוש מהאינטגרציה כתוצאה אנרגיה בתשואת היעילות את משמעותיות
.מבוזר חשמל בייצור המשמשות (CCHP, CHPC, mCCHP, או mCHPC) חשמל ומערכות חימום ,קירור ,שילובב שמש מיקרו או (MCHP או CHP) והכוח החום בשילוב שמש ארוז או קומפקטי מיקרו כוללות אופייניות היברידיות סולארית אנרגיה
של במודלים גם משמשים שמש מעקב ריתמיאלגו .מבוזר כוח מתחדשת אנרגיה ומערכות minigrid ,המבודד microgrid או אי ,כפרית לרשת למחוץ CPV החכם microgrid ותצורות המרוכז הסולרי CSPב קרובות לעתים משולבות אלה מערכות
אופטימיזציה ובקרת למידה שליטת אסטרטגיות ,אובייקטיבית רב ,אינטליגנטי ניתוח באמצעות מתחדשות אנרגיה מערכות של ובקרה באוטומציה גם כמו ,פלטפורמה (TRNSYS או Modelica) Matlab Simulink באמצעות trigeneration מערכות
.אדפטיבית

,שמש DNI .מסוים באזור (ומפוזרת ישירה קרינה כלומר) השמש קרינת של התנודות של לניתוח או מדידה של במונחים למשל ,מיקום או מדינה ספציפיים סולריים ללימודים סולריים מודלים בפיתוח היישום את למצוא גם שמש מעקב גוריתמיאל
ההערכה של במונחים ערך בעל להיות שעשויה ספציפיים לאזורים מקומיים פרמטרים להגדרת מאפשר כאלה מודלים .(GIS) גיאוגרפיות מידע מערכות או שמש אטלס ,סולרית מפה לשלב ניתן ובכך אטמוספריים ומודלים ומידע שמש irradiance
.DER-CAM או EnergyPLAN , להלחין כגון אובייקטיביות רבות או ליניארית אופטימיזציה לגוריתמא בפלטפורמות או Simulinkו Matlab כגון פלטפורמות וסינתזת סימולציה על CSP מערכות של בפוטו שונה שמש של

שמש Concentrator.אדום אינפרא שמש nantenna או סולארית אנטנה ,PV פנל ,heliostat מערך ,פנל סולארי מערך ,שמש המנה את למצב שמש גשש או שמש גשש תכנית באלגוריתם להשתמש עשוי ציר בודד שמש וגשש ציר כפול שמש גשש
אסטרונומיים תוכנה באלגוריתמי משתמשת היא .השמש של המיקום את לחשב אסטרונומים אלגוריתם להשתמש (אלגוריתמים PSA או TwinCAT, SPA,) שמש עמדת אלגוריתמי .השמש וקטור חישוב ידי על אוטומטי שמש מעקב מבצע עצמי מעקב
לעקוב כדי השמש של עמדתה על ומנעולים בשמש השמש רפלקטור שמש עמדת אלגוריתם נקודות פיני ,אופטי שמש טלסקופ כמו .ביום שעה בכל הארץ כדור פני על מיקום כל עבור בשמיים השמש של עמדתה שובבחי שמש למעקב ומשוואות
(המיקרו לקוד קישורים עם) בספר סעיף כללנו גם אנחנו האחרון בזמן .אופטי דיוק משוב כמכשירי משמשים photoresistors או (LDR)-נגדים-תלוי אור ,דיודות כגון אופטיים חיישנים .היום כל לאורך מתקדמת השמש כמו השמים פני על השמש אחר
.אדום אינפרא שמש מעקב ביישומי לשמש עשויה Wiimote Wii או הרחוק בשלט PixArt Wii אדום אינפרא מצלמת איך על

לקרני ,שמש חיישן אמצעי כגון ,מעקב אופטיות בטכניקות משתמשות אלה סולריות מעקב אסטרטגיות .השמש מעקב מכשיר את לכוון כדי אופטיים באמצעים להשתמש אוטומטיות שמש מיקום מערכות כמה ,מהשמש חופשית אנרגיה לקצור כדי
במעקב.סיליקון למצע חשוף אור שבו מסכה בצלחת קטן חור פיני באמצעות השמש חיישן נכנסה תקרית שמש אור ,חיישן-שמש שמש MEMS בהתקן.השמש של ומהמיק של קואורדינטות Y ו X את לקבוע כדי CMOS מצע או סיליקון על ישירה שמש
את לתיבה מתמטי עיבוד מבצעת תמונה עיבוד תוכנת ,שמש אובייקט מעקב בטכניקת.נעו אובייקט מעקב שיטות או רב אובייקט מעקב מבצעת אובייקט אחר מעקב תוכנת ,הבאה השמש ואמצעי שמש תמונת עיבוד מצלמה או האינטרנט מצלמת
.שמש וקטור קואורדינטות את לקבוע כדי קצה זיהוי אלגוריתם עם מתבצעת הלוקליזציה שמש ואילו ,שצולמה התמונה מסגרת בתוך שמש כתם או שמש לכאורה הדיסק של המתאר קווי

זווית ומחשבון מעקב שמש בטכניקות משתמשת סולארי פנל מיקום מערכת ,כגון מתחדשות אנרגיה במערכות .השמש של אנרגיה לרתום שמש מעקב שליטת באמצעות סולריות כוח תחנות של התשואות את למקסם רלעזו אוטומטי מיקום מערכת
אנרגיית בתשואת ממונעת מיקום מערכת כי ידוע זה .ציר כפול ציר בודדת שמש או שמש מעקב סולרי מעקב להיות יכול PV סולרית מעקב במערכת מטיאוטו הציר על שמש מעקב .מרוכזות פוטו CPV ומערכות פוטו במערכות מיצוב PV בלוחות שמש
אנרגיה תשואת שליטת באופטימיזציה מלאכותית בינה עם Robotica משתמשים רובוטית ולריתס מעקב מערכת או רובוטית שמש גשש כגון אחרים יישומים .יחיד ציר סולרי מעקב בתצורת אפילו ,כוח תפוקת עלתה ומבטיחה פוטו פנל גשש עליית
.רובוטית מעקב מערכת באמצעות סולארית בקצירה

מבצע כזה שמש קולט או שמש concentratorב שמש בקולט השמש מעקב מכשיר.צלחת סטירלינג ומערכות תרמיות כוח שמש המרוכז CSP כגון ,אחרים חופשית אנרגיה בגנרטורים גם משמשות סולריים מעקב בעיצובי אוטומטיות מיקום מערכות
הסירה את ניווטה יתפרבול רפלקטור או מנה הוא .מראה מטריצת / מערך או פרנל עדשת ,רפלקטור פרבולית ,פרבולית מראה להיות שיכול ,אופטי שמש קולט באמצעות השמש מן אנרגיה לרתום כפול ציר שמש גשש מסייע ,שמש מעקב ציר על
או פרבולית צלחת נקודת על השמש של האנרגיה מתמקד אופטי פרבולית צלחת במערכת אומר actuationו הכח צלחת מפעיל ,השמש עם להתמודד הצלחת את במנווט.אומר שמש מעקב ארוכה שורה כונן או הולכה מערכת באמצעות דינמי באופן
מערכת נקראת המנה סטירלינג מנוע תצורת.המוקד שמש מגביר של בנקודה ממוקם פירושו אופטי סיבים שמש אור מקלט או ,שמש מהותי שינוי שלב PCM מקלט ,thermosyphin ,שמש חום צינור ,סטירלינג מנוע.המוקד שמש ריכוז אמצעי
כל .אחסון באמצעי שמש אנרגיית את ולאחסן לרתום כוח מקורות של בשילוב להשתמש (PNG או טבעי גז ,דיזל ,אתנול ,בנזין ,ביולוגי דלק ,יוגזב עם בשילוב שימוש) כוח סולריות היברידיות מערכות .סטירלינג חשמל ייצור מערכת או צלחת סטירלינג
,אורגנית ברייטון ,רנקין מחזור) תרמודינמיים מחזורים באמצעות שנדרש להספק תומרנה בקוגנרציה וצורה ,תרמי חום אחסון ,מהותי שינוי שלב ,בסוללות האצורה האנרגיה ואת בקרים באמצעות משולב להיות יכול אנרגיה מקורות של שפע
.ותשלום מהפך בקר עם (סטירלינג ,מיקרו טורבינת

Abstract for Google Translate in Spanish

Ce livre détaille solaire de suivi automatique, de suivi du soleil-Systems, solaire-Trackers et systèmes Sun Tracker. Un suiveur solaire automatique intelligent est un dispositif qui oriente une charge utile vers le soleil. Un tel dispositif de poursuite solaire à base d'ordinateur programmable comprend des principes de poursuite solaire, les systèmes de poursuite solaire, ainsi que le microcontrôleur, un microprocesseur et / ou un PC à base de commande de poursuite solaire pour orienter les réflecteurs solaires, des lentilles solaires, panneaux photovoltaïques ou autres configurations optiques vers le soleil. Structures spatiales motorisés et des systèmes cinématiques assurer la dynamique du mouvement et utilisent la technologie d'entraînement et engrenages principes pour diriger configurations optiques tels que Mangin, paraboliques, coniques ou Cassegrain capteurs d'énergie solaire pour faire face au soleil et suivre le soleil mouvement contour continu.

En exploitant la puissance du soleil à travers un tracker solaire ou pratique système de suivi solaire, les systèmes d'automatisation de contrôle de l'énergie renouvelables nécessitent un logiciel de suivi solaire automatique et des algorithmes de position solaires pour accomplir le contrôle de mouvement dynamique à l'architecture d'automatisation de contrôle, cartes de circuits imprimés et du matériel. Système sur l'axe poursuite du soleil tels que les systèmes de trackers solaires altitude-azimut double axe ou multi-axes utilisent un algorithme de poursuite du soleil ou de ray tracing des capteurs ou des logiciels pour assurer le passage du soleil dans le ciel est tracée avec une grande précision dans les applications tracker solaire automatisés , en passant par le solstice d'été, équinoxe solaire et solstice d'hiver. Un algorithme de haute précision de la calculatrice de la position du soleil ou la position du soleil utilise une routine de logiciel pour aligner le tracker solaire au soleil et est un élément important dans la conception et la construction d'un système automatique de suivi solaire.

De soleil traçage point de vue logiciel, le sonnet Tracing Le Soleil a un sens littéral. Dans le contexte de la piste de soleil et trace, ce livre explique ce chemin tous les jours du soleil dans le ciel est dirigé par des principes relativement simples, et si saisi / compris, il est relativement facile de suivre le soleil avec le soleil logiciels suivants. Sun logiciels de position pour le traçage du soleil sont disponibles en code source ouvert, les sources qui est répertorié dans ce livre. Ironiquement il y avait même un système appelé soleil chasseur, dit-on, un système de positionnement solaire connu pour chasser le soleil toute la journée.

En utilisant les équations solaires dans un circuit électronique pour le suivi solaire automatique est assez simple, même si vous êtes un novice, mais les équations mathématiques solaires êtes trop compliquée par des experts universitaires et des professeurs dans les manuels, articles de journaux et des sites Internet. En termes de loisirs solaires, des universitaires, des étudiants et Amateur de la recherche sur les programmes de l'électronique de suivi ou PC solaires pour le suivi solaire sont généralement surmonter par le volume de ressources matérielles et de l'internet scientifique, ce qui laisse de nombreux développeurs de frustration lorsque la recherche de source simple de suivi solaire expérimental -code pour leurs systèmes de suivi du soleil dans l'axe. Ce livret vous simplifier la recherche des formules de suivi de soleil mystique pour votre Sun Tracker innovation et vous aider à développer votre propre contrôleur de suivi solaire autonome.

En orientant le capteur solaire vers le soleil, une récolte solaire moyen ou dispositif peut exploiter la lumière du soleil ou de la chaleur thermique. Afin de suivre le soleil que la terre tourne (ou que le soleil se déplace dans le ciel) à l'aide de formules de l'angle du soleil, les formules de l'angle solaire ou des procédures de suivi solaire est nécessaire dans le calcul de la position du soleil dans le ciel. Automatique du logiciel système de poursuite du soleil inclut des algorithmes solaires calculs d'angle d'azimut altitude nécessaires pour suivre le soleil dans le ciel. En utilisant la longitude, la latitude GPS de l'emplacement de suiveur solaire, des outils de suivi de logiciels ces soleil soutient précision de suivi solaire en déterminant l'altitude-azimut solaire coordonnées pour la trajectoire du soleil en altitude-azimut suivi à l'emplacement du tracker, l'utilisation de certaines formules d'angle de soleil dans les calculs de vecteurs de soleil. Au lieu de suivre le logiciel de soleil, un capteur de poursuite du soleil, tel qu'un capteur de soleil ou une webcam ou une caméra vidéo en fonction de vision soleil suivant le logiciel de traitement d'images peut également être utilisé pour déterminer la position du soleil optiquement. Ces dispositifs de retour optiques sont souvent utilisés dans les systèmes de suivi solaire du panneau et des systèmes de suivi de plat.

Traçage de soleil dynamique est également utilisé dans l'arpentage solaire, analyseur DNI et systèmes solaires arpentage qui construisent foot solaires cartes avec rayonnement solaire, rayonnement et modèles DNI pour SIG (système d'information géographique). De cette façon, les méthodes géospatiales sur l'interaction environnement solaire / fait usage l'utilisation des technologies géospatiales (SIG, de télédétection et cartographie). Les données climatiques et les données de la station météorologique ou centres météorologiques, ainsi que des requêtes provenant de serveurs du ciel et des systèmes de bases de données de ressources solaires (c'est à dire sur DB2, Sybase, Oracle, SQL, MySQL) peuvent également être associés à des cartes SIG solaires. Dans de tels systèmes de modélisation des ressources solaires, un pyranomètre ou solarimètre est normalement utilisé en plus de mesurer dispersé, dispersé, le rayonnement de réflexion directe et indirecte, pour un lieu géographique particulier. Analyse de soleil est important dans la photographie au flash où l'éclairage photographique sont importantes pour les photographes. SIG sont utilisés par des architectes qui ajoutent soleil applets ombre d'étudier ombrage architectural ou analyse de soleil ombre, calcul des flux solaires, la modélisation optique ou d'effectuer la modélisation météorologique. De tels systèmes emploient souvent un mécanisme de type télescope informatique fonctionnant avec un logiciel de tracé de rayons programme de navigateur solaire soleil ou traceur qui détermine la position et l'intensité solaire.

Le but de cette brochure est d'aider les développeurs à Track and Trace code source approprié et des algorithmes de poursuite solaire pour leur application, que ce soit un amateur, scientifique, technicien ou ingénieur. Beaucoup soleil open-source suivants et le suivi des algorithmes et du code source des programmes de suivi et de modules solaires sont disponibles gratuitement en téléchargement sur l'Internet aujourd'hui. Certains kits tracker solaire propriétaires et les contrôleurs de suivi solaire comprend un SDK kit de développement de logiciels pour ses attributs de l'API de l'interface de programmation d'application (galets). Widget bibliothèques, des outils widgets, boîte à outils graphique et les bibliothèques UX avec des éléments de contrôle graphiques sont également disponibles pour construire l'interface utilisateur graphique (GUI) pour votre suivi solaire ou d'un programme de surveillance de l'énergie solaire.

La bibliothèque solaire utilisée par les calculatrices de position solaires, logiciels de simulation solaire et calculatrices de contour solaires comprend la machine code de programme pour le contrôleur de matériel solaire, qui sont des logiciels programmés dans les micro-contrôleurs, des automates programmables PLC, Programmable Gate Array, processeur de traitement ou PIC Arduino. Suivi solaire à base de PC est également très en demande l'aide de C ++, Visual Basic VB, ainsi que MS Windows, Linux et Apple Mac systèmes d'exploitation pour les tables de chemin de soleil sur Matlab, Excel. Des livres et des pages internet utilisent d'autres termes, tels que: la calculatrice de l'angle du soleil, la position du soleil calculatrice ou calculateur d'angle solaire. Comme dit, par exemple un code de logiciel de calculer l'angle du soleil en azimut, l'angle d'altitude solaire, l'angle d'élévation solaire ou l'angle zénithal solaire (angle solaire Zenith est simplement référencé par rapport au plan vertical, le miroir de l'angle d'élévation mesurée par rapport au niveau horizontal ou plan de masse) . Code logiciel similaire est également utilisé dans les applications de la calculatrice solaire ou les applications de calcul de l'énergie solaire pour les téléphones intelligents IOS et Android. La plupart de ces applications mobiles solaires smartphones montrent le chemin et chaises-angles pour n'importe quel endroit et la date sur une période de 24 heures. Certains smartphones inclure des fonctions de réalité dans lequel vous pouvez voir physiquement et regarder le chemin solaire grâce à votre appareil photo de téléphone portable ou un appareil photo de téléphone portable à la position GPS de votre téléphone augmentées.

Dans l'environnement de programmation informatique et de traitement numérique du signal (DSP), (libre / open source) code de programme sont disponibles pour Gambas, VB, Net, Delphi, Python, C, C +, C ++, PHP, Swift, SMA, F, Flash , Basic, QBasic, GBasic, KBasic, langue SIMPL, écureuil, Solaris, la langue de l'Assemblée sur les systèmes d'exploitation tels que MS Windows, Apple Mac, DOS, Unix ou Linux. Les algorithmes logiciels position du soleil dans le ciel de prévision sont généralement disponibles comme les plates-formes graphiques de programmation tels que Matlab (Mathworks), les modèles Simulink, les applets Java, Trnsys simulations, applications du système Scada, module de Labview, Beckhoff TwinCAT (Visual Studio), Siemens SPA, applications mobiles et iPhone, Android ou iOS apps tablettes, et ainsi de suite. Dans le même temps, le code du logiciel PLC pour une gamme de technologies soleil d'automatisation de suivi peut suivre le profil de soleil dans le ciel pour Siemens, HP, Panasonic, ABB, Allan Bradley, Omron, SEW, Festo, Beckhoff, Rockwell, Schneider, Endress Hauser , Fudji électrique. Honeywell, Fuchs, Yokonawa, ou Muthibishi plates-formes. Le logiciel Sun projection du parcours sont également disponibles pour une gamme de modules cartes mères de PC IPC embarqués, PC industriel, PLC (Programmable Logic Controller) et le PAC (contrôleur d'automatisme programmable) comme le Siemens S7-1200 ou Siemens Logo, Beckhoff IPC ou de la série CX, OMRON, Ercam PLC, AC500plc ABB, national Instruments NI PXI ou nI cRIO, processeur PIC, Intel 8051/8085, IBM (Cell, alimentation, cerveau ou de la série truenorth), FPGA (Xilinx Altera Nios), Intel, Xeon, Atmel megaAVR , MPU, érable, Teensy, MSP, XMOS, Xbee, ARM, Raspberry Pi, Aigle, Arduino ou Arduino AtMega microcontrôleur, avec servo-moteur, moteur pas à pas, PWM à courant continu de largeur d'impulsion de modulation (pilote actuel) ou en courant alternatif AC SPS ou IPC fréquence variable conduit VFD variateurs de vitesse (aussi appelé entraînement à fréquence ajustable, variateur de vitesse, variateur AC, micro dur ou lecteur onduleur) pour électrique, mécatronique, pneumatiques ou hydrauliques actionneurs de suivi solaire.

Les systèmes de contrôle de commande de mouvement ci-dessus et robots comprennent analogique ou ports d'interface numérique sur les processeurs pour permettre angle tracker asservissement de l'orientation par un ou une combinaison de capteur d'angle ou angle codeur, le codeur d'arbre, la précision codeur, codeur optique, encodeur magnétique, direction codeur, codeur rotatif, codeur puce, capteur d'inclinaison, capteur d'inclinaison, ou capteur d'inclinaison. Notez que l'élévation ou zénith l'angle de l'axe de tracker peut mesurée en utilisant un Angle-altitude, la déclinaison Angle-, inclinaison Angle-, terrain Angle-, ou Angle-vertical, zénith capteur Angle-ou inclinomètre. De même azimut l'angle de l'axe de tracker être mesurée avec un Angle-azimut, Angle-horizontale, ou rouleau capteur Angle-. Intégrés des capteurs d'angle de type gyroscope accéléromètre de magnétomètre à puce peuvent également être utilisés pour calculer le déplacement. D'autres options incluent l'utilisation de systèmes d'imagerie thermique comme un imageur thermique Fluke, ou des systèmes robotisés ou de vision en fonction solaires trackers qui emploient suivi du visage, suivi d'une tête, suivi de la main, suivi de l'oeil et les principes de suivi de voiture en suivi solaire.

Avec sans surveillance rurale décentralisée, île, isolé, ou installations électriques hors réseau autonomes, contrôle à distance, surveillance, acquisition de données, l'enregistrement de données numériques et d'équipements de mesure et de vérification en ligne devient cruciale. Il aide à l'opérateur un contrôle de supervision pour surveiller l'efficacité des ressources et à distance des systèmes d'énergie renouvelable et fournir une rétroaction sur le Web précieux en termes de CO2 et le mécanisme de développement propre (MDP) rapports. Un analyseur de qualité d'énergie pour le diagnostic grâce à Internet, Wi-Fi et les liaisons mobiles cellulaires est le plus précieux dans le dépannage de première ligne et la maintenance prédictive, où l'analyse diagnostic rapide est nécessaire pour détecter et prévenir les problèmes de qualité de l'énergie.

Applications tracker solaires couvrent un large spectre d'applications solaires et application assistée solaire, y compris la production concentrée d'énergie solaire, le dessalement solaire, purification de l'eau solaire, production solaire de vapeur, la production d'électricité solaire, l'énergie solaire de la chaleur industrielle, le stockage de chaleur solaire thermique, un sèche-alimentaires solaires, le pompage de l'eau solaire, la production d'hydrogène à partir du méthane ou de l'hydrogène et produire de l'oxygène à partir d'eau (HHO) par électrolyse. Beaucoup breveté ou un appareil solaire non brevetés comprennent suivi dans un appareil solaire pour le générateur solaire électrique, dessalinisateur solaire, machine à vapeur, solaire machine à glaçons, purificateur d'eau solaire, climatisation solaire, la réfrigération solaire, USB chargeur solaire, chargeur de téléphone solaire, recharge solaire portable tracker, solaire préparation du café, la cuisine solaire ou moyen meurent solaires. Votre projet peut être la percée prochaine ou le brevet, mais votre invention est freinée par la frustration à la recherche du soleil Tracker vous avez besoin pour votre appareil solaire, générateur solaire, robot suiveur solaire, congélateur solaire, cuiseur solaire, séchoir solaire, pompe solaire , congélateur solaire, ou un projet de séchoir solaire. Que votre solaire schéma électronique comprend une conception simplifiée solaire de contrôleur dans un projet d'énergie solaire, kit solaire, kit de bricolage solaire, générateur de vapeur solaire, système d'eau chaude solaire, solaire machine à glaçons, dessalinisateur solaire, panneaux solaires amateurs, robot passe-temps, ou si vous développez l'électronique professionnelle ou de loisirs pour un utilitaire solaire ou l'échelle micro motorisation solaire pour votre propre ferme solaire ou l'agriculture solaire, cette publication peut aider à accélérer le développement de votre innovation de suivi solaire.

Dernièrement, polygénérationnelle solaire, trigénération solaire (solaire génération triple), et la génération de quad solaire (ajout de livraison de vapeur, liquide / combustible gazeux, ou la capture de qualité alimentaire CO _2 $) systèmes ont besoin de suivi solaire automatique. Ces systèmes sont connus pour les augmentations de productivité significatifs dans le rendement de l'énergie à la suite de l'intégration et la réutilisation des déchets ou de la chaleur résiduelle et sont adaptés pour centrales électriques compacts emballés micro solaires qui pourraient être fabriqués et transportés en kit et fonctionnent sur une prise -et base de lecture. Systèmes solaires hybrides typiques incluent micro compacts ou emballés solaires combinée de chaleur et d'électricité (PCCE ou CMPS) ou micro solaires combinés, de refroidissement, (CCHP, epa, mCCHP, ou mCHPC) systèmes utilisés dans la production d'énergie distribuée chauffage et l'électricité. Ces systèmes sont souvent combinés dans CSP solaire concentrée et CPV configurations de micro-réseaux intelligents pour rurale hors réseau, île ou microréseau isolé, minigrid et de puissance distribuée systèmes d'énergie renouvelable. Algorithmes de suivi solaires sont également utilisés dans la modélisation des systèmes de trigénération Matlab Simulink (Modelica ou TRNSYS) plate-forme ainsi que dans l'automatisation et le contrôle des systèmes d'énergies renouvelables par le biais de l'analyse intelligente, multi-objectifs, les stratégies de contrôle d'apprentissage et d'optimisation de commande adaptatifs.

Algorithmes de suivi solaire trouvent également une application dans le développement de modèles solaires pour pays ou l'emplacement des études solaires spécifiques, par exemple en termes de mesure ou l'analyse des fluctuations du rayonnement solaire (c'est à dire le rayonnement direct et diffus) dans un domaine particulier. DNI solaire, le rayonnement solaire et de l'information et des modèles atmosphériques peuvent ainsi être intégrés dans un plan solaire, atlas solaires ou systèmes d'information géographiques (SIG). Ces modèles permettent de définir des paramètres locaux pour des régions spécifiques qui peuvent être utiles en termes de l'évaluation de l'énergie solaire différente en photovoltaïque des systèmes de CSP sur la simulation et de synthèse des plateformes telles que Matlab et Simulink ou dans les plates-formes de l'algorithme d'optimisation linéaires ou multi-objectifs tels que COMPOSE , EnergyPLAN ou DER-CAM.

Un tracker solaire à deux axes et un seul axe suiveur solaire peut utiliser un algorithme de programme soleil tracker ou Sun Tracker à une parabole solaire, panneau solaire de panneau, tableau héliostat, panneau photovoltaïque, antenne solaire ou nantenna solaire infrarouge. Un concentrateur solaire auto-suivi effectue le suivi solaire automatique en calculant le vecteur solaire. Algorithmes de position solaires (TwinCAT, SPA, ou PSA algorithmes) utilisent un algorithme astronomique pour calculer la position du soleil. Il utilise des algorithmes et équations de logiciels astronomiques de suivi solaire dans le calcul de la position du soleil dans le ciel pour chaque emplacement sur la terre, à tout moment de la journée. Comme un télescope solaire optique, l'algorithme de position broches points solaires l'réflecteurs solaires vers le soleil et se verrouille sur la position du soleil pour suivre le soleil dans le ciel que le soleil progresse tout au long de la journée. Capteurs optiques tels que les photodiodes, dépendantes-résistances lumière (LDR) ou les photo sont utilisés comme dispositifs de rétroaction de précision optique. Dernièrement nous avons également inclus une section dans le livre (avec des liens vers le code du microprocesseur) sur la façon dont la caméra infrarouge PixArt Wii dans la télécommande Wii ou Wiimote peut être utilisé dans des applications de suivi solaires infrarouges.

Afin de capter l'énergie gratuite du soleil, certains systèmes de positionnement automatique solaires utilisent des moyens optiques pour diriger le dispositif de suivi solaire. Ces stratégies de poursuite solaire utilisent des techniques de suivi optique, comme un moyen de capteur de soleil, aux rayons directs du soleil sur un substrat de silicium ou CMOS afin de déterminer les coordonnées X et Y de la position du soleil. Dans un dispositif MEMS solaires à capteurs solaires, la lumière solaire incidente entre le capteur de soleil à travers un petit trou dans une plaque de masque où la lumière est exposée à un substrat de silicium. Dans une webcam ou une caméra de traitement d'image suivi de chaises suivante moyen, logiciel de suivi d'objets effectue le suivi d'objets multiples ou mobiles méthodes de suivi d'objets. Dans une technique de suivi d'objet solaire, un logiciel de traitement d'image effectue le traitement mathématique à la boîte le contour du disque solaire apparent ou soleil goutte à l'intérieur de la trame d'image capturée, tandis que le soleil localisation est effectuée par un algorithme de détection de bord pour déterminer les coordonnées solaires vectorielles.

Un système de positionnement automatisé aider à maximiser les rendements des centrales solaires à travers le contrôle de suivi solaire pour capter l'énergie solaire. Dans de tels systèmes d'énergie renouvelable, le système de positionnement de panneau solaire utilise un soleil techniques de suivi et un calculateur d'angle solaire dans des panneaux photovoltaïques de positionnement dans les systèmes photovoltaïques et systèmes photovoltaïques CPV concentrés. Poursuite solaire automatique sur l'axe dans un système de poursuite solaire photovoltaïque peut être à double axe poursuite du soleil ou à un seul axe soleil poursuite solaire. Il est connu qu'un système de positionnement motorisé avec un rendement énergétique de l'augmentation de suiveur de panneaux photovoltaïques et assure une puissance de sortie accrue, même dans une configuration de poursuite solaire à un seul axe. D'autres applications telles que la robotique suiveur solaire ou système robotique de poursuite solaire robotica utilise une intelligence artificielle dans l'optimisation de la conduite de production d'énergie solaire dans la récolte au moyen d'un système de suivi de robot.

Systèmes de positionnement automatique dans les conceptions de suivi solaire sont également utilisés dans d'autres générateurs d'énergie libre, comme le concentré CSP d'énergie solaire thermique et systèmes Stirling plat. Le dispositif de poursuite du soleil dans un collecteur solaire dans un concentrateur solaire ou capteur solaire tel un effectue sur l'axe suivi solaire, un double axe solaires passes tracker pour exploiter l'énergie du soleil grâce à un capteur solaire optique, qui peut être un miroir parabolique, parabolique réflecteur, lentille de Fresnel ou miroir tableau / matrice. Une antenne parabolique ou un réflecteur est dynamique gouverné à l'aide d'un système de transmission ou de suivi solaire flopée variateur font. Dans le pilotage du plat vers le soleil, l'actionneur de boîte de puissance et moyens d'actionnement dans un système parabolique concentre ses activités optiquement l'énergie du soleil sur le point focal d'une antenne parabolique ou moyen solaires à concentration. Un moyen de moteur Stirling, tuyau de chaleur solaire, thermosyphin, changement de phase récepteur solaire matériau PCM, ou un récepteur de la lumière du soleil de la fibre optique est situé au point focal du concentrateur solaire. La configuration Antenne moteur Stirling est désigné comme un système Stirling Stirling plat ou système de génération d'énergie. Systèmes solaires hybrides (utilisées en combinaison avec du biogaz, biocarburants, l'essence, l'éthanol, le diesel, le gaz naturel ou PNG) utilisent une combinaison de sources d'énergie à exploiter et stocker l'énergie solaire dans un support de stockage. Tous multitude de sources d'énergie peuvent être combinés par l'utilisation de régulateurs et de l'énergie stockée dans les batteries, la matière à changement de phase, le stockage de la chaleur thermique, et dans la cogénération forme convertie en la puissance requise en utilisant des cycles thermodynamiques (cycle de Rankin, Brayton organique, micro turbine, Stirling) avec un contrôleur de l'onduleur et la charge.

Abstract for Google Translate in Arabic

ذا كتاب الكتاب ليصاف يتي تلتقيال تتبعال ت تتبع لشمسيةال شمس لشمسال وتتبع الشمسية، ولطاقة الدنظم لتتبع لشمسال نظمة الكفاءة ي ت عقب العقب ظمة فيئة في ق ت ضمن ج هاز و ل تلتقي ي ك الت كي ل شمسية ي عقب ت جهازب رمجة ذا في شمل ال شمسن حو حمل في وجه ال ذي ال جهاز و ل تلتقي

ر ي ت بمك عمل يي نظام ت بعتت لي سمشلا ئداب متتبع ال، ي سمشلا ةمظل و فقو ال بتع ، ةيسمشلا ك ل ك ل ق يقةال معل جات متحكم، وكل ك ي رأساس على أو / ول ق ي ضرك شخصي ال لكمبيوتر ت تتبع ال شمسي ال توجيه ال تناك س عل ال شمسية ال سمت وال

ال شمسية، وال واح ال والأ ية ضو ال أو ت ات نات ي تك ق ت ي ص بر أخري حو ال شمسن ال إطارات ضاءف ال ة ي الآ نظم ول ة ي حرك ال نمض مكيات ي ي ة حرك ال م خدت س ت و ن ك ت ي جيه و ت حركل م راص الأ ي د ع تس ت ئ ادبم ه جيه و ت ال ناتك ي ت ق ي ص ب ل ث م ، ن ج ال

ئ، ف طلم أو مخروطي، cassegrain أو مخروطي، ال طاقة ال شمسية ال مواجهة ال شمسل ال ع ة ت بع و حرك ة ف اف ك ال شمس ك ال شك ل ب ر ت س م ج.

ي ف ي رخ س ت ق ا ط ل ن م ال شمس ن م ال شمس لالخ ب ق ع ت ق ت ا ط ل ية ال شمسية أو ي ل م ع ال م ا ظ ن ع ت ب ت ت ال ، ي س م ش ال ة م ظ و ال م ك ح ت ال ي ال ة ق ا ط ل ل د د ج ت م ال ب ل ط ت ت ي ت ل ا ق ي ب ط ت ر ن ع ب ت ت ي س م ش ال ت ا ي م ز ر ا و خ ل ا و ف ق ي م ة ي س م ش ل ا ق ي ق ح ت ل م ك ح ت ي ال ف

ة ك ر ح ل ا ة ي ك ي م ا ن ي د ل ا ي ف م ل ع و ة س د ن ه م ك ح ت ل ا ، ي ال ات ح و ر ل ا ر و د ز ل ا ة ز م جلأا و . ى ل ع ر و ح م ام ظ ن ع ب ت ت ي س م ش ل ا ل ث م ام د خ ت س ا ة م ظ ن أ ب ق ع ت ق ا ط ل ا ة ي س م ش ل ا ل ع ا ف ت ا الا ت م س ل ا ر و ح م ي ت ل ا ث أ د د ع ت م ر و ح م ة ي م ز ر ا و خ ع ب ت ت ت ي س م ش ل ا و أ ة ع ش لأ ا ع ب ت ت ت ا ز ه ج أ

ار ع ش ت س ا ال و أ ت ا ي ج م ر ب ال ن ا م ض ل و ر م س م ش ال ي ف ا س م ل ا ت ع ب ت ت ق ي ب ق ي ف ي ق ي ب ط ت ت ب ق ع ت ق ا ط ل ا ة ي س م ش ل ا ، ق ح ل و م ن م ال خ ب ال ق ل ا ي الا ، ي ف ي ص ل ا ل ا د ت ع ا ال ي س م ش ال ب ال ق ل ا و ي و ت ش ل ا م د خ ت س ي ي ي م ز ر ا و خ ة ي ل ع ة ق ال

ف ق م س م ش ال ة ب س ا ح و أ ف ق م س م ش ال ن ي ت ر ا م ن ر ي ب ي ف و س ا ح ة ا ذ ا ح م ل ب ق ع ت ق ا ط ل ا ة ي س م ش ل ا ى ل ا س م ش ل ا ر ص ن ع و ا م ي ف ي م ص ت ا ن ب م ا ظ ن ع ب ت ت ي س م ش ال ي ل ا ق ي ق ت ل ا.

ن م ر و ظ ن م س م ش ل ا ع ب ت ت ت ا ي ج م ر ب ال ة ك ن و س ال و ع ب ت ت ي س م ش ال ه ى ل ع ن ع م ي ف ح ي ل ا ي ف ا ي س ر ا س م س م ش ال ، ع ب ت ت و ل ح ض و ي ه ا ذ ب ا ت ك ل ا ن أ ر ا س م س م ش ال ي م و ي ل ا ر ب ع ء ا م س ال ج ا ر خ ا و ئ د ا ب م ة ط ي س ب ب ا ي ب س ن ا ذ ا و ب ع و ت س ا / ، ة م و ه ف م ن م ف

ل س ل ا ي ب س ن ع ت ت ل س م ش ل ا ع م س م ش ل ا ة ي ل ت ا ل ا ت ا ي ج م ر ب ال ف ق م س م ش ل ا ج م ا ر ب ر ت و ي ب م ك ل ل ع ب ت ت ل ت ة ع ش أ س م ش ل ا ر ف و ت ت ي ل ع ح ت ق ر ف ش ، ر د ص م ل ا ر د ا ص م ل و ي ت ل ا م ت د ر س ي ف ه ب ا ت ك ل ا و ل ا ق ت ا ق ر ا ف م ل ا ن ا ك ل ذ ى ت ح ق ل ط ي

م ا ظ ن ل ا د ر ا ط م ل ا س م ش ل ا ن و ك ي ل ا ظ ل ن ر و ا ن م ة ي س م ش ل ا ة ف ر ع م ل ا ة د ر ا ط م ل ا س م ش ل ا ل و ا ط م و ي ل ا.

م ا د خ ت س ا ت ا ل د ا ع م ب ة ق ا ط ل ا ة ي س م ش ل ا ي ف ر ة ي ن و ر ت ك ل الإ ع ب ت ت ل ة ي س م ش ل ا ي ق ل ت ل ا و ط ي س ب ب ا ذ ج ى ت ح و ل ت ن ك ا ، ئ د ت ب م ل ن ك ل ت ا ل د ا ع م ل ا ة ي ض ا ي ر ل ا ي ف ة ي س م ش ل ا ى د م و د ي ق ع ت ن م ل ب ق ا ر ب خ ة ذ ت ا س أ و ة ي م ي د ا ك الأ ي ف ص ن ، ب ت ك ل ا

ت ا ل ا ق م ل ا و ة ي ف ح ص ل ا ع ق و م و ت ن ر ت ن الإ . ن م ث ي ح ت ا ي و ه ل ا ة ي س م ش ل ا ء ا م ل ع ل ا و ب ال ط ل ا و ى ل ع و ي و ا ه ل ا ر ظ ن ل ا ي ف ج م ا ر ب ت ا ي ن و ر ت ك ل الا ع ب ت ت ت و أ PC ة ي س م ش ل ا ع ب ت ت ل ة ي س م ش ل ا ة د ا ع ا م ت م ت ي ب ل غ ت ل ا ه ا ي ل ع م ج ح ل ا ل ل ئ ه ل ا ن م د ا و م ل ا ت ا و ن ر ت ن الإ

د ر ا و م ل ا ، ة ي م ل ع ل ا ل ا م ه ك ر ت ي ت ح ى ن م ل ا ن و ر ط م ل ا ي ف ط ا ب ح الإ د ن ع ث ح ب ل ا ن ع ي ب ي ج ت ل ا ر د ص م ع ب ت ت ت ي س م ش ل ا ط ي س ب ة ئ ف ة س م ا خ ل ا ة م ظ لأ ع ب ت ت ت ي س م ش ل ا ى ل ع ر و ح م ل ا ا ذ و ب ي ت ك ل ا ط ي س ب ت ح ب ل ا ن ع غ ي ص ل ا ة ض م ا غ ل ا ز ا ه ج ل ب ق ع ت

ر ا ك ت ب ا ال س م ش ل ا ع ب ت ت ت ي س م ش ل ا ك ل ا د ع ا س ت و ي ل ع ر ي ط ت م ك ح ت ع ب ت ت ت ي ص ا خ ل ا ل ق ت س م ل ا ي س م ش ل ا.

ه ي ج و ت ب ي ع م ي ج ت ق ا ط ل ا ة ي س م ش ل ا ة ر ش ا ب م ل ا ى ل ا ، س م ش ل ا د ا ص ح و ي س م ش ل ا ي ن ي ع ي و أ ز ا ه ج ن ك م ي ر ي خ س ت ء و ض س م ش ل ا و أ ة ر ا ر ح ل ا ة ي ر ا ر ح ل ا ن م ل ج أ ع ب ت ت ت ي س م ش ل ا ر و د ت و ض ر ال أ) و أ ء ا ن ث أ ة ك ر ح س م ش ل ا ر ب ع ء ا م س ل ا) ة د ع ا س م ن م غ ي ص ل ا ة ي و ا ز

، س م ش ل ا غ ي ص ل ا ة ي و ا ز ة ي س م ش ل ا و أ ت ا ء ا ر ج إ ع ب ت ت ت ي س م ش ل ا ب و ل ط م ل ا ي ف ب ا س ح ف ق و م س م ش ل ا ي ف ا س م ل ا ل م ش ي ف ي ق ل ت ل ا س م ش ل ا ت ا ي ج م ر ب ل ا م ا ظ ن ع ب ت ت ت ا ي م ز ر ا و خ ب ا س ح ل ئ ا و ز ت م س ل ا ة ي س م ش ل ا ة ي و ل ط م ل ا ي ل ا ع ف ا ت الا د ع ب

س م ش ل ا ر ب ع ء ا م س ل ا ي ف م ا د خ ت س ا ط خ ، ل و ط ط خ ض ر ع ت ا ي ث ا د ح إ ل ا GPS ع ق و م ل ا ل ب ق ع ت ق ا ط ل ا ، ة ي س م ش ل ا ة د و س م ش ل ا ع ب ت ت ت ا و د أ ج م ا ر ب ل م ع د ي ف ع ب ت ت ت ي س م ش ل ا ن م ل ال خ د ي ح ع ف ا ت الا ت م س ل ا ي س م ش ل ا ق ل ف ت ي م ع م ر ا س م

س م ش ل ا ي ف ع ف ا ت الا ت م س ل ا ع ب ت ت ت ي ف م و ، ي ف ت ق و م ل ا ك ل و م ا د خ ت س ا ب ر ض ع غ ي ص ل ا ة ي و ا ز س م ش ل ا ي ف ا س م ل ا ب ي س ح ت ا ل ق ن س م ش ل ا ل د ب ن م ع ا ب ك ج م ا ر ب س م ش ل ا ز ا ه ج ر ا ع ش ت س ا ث ع ب ت ت ي س م ش ل ا ل ث م ز ا ه ج ر ا ع ش ت س ا س م ش ل ا و أ ا ر ي م ا ك و أ

ا ر ي م ا ك و ي ي ف م ة ي ر س م ش ل ا ل ق م ة ي ل ت ل ا ج م ا ر ب ج ل ع م ر و ص ل ا ن ك م ي ن أ م د خ ت س ت ض ي د ي ح ت ع ل ع ف ق م س م ش ل ا ي ف ص ب ا ب ل ا غ و م ا م د خ ت س ت ت ز م أ ج ال أ د و د ر ل ع ف ة ا ل ي ر ص ب ل ا ي ف ظ ن ع ب ت ت ح ا و لأ ا ة ي س م ش ل ا ة م ظ أ و ع ب ت ت ق ب ط ل ا.

م د خ ت س ت ي ت ع ب ت ت ي س م ش ل ا ي ك ي م ا ن ي ي ل ا ض أ ي ي ف س م ل ا ، ة ي س م ش ل ا ل ل ح م ت ا ر ا ب خ ت س الا ة ي و ق ل ا س م ش ل ا و ح س م ة م ظ لأ ا ي ت ل ا ء ا ن ب و س ر ل ا ة ي ل ي ب ط ل ا ط ي ر خ ل ا ة ي س م ش ل ا ع م ع ا ع ش الا ، ي س م ش ل ا ع ا ع ش الإ و ج ذ ا م ن ر ي ه ت ا ر ا ب خ ت س الا ة ي ن ط و ل ا

م ظ ن ل ا ت ا م و ل ع م ل ا ة ي ف ا ر غ ج ل ا) م ظ ن ت ا م و ل ع م ل ا ة ي ف ا ر غ ج ل ا . ه ذ ه ق ب ي ط ق ل ا ط ي ر ة ي ف ا ر غ ج ة ي ل ك م ل ا ى ل ع ة ق ا ط ل ا ة ي س م ش ل ا / ل ع ا ف ت ي ب ي ب ل ا ع ج ي ن م م ا د خ ت س ا م ا د خ ت س ا ت ا ي ج و ل و ن ك ت ل ا ة ي ف ا ر غ ج ل ا ة ي ل ك م ل ا) GIS ر ا ع ش ت س الا و ن ع ، د ع ب س و ر و

ط ئ ر خ ل ا).

ت ا ن ا ي ب ل ا ة ي خ ا ن م ل ا ة ط ح م و س ق ط ل ا و أ س ق ط ل ا ز ك ر م ، ت ا ن ا ي ب ل ا ال ض ف ع ت ا ر ا س ف ت س ا ن م م د ا و خ ء ا م س ظ م ل ا ن م د ح ا و ق ا ي ب ل ا ت ن د ر ا و م ل ا ة ي س م ش ل ا) ي أ ى ل ع DB2 ، س ي ب ي ي س ، ل ك ر و أ و SQL و MySQL) ن ك م ي ف ا ض أ ي ن أ ن و ك ت ة ق ا ط ب ت م ع م ط ئ ر خ م ظ ن

ت ا م و ل ع م ل ا ة ي ف ا ر غ ج ل ا ة ي س م ش ل ا ي ف ل ث م ه ذ ه ة م ظ لأ ا ة ج ذ م ن ل ا د ر ا و م ل ا ، ة ي س م ش ل ا ل م ت ي ج ا ذ خ ت س ا ر ت م و ر ي ب ل ا و أ solarimeter ة د ا ع ة ف ا ض لإ ا ب ي ع ل ا س ي ا ق ر ة ن ي ت م ، ة ت ت ش م ل ا ع ا ع ش الإ س ك ع ر ش ا ب م ل ا و غ ي ر ش ا ب م ، ر ش ا ب م ى ل ع ع ق و م ي ف ي ف ا ر غ ج ن ي ع م.

ل ي ل ح ت ء و ض س م ش ل ا م ه م ل ا ي ف ر ي ص ت ل ا ي ف ي ف ا ر غ ي ل ا و ت ف ش ك ال ل ا ف ي ي ح ة ء ا ض الإ ر ي ص ت ل ا ة م ه م ل ا ن و ر و ص م ل ل م د خ ت س ت م ظ ن ت ا م و ل ع م ل ا ة ي ف ا ر غ ج ل ا ن م ل ب ل ق ي ز ن د ن ه م ل ا ن ي ي ر ا م ع م ل ا ن ل ي ف ة ل ا ف ض إ ت ا ق ي ب ط ت ع ب ت ت ي س م ش ل ا ل ظ ل ا ة س ا ر د ل ل ي ل ظ ت ل ا

ي ر ا م ع م ل ا و أ ل ي ل ح ت ت س م ش ل ا ت ا ن ا ك ي س ح و ق ف ت ق ا ط ل ا ، ة ي س م ش ل ا ة ج ذ م ن ل و ة ي ر ص ب ل ا و أ ء ا د أ ل ة ج ذ م ن س ق ط ل ا ل ث م ه ذ ه ة م ظ لأ ا ب ل غ ا م م د خ ت س ت ي ت ل ا و ع ن و ب ك س ل ت ل ا ر ت و ي ب م ك ل م ع م ع ب ت ت ت ا ي ج م ر ب ل ا ج م ا ر ب ن ر ط ف ص و ح ال م ل ا

ة ي س م ش ل ا و أ ع ب ت ت ت ل ا س م ش ل ا ي ت ل ا د د ح ت ح ت ف ي م ي س م ش ل ا ة ل ا ف ت ك ي.

رمز ومصدر ال خوارزميات تتبع ال تي ال شمس ال مفتوحة ال مصادر من ال عي د .مهندس أف ني عل م، ال هاوي، سواء تطبيقها، ال شمسي تتبع وخوارزميات رمز مصدر مناسبة تعقيبل تتبع ال مطوري ن مساعدة و ال كتيب ذا من ول غرض
ال ما API ال تطبيقات ل برمجة SDK ال برامج طوير ل مجموعات تتبع ال شمسي تحكم وحدات ال شمسية ال طاقة تعقب ال ملكية معينة مجموعات تشمل ال يوم نترن ت ال شبكة على ال تحميل مجال ومتاح ال شمسية ال طاقة وحدات تتبع ال برامج
تي ضا ال شمسية ال طاقة رصد برامج أول ال شمسي تتبع (GUI) ال رسومية ال مستخدم واجهة ال رسومية ال مستخدم واجهة ال مكتبات أدوات ال UX مع عناصر تحكم رسوميات توفر بناء واجهة مستخدم ال رسومية ال قطعة، الأدوات ال قطعة، ال مكتبات يل (إ) واجهة سمات

وحدات ال ق يقف ي ال مبرمج ال برمجيات هي ال تي ال شمسية الأجهزة ال لتحكم ال قبرن امجك ودت شمل ال شمسية فاف ال حاسبة والآلات ال شمسية ال طاقة محاكاة رامج ال شمسية، من ف ال حاسبة الآلات واسطة ال مستخدمة ال شمسية ال مكتبة
،++ C ب استخدام ال طلب ي ات فاع أي ضا و ال شمسي ال تتبع ال شخصي ال كمبيوتر أساس على ال معلم ج أول معلم ج PIC اردوي نول ل برمجة، ال قيل لة ال بويل ات مصنف ات PLC ل ل برمجة ال قيل لة ال منطقي ال تحكم وحدات ال تحكم،
ال ة زاوي ة ال شمس :مثل أخرى، مصطلحات استخدام الإ نترن ت وصفحات ال كتيب عض .Excel و ال مك لاب على ال شمس مسار ال جداول على ال قئ مة ال تشغيل نظم ماك ويل لل ينكس في ندوز، في كروسوف ت عن ضلاف الأساسية، VB في جوال
ال شمسية زاوي ة في نيث ال يها ال مشار) ال شمسية في نيث زاوي ة أول ال شمسية الات فاع زاوي ة ال شمس، ات فاع وزاوي ة ال شمسية، ال سمت زاوي ة حساب ال برن امج رمز ذلك ال ك ما .حاسبة ال ة ال شمسية زاوي ة أول شمس من ف حاسبة ال ة حاسبة،
وأجهزة IOS ال حاسبة ال ة ال شمسية ال طاقة تطبيقات أول ال شمسية حاسبة ال ة ال تطبيقات ف ي أي ضا مشار يل هب رمجية شفرة ي ستخدم . (الأرض على ال ظل رة أو الأف ق ي ال مستوى من الات فاع زاوي ة ال قياس ومرآة ال عمودي ة، ال ظل رة من ب بساطة
ن ظرة و ال قاء جسي ت رون ال ذي ال عل و ملامح زدت ال تي ال ة موقع في عض شمل .ساعة 24 تمرة جدي على ي اي خ ال ذان لاي زول أول ال شمس مسارات ظهرت ال ت يال ت في ال شمسية محلي ة ال تطبيقات ذه معظم ال ت يال ت في ف ي ال ت
على جسار ال شمسية من ال خلال ك اميرا أو ال ذي ال ت في ال ك اميرا ف ك ال محمول ال تي ال كفايف معين GPS تك فك ت.

ي في عيك ر ب ر ك مبيوترغ ال ج مع اتلإ شارات ال رقمية (DSP)، حاسبة، ل ل حاسب، VB، ف ي صفيك، ل غي، ف ي نثون، ال ي ب C ،++ C (حرة / ال مفتوحة المصدر) رمز ن ب ي ,+ PHP، ADM، F، فيس ت، ف ال QBasic، GBasic، KBasic، الأساسية،
ل غة SIMPL، ال سنجاب، ل س، وسولاي ي ن ظمة ال تشجيع على ال تشغيل مثال تدوين ه من، ال كروسوف ت، ل في ال ويل، ماك، دوس، ال يكس أوي ال ينكس ال نظام تشغيل ي في ال تشغيل برمجيات خوارزميات ي في عل ي عن من ال شمس يف ي ال سماء ال متاحة ال عموم
ومنصات ال برمجة ال رسومية ال مثل ب لاب (ماك وورك س)، من ماذج ن يك ال سيميول ال تطبيقات ات ك علم ات حاك ال ال طبيقات نظام ال مكاداء، وحدة ال طيف فيف BECKHOFF TwinCAT (ة TRNSYS (مشتوي ر ال بصري، SPA، سيمينز ال تطبيقات جوال ي ال وا
ب ي، وي ب ش س ل ال سيمينز ل شرك ال ة سماف ي ال شمسية ال شخصي ال ملف ن جيب عت تعقب ك متابعة ال شمس ال تقنيات مثل مجموعة برمجية شفرة PLC ن ما ي مثل نفسه، ال ق ت في ن ي دول ال يك و ك ذل ك داخل ي ل تعقب ال كل ر طا ق رمت برمجيات أول رب ي ن ,ون
ي ك ال سيمينز ABB، ي ال ن ... ، OMRON ال رال ي، وخياطة، يستوب، BECKHOFF، ل ب ، ر ك ي ... دري نفس ي ... ، Fujji ... ، في ي ال... Yokonawa ... Muthibishi أو منصات ال شمس ال برمجيات الإسقاط بسار ال متاحة جاهزة في ال
مجموعة من وحدات ال لوحات PC IPC ال جهاز ، لا ال تجزء ، ر وأجهزة ك مبيوتر وال مجلس ال صناعية، ال ... ال تشغيل رمجة) ال منظمة ب ال ... ي ي ال PAC ... S7-1200 سيمينز سيمنز مثل ال ... ال شعار ، أو BECKHOFF IPC أو
ال سلسلة CX، OMRON PLC، PLC Ercam، AC500plc ABB، وال صلكم، وال نظم NI NI PXI أو CRIO، PIC ج، مثل ال 8051/8085، IBM (... ، خلية، ال سلطة أو وال دماغ Truenorth (ال سلسلة)، FPGA (XILINX الي تيرا (NIOS)، ... و ون، وال تل، و في تك
megaAVR، MPU، ... ال تقيق، ... ن ... جدا، صغير MSP، XMOS، Xbee، ARM، ... ت ي ال تي ت أول نورسبب ... ATMEGA مع ... ، أجهزة ... ي ارات، ... ال DC PWM مباشر ال تيار ال محرك ات ... من ال تشغيل ... ال تشغيل
ي ال ح... ال تيار ال مترددة AC أو SPS IPC ردد VFD بتغيرات محرك AC، ... سرعة، ... محرك ... ال تردد ... ال ... ي ال تي ... ال ... ، ال ... محرك ... أول ... ، ... ال ... مع ال ... ب ال ... ال
ال شمسي تتبع ال ... ال ... ات أول ال ... ال مضغوطة.

أو زاوي ة زاوي ة الاستشعار أجهزة من مجموعة أو واحد من خلال من ال توجيه ... ال ... ن ... ال ... ال ... ال ... ال ... ال تحكم ال تحكم ال ... ال ... ال شمس ... تحكم في ... ال ... ال تحكم ال ... ال ... ال ... في ... شمل
... ، ... ال تشغير ، ... ال ... ، ... ال ... ، ... ال ... ، ... الاستشعار ... ، ... الاستشعار ... ، ... ال ... ال ... ال ... ال ... ال ... ، ... عقب
فاع ... زاوي ة ... محور ... angle- ... angle- ... angle- ... angle- ... angle- ... angle- ... angle- ... angle- ... ال ... ، ال سمت، angle- مع محور ...
... angle- ... angle- الاستشعار ال ... angle- ... ال ... ، ... ال ... ، ... الاستشعار ... ال ... ، ... حظ ...
ال شمسي ال ... ال ... ال ... ال ... ال ... ال ...

مع ... datalogging ال ... ، ... ال ... ال ... ال ... ، ... ، ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... .حاسوبي صب ح ...
... (CDM) ال نظيفة ال تنمية ... CO2 ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ، ... ال ...
... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ...

ب ال ... شمل
... (HHO) ... USB ... ال ... ال ... ال ... ال ... ال ... ال ... ال ... ال ...
ال شمسي ال تتبع ال خاص الإ ... ال ... ال ... ال ... ال ... ال ... ال ...

في ... الأن ف ... الاخ ي ... polygeneration ... ال شمسية، ... ال ... ال ... ال ... CO ال ... ال ... ال ... ال ... ال ... ق د (2_ $ ...
... (mCHP) أو (CCHP، CHPC، mCCHP، أو mCHPC) ... microgrid ... CSP ... CPV ... microgrid، minigrid ... (Modelica أو TRNSYS) ... ال ... ال ...
الأمثل ول ال تحكم ال ... ال ... ال ...

ف ي (ونتشرل ... الإشعاع أي) ال شمسي ... ال ... ال ... ال ... (GIS) ... CSP ... EnergyPLAN أو DER-CAM.

A- ... heliostat، ... PV، ... (PSA) ... (TwinCAT، SPA، ... nantenna ... photoresistors ... (LDR) ... PixArt في ال حمراء تحت الأشعة
ال شمسي تتبع انت طبيف ي ال حمراء تحت الأشعة أوب عيدي يموتويوى PixArt ف ي ال حمراء تحت الأشعة.

مثل ال بصري ة، ال تتبع تقنيات تستخدم ال شمسي تتبع الاسترات يجيات ذه ال شمسي ال تتبع جهاز ل توجيه صري ة وسيلة استخدام أي ومه يك ي ة ال شمسية ال موقع عت حي د أ ظمة ب عض ال شمس، من ال حرارة ال طاقة حصاد أجل من
ب وس صغير ال شمس استشعار خلال من ي دخل ال شمس ضوء ال حادث الاستشعار، ال شمس ال شمسية مصم جهاز في ال شمس ال موقع في Y ونسق X ال تحي د ال رك يزة CMOS أول ال سيليكون على ال مباشرة ال شمس لأشعة ال شمس، استشعار وسيلة
ت تتبع أسل ي بن قل أو متعددة ال كثيرة تتبع ال برامج تتبع ال كثيرة نو ال قوم ال تي ال ي، ال شمس ووسيط ل ال شمسية تتبع ال صور معالجة ك اميرا أوك اميرا في ب صف حف ي ال سيليكون رك يزة على ال ضوء تعرض حيث ق ناع ل وحف ي حفرة
مع ال تعوي ب ال شمسية ف يث ني تم حي في ي ال ملتقطة، ال صورة إطار ف ي ال شمسية قاعة أو ظاهرة ال شمسية ل قرص ال عي ضة ال خطوط مب عل ي ي ذي ال ي اضي معال جة ال صور معالجة برامج ال شمسية، ال كثيرة تتبع تقنية ف ي ال كثيرة ن
ال شمسية ق لات الإ حداث يات ال تحي د ال خ ة عن ال كشف خوارزمية.

ال شمسية ال طاقة ال وحدة ال موقع عت حي دن ظامي ي ستخدم ال متجددة، ال طاقة ن ظم ذه مثلف ي ال شمس ال شمسية ال طاقة تسخير تتبع ال سيطرة خلال من ال شمسية ال طاقة محطات من ال عوائد تعظيم على ي ساعد الآ ي ال موقع عت حي دن ظام
ال تتبع ن ظاف ي ال شمسي ال تتبع ال محور على ال تلق ي ال مرك زة CPV ال ضوئ ي ة ال كهرب ائ ي ة ول ن ظم ال ضوئ ي ة ال كهرب ائ ي ة ال ن ظف ي ال موقع عت حي د ال كهروضوئ ي ة الأ واخ ف ي ال شمسية حاسبة وزاوي ة ال شمس تتبع وتقنيات
واحد محور وف ي ح تى ال طاق ة، ال تاج زي ادة في ضمن ال طاق ة عقب ال ع د زي ادة ال ضوئ ي ة ل ف وحف يب محرك ات ال موقع عت حي د ن ظام أن ال معروف من ال شمسي ال تتبع ال شمس واحد محور أول ال شمسي ب ع ت محورث ن ائ ي يك ون أن ي مكن PV ال شمسي
ال حصاف ي ال شمسية ال طاق ة ال تاج على ال سيطرة حسي ف ي الاصطناعي ال ذك اء مع ROBOTICA ت ستخدم ال شمسي ال تتبع ظام ن ال روبوت ي ة ال روبوت ي ة أول ال شمسية ال طاق ة عقب مثل الأخ رى ال تطبيقات ال شمسي ال تتبع ال تقني ن
من خلال ن ظام ال تتبع ال ي الآ.

ستخدم ت ظمة دأ حي ت ع موق ال ي ال ت لق ي ف يما ص ات تتبع شمسية ال ض اءي ف ي في غير من ذات ي ال طاق ة، ال حرة ال مثل ة ال حراري ة ال شمسية ال مرك زة ال CSP سلطة ال مظمة وال غن ي ال ست ي ال طب ق جهاز تتبع ال شمسية ف ي جمي ع ت ال طاق ة
ال شمسية ف ي ال شمسية مرك زات ف ي أول ال شمسية ال طاق ة جمي ع ذا ال مثل ال شمسية ال طاق ة جمي ع خلال من ال شمس من ال طاق ة تسخير ال شمسية ال طاق ة ق ي عب ساعد مزدوج محور ال شمسي، ال تتبع محور على ي نف ذ ذا مثل ال شمسية ال طاق ة جمي ع خلال ... أن ي مكن ال تي ال ضوئ ي ة ال طاق ة ...
... thermosyphin ... PCM ... (PNG) ... ال ... ال ...
.وال آ مام ال ... ال ...

Abstract for Google Translate in Korean

이 책은 자동 태양 광 추적, 일 - 추적 - 시스템, 태양 추적자와 일 트래커 시스템에 대해 자세히 설명합니다. 지능형 자동 태양 광 추적 장치는 태양을 향해 페이로드의 방향을하는 장치입니다. 프로그래밍 가능한 컴퓨터 기반의 태양 추적 장치는 태양 추적, 태양 추적 시스템뿐만 아니라, 마이크로 컨트롤러, 마이크로 프로세서 및 / 또는 태양을 향해 태양 반사기, 태양열 렌즈, 태양 광 패널 또는 다른 광학 구성을 배향하는 PC 기반의 태양 추적 제어의 원리를 포함한다. 전동 공간 프레임과 운동 시스템은 운동 역학을 보장하고 드라이브 기술을 사용하고 원칙을 준비하는 것은 같은 mangin, 일에 직면하고 지속적으로 일 운동의 윤곽을 따라 포물선, 원뿔 곡선 (이차 곡선) 또는 카세그레인 태양 에너지 수집 등의 광학 구성을 조종 할 수 있습니다.

태양 광 추적 또는 실용적인 태양 추적 시스템을 통해 태양으로부터 전력을 활용에서는 재생 에너지 제어 자동화 시스템 제어 자동화 아키텍처, 회로 기판 및 하드웨어 동적 모션 제어를 수행하는 자동 태양 추적 소프트웨어 및 태양 위치 알고리즘을 필요로한다. 온 - 축 태양 추적 시스템은 고도 - 방위각 이중 축 혹은 다중 축 태양 추적 시스템은 태양 추적 알고리즘 또는 하늘을 일의 통로를 보장하기 위해 센서 또는 소프트웨어를 추적 선을 사용하는 등하는 자동화 된 태양 광 추적 애플리케이션에서 높은 정밀도로 추적 하였다 바로 여름 최고점, 태양 춘분과 동지를 통해.고정밀 태양 위치 산출하거나 일 위치 알고리즘은 태양 태양 추적기를 정렬 소프트웨어 프로그램 루틴을 사용하여 자동 태양 추적 시스템의 설계 및 구조에있어 중요한 요소이다.

태양 추적 소프트웨어 관점에서 일을 추적 소네트는 문자 그대로의 의미를 갖습니다. 태양 추적 관리의 맥락에서,이 책은 하늘을 가로 질러 태양의 일상 경로가 비교적 간단한 원리에 의해 지시되어 있는지 설명하고, 파악 경우 / 이해, 그것은 소프트웨어 다음 태양 태양을 추적하기가 상대적으로 쉽다. 태양을 추적하는 일 위치 컴퓨터 소프트웨어는,이 책에 나와있는 소스 오픈 소스 코드로 사용할 수 있습니다. 역설적이게도 시스템이라고 일 체이서가 있었다, 하루 종일 일을 쫓는 알려진 태양 포지셔너 시스템 였다고.

자동 태양 추적을위한 전자 회로 태양 방정식을 사용하면 초보자이지만, 수학 태양 방정식을 통해 텍스트 책, 저널 기사 및 인터넷 웹 사이트에서 교육 전문가 및 교수에 의해 복잡하더라도, 매우 간단합니다. 태양 추적을위한 태양 추적 전자 장치 또는 PC 프로그램을보고 태양 취미, 학자, 학생 및 아마추어의 측면에서 일반적으로 좌절감에 많은 개발자 나뭇잎 과학 재료 및 인터넷 자원의 엄청난 양에 의해 극복 될 때

간단한 실험 태양 광 추적 소스에 대한 검색 자신의 축 태양 추적 시스템 -code. 이 책자는 당신의 일 추적기 혁신을위한 신비로운 태양 추적 식에 대한 검색을 단순화하고 당신이 당신의 자신의 자율적 인 태양 추적 컨트롤러를 개발하는 데 도움이됩니다.

태양에 직접 태양열 집열기를 연출함으로써, 태양 광 수확 수단 또는 장치는 햇빛 또는 열 열을 활용할 수 있습니다. 일 각 공식의 도움을 (태양이 하늘을 가로 질러 이동 또는) 지구 회전과 같은 일을 추적하기 위해, 태양 각도 수식이나 태양 광 추적 절차는 하늘에서 태양의 위치의 계산에 필요합니다. 자동 태양 추적 시스템 소프트웨어는 하늘 걸쳐 해 다음에 필요한 태양 고도 방위각 계산을위한 알고리즘을 포함한다.경도를 사용하여, 태양 광 추적 장치 위치의 위도의 GPS 좌표, 소프트웨어 툴 추적이 태양은 태양 고도 - 방위각을 결정함으로써 정밀한 태양 추적을 지원하는 특정 일 각 수식을 사용하여 추적기 위치 추적 고도 - 방위각에서 태양 궤도 좌표 일 벡터 계산. 대신 일 소프트웨어, 태양 추적 센서를 따라 같은 비전 근거 해 다음의 화상 처리 소프트웨어를 사용하여 태양 센서 또는 웹캠이나 비디오 카메라로도 광학적 태양의 위치를 결정하는데 사용될 수있다. 이러한 광학 피드백 장치는 종종 태양 전지 패널 추적 시스템과 요리 추적 시스템에 사용됩니다.

동적 일 추적은 태양 측량, DNI 분석기와 GIS에 대한 태양 복사 휘도, 조도 및 DNI 모델 (지리 정보 시스템)와 태양 광 인포 그래픽지도를 구축 일 조사 시스템에 사용된다. 이 방법으로 태양 광 / 환경의 상호 작용에 대한 지리 공간 방법은 지리 정보 기술 (GIS, 원격 탐사 및지도 제작)의 사용을 사용합니다.
기후 데이터와 기상 관측소 나 기상 센터 데이터뿐만 아니라 하늘 서버 및 태양 자원 데이터베이스 시스템에서 쿼리 (즉, DB2에은, 사이베이스, 오라클, SQL, MySQL은)도 태양 GIS 맵과 연관 될 수있다. 태양 자원 모델링 시스템에있어서, 일사량 또는 solarimeter 일반적 특정 지리적 위치에 대해, 직접 및 간접 흩어져, 분산, 반사 된 방사선을 측정하기 위해 추가로 사용된다. 햇빛 분석은 사진 조명 사진 작가를위한 중요한 플래시 촬영에서 중요하다. GIS 시스템은 건축 음영 또는 일의 그림자 분석, 태양 플럭스 계산, 광학 모델링을 연구하거나 기상 모델링을 수행하는 일의 그림자 애플릿을 추가 건축가에 의해 사용됩니다. 이러한 시스템은 종종 광선이 태양의 위치와 강도를 결정하는 태양 네비게이터 또는 태양 추적으로 프로그램 추적 소프트웨어가있는 컴퓨터 망원경을 운영 유형 메커니즘을 사용한다.

이 책의 목적은 추적하고 자신의 응용 프로그램에 적합한 소스 코드 및 태양 추적 알고리즘을 추적, 취미, 과학자, 기술자 또는 엔지니어 여부 개발자를 지원하는 것입니다. 많은 오픈 소스 일 다음과 태양 추적 프로그램에 대한 알고리즘과 소스 코드를 추적하고 모듈은 오늘날 인터넷에서 다운로드 할 수 자유롭게 사용할 수 있습니다. 특정 독점적 인 태양 광 추적 키트 및 태양 추적 컨트롤러는 응용 프로그램 프로그래밍 인터페이스 API 특성 (조약돌)을위한 소프트웨어 개발 키트 SDK를 포함한다. 그래픽 제어 요소와 위젯 라이브러리, 위젯 툴킷 GUI 툴킷 및 UX 라이브러리는 또한 태양 광 추적이나 태양 광 발전 모니터링 프로그램의 그래픽 사용자 인터페이스 (GUI)를 구성 할 수 있습니다.

태양의 위치 계산기, 태양 광 시뮬레이션 소프트웨어 및 태양 윤곽 계산기에 사용되는 태양 라이브러리는 프로그래머블 로직 컨트롤러 PLC, 프로그래머블 게이트 어레이, 아두 이노 프로세서 또는 PIC 프로세서 마이크로 컨트롤러에 프로그램 소프트웨어 아르 태양 하드웨어 컨트롤러에 대한 시스템 프로그램 코드를 포함한다. PC 기반의 태양 추적 또한 C + +, 비주얼 베이직 VB뿐만 아니라, MS 윈도우, 리눅스, 맥 애플 matlab에, 엑셀 태양 경로 테이블 기반 운영 체제를 사용하는 수요가 높다. 태양의 각도 계산기, 일 위치 계산기 또는 태양 각도 계산기 : 일부 책과 인터넷 웹 페이지와 같은 다른 용어를 사용합니다. 말했듯이, 이러한 소프트웨어 코드는 태양 방위각, 태양 고도 각, 태양 앙각 또는 태양 천정각 계산 (제니스 태양 각도 단순히 수직면에서 참조되는, 수평 또는 접지면 레벨에서 측정 앙각의 거울) . 비슷한 소프트웨어 코드는 태양 계산기 응용 프로그램 또는 IOS와 안드로이드 스마트 폰 장치에 대한 태양 광 발전 계산기 응용 프로그램에 사용됩니다. 이러한 스마트 폰 태양 광 모바일 애플 리케이션의 대부분은 24 시간 동안 임의의 위치와 날짜에 대한 일 경로와 태양 각도를 보여줍니다. 일부 스마트 폰은 물리적으로 확인하고 휴대 전화의 특정 GPS 위치에서 휴대 전화 카메라 나 휴대 전화 카메라를 통해 태양 경로를 볼 수있는 현실 기능을 증강 등이 있습니다.

컴퓨터 프로그래밍 및 디지털 신호 처리 (DSP) 환경에서 (무료 / 오픈 소스) 프로그램 코드 + + 감바, VB 닷넷, 델파이, 파이썬, C, C +, C 사용할 수 있습니다, PHP, 스위프트, ADM, F, 플래시 , 기본, QBasic에, GBasic, KBasic, 간체 언어, 다람쥐, 솔라리스, 같은 MS 윈도우, 애플 맥, DOS, 유닉스 또는 리눅스 OS 등의 운영 체제에서 어셈블리 언어. 하늘에 태양의 위치를 예측하는 소프트웨어 알고리즘은 Matlab과 (매스 웍스)와 같은 그래픽 기반 프로그래밍 플랫폼, 시뮬링크 모델, 자바 애플릿 등 일반적으로 사용할 수있는 시뮬레이션을 TRNSYS, SCADA 시스템 응용 프로그램, LabVIEW는 모듈 인 Beckhoff 트윈 캣 (비주얼 스튜디오), 지멘스 SPA, 모바일 및 아이폰 앱, 안드로이드 나 아이폰 OS 태블릿 앱, 등. 동시에, 태양 추적 자동화 기술의 범위에 대한 PLC 소프트웨어 코드는 지멘스, HP, 파나소닉, ABB, 앨런 브래들리, OMRON, SEW, Festo의,는 Beckhoff, 로크웰, 슈나이더, 엔드레스 하우저에 대한 하늘에서 태양의 프로필을 따를 수있다 , Fudji 전기. 하니웰, 푹스 Yokonawa 또는 Muthibishi 플랫폼. 일 경로 투영 소프트웨어는 모듈 형 IPC 임베디드 PC 마더 보드의 범위도 사용할 수 있으며, 이러한 지멘스 S7-1200 또는 지멘스 로고는 Beckhoff IPC 또는 CX 시리즈와 같은 산업용 PC, PLC (프로그래머블 로직 컨트롤러) 및 PAC (프로그래밍 가능한 자동화 컨트롤러), OMRON PLC, Ercam PLC, AC500plc ABB, 내쇼날 인스트루먼트의 NI PXI 또는 NI하여 cRIO, PIC 프로세서, 인텔 8,085분의 8,051, IBM (셀, 파워, 뇌 또는 Truenorth 시리즈), FPGA (자일링스 알테라의 Nios), 인텔, 제온, 아트멜 megaAVR , MPU, 서보 모터, 스테퍼 모터, 직류 DC 펄스 폭 변조 (PWM 현재 드라이버) 또는 교류 AC SPS 메이플, 왜 그래, MSP, XMOS, XBEE, ARM, 라즈베리 파이, 독수리, 아두 이노 나 아두 이노 ATMEGA 마이크로 컨트롤러, 또는 IPC 가변 주파수 VFD 모터 드라이브 (일명, 가변 주파수 드라이브, 가변속 드라이브, AC 드라이브, 마이크로 드라이브 또는 인버터 드라이브) 전기, 전자 기계, 공압 또는 유압 태양 트랙킹 액츄에이터 구동한다.

상기 동작 제어와 로봇 제어 시스템은 하나 또는 각 센서 나 각도 인코더, 샤프트 인코더, 정밀 인코더, 광학 인코더, 자기 엔코더, 방향의 조합을 통해 추적 각도 방향 피드백 제어를 허용하도록 프로세서에 아날로그 또는 디지털 인터페이스 포트를 포함 인코더, 회전 인코더, 인코더 칩, 기울기 센서, 경사 센서, 또는 피치 센서. 추적기의 상승 또는 천정 축 각도 고도 angle-, 편각 angle-, 경사 angle-, 피치 angle-, 또는 수직 angle-, 천정 angle- 센서, 경사계를 사용하여 측정 할 수 있습니다. 마찬가지로 추적기의 방위각 축 각도는 방위 angle-, 수평 angle- 또는 롤 angle- 센서로 측정 될 수있다. 칩 집적 가속도계 자력계 자이로 스코프 타입 각도 센서는 변위를 계산하는데 이용 될 수있다. 다른 옵션은 플루크 열 화상, 또는 태양 추적에 얼굴 추적, 헤드 트랙킹 손 추적, 안구 추적 및 자동차 트래킹 원리를 채용 로봇 또는 비전 기반의 태양 추적 시스템과 같은 열 이미징 시스템의 사용을 포함한다.

무인 분산 농촌, 섬, 고립 된, 또는 자율 오프 그리드 전원 설치, 원격 제어, 모니터링, 데이터 수집, 디지털 데이터 로깅 및 온라인 측정 및 검증 장비로 매우 중요하게된다. 그것은 원격 재생 에너지 자원과 시스템의 효율성을 모니터링하고 CO2 및 청정 개발 체제 (CDM)보고의 관점에서 가치있는 웹 기반 피드백을 제공하기 위해 감시 제어 연산자를 지원합니다. 인터넷, WiFi와 셀룰러 이동 링크를 통해 진단을위한 전력 품질 분석기는 빠른 진단 분석이 감지하고 전력 품질 문제를 방지하는 데 필요한 전선 문제 해결 및 예방 정비에 가장 유용합니다.

태양 광 추적 응용 프로그램, 집중 태양 광 발전, 태양열 해수 담수화, 태양 물 정화, 태양 증기 발전, 태양 광 발전, 태양 광 산업 공정 열, 태양열 축열, 태양 식품 건조기를 포함하여 태양 광 응용 프로그램 및 태양 광 어시스트 응용 프로그램의 넓은 스펙트럼을 커버 태양 물 펌프, 전기 분해를 통해 물 (HHO)에서 메탄 생산 수소와 산소로부터 수소 생산. 많은 특허 또는 비 특허 태양 광 장치는 태양 광 발전기, 태양 desalinator, 태양 증기 기관, 태양 제빙기, 태양 정수기, 태양 냉각, 태양 냉동, USB 태양 충전기, 태양 광 휴대폰 충전, 휴대용 태양 광 충전을위한 태양 광 장치에서 추적 포함 추적기, 태양 커피 추출, 태양 요리 또는 태양 죽음을 의미한다. 당신의 프로젝트는 다음 돌파구 또는 특허 수 있지만, 당신의 발명은 당신이 당신의 태양 광 전력 기기에 필요한 태양 추적기, 태양 광 발전기, 태양 광 추적 로봇, 태양 냉장고, 태양 광 조리기, 태양 건조, 태양 펌프에 대한 검색에 좌절에 의해 다시 개최 태양 냉동고, 또는 태양 건조기 프로젝트. 태양 광 전자 회로 다이어그램은 전기를 태양 광 발전 프로젝트의 단순화 된 태양 광 컨트롤러 설계, 태양 광 키트, 태양 취미 키트, 태양 증기 발전기, 태양열 온수 시스템, 태양 제빙기, 태양 desalinator, 취미 태양 전지 패널, 취미 로봇, 또는 포함 여부 당신이 태양 농장이나 태양 농사 자신을위한 태양 광 유틸리티 또는 마이크로 규모의 태양 광 발전소에 대한 전문가 또는 취미 전자 제품을 개발하는 경우,이 책은 태양 광 추적 혁신의 개발을 가속화하는 데 도움이 될 수 있습니다.

최근 태양 polygeneration, 태양 삼중 열병합 발전 (태양 트리플 세대), 태양 쿼드 세대 시스템은 자동 태양 추적에 필요한 한 (증기, 액체 / 기체 연료 또는 캡처 식품 등급 CO $ $ _2의 배달을 추가). 이러한 시스템 통합의 결과로서 에너지 수율로 상당한 효율 증가 및 폐기물 또는 잔열의 재사용을 위해 알려진 제조 및 수송 킷 형태와 플러그상에서 동작 될 수 소형 패키지화 마이크로 태양열 발전소에 적합한 아르 - 그리고 플레이 한 기준입니다. 일반적인 하이브리드 태양 광 발전 시스템은 열병합 (CHP 또는 한병돈) 결합 소형 또는 포장 태양 마이크로 또는 결합 태양 마이크로, 냉각, 난방 및 전력 분산 발전에 사용 (CCHP, CHPC, mCCHP 또는 mCHPC) 시스템을 포함한다. 이러한 시스템은 종종 농촌 오프 그리드 (off-grid), 섬 또는 고립 된 마이크로 그리드, minigrid 및 분산 전원 신 재생 에너지 시스템을위한 집중 태양 CSP와 CPV 스마트 마이크로 그리드 구성으로 결합됩니다. 태양 추적 알고리즘은 또한 삼중 매트랩 시뮬링크 (Modelica 또는 TRNSYS)를 사용하는 시스템 플랫폼의 모델링뿐만 아니라, 자동화 및 지능형 파싱, 다목적, 적응 학습 제어 및 제어 최적화 전략을 통해 재생 에너지 시스템의 제어에 사용된다.

태양 추적 알고리즘은 또한 특정 지역 (즉, 직접 및 확산 방사) 측정 또는 일사량 변동 분석의 관점에서, 예를 들어, 국가 또는 위치 특정 태양 태양 모델 연구 개발에 응용 프로그램을 찾을. 태양 DNI, 태양 복사와 대기 정보와 모델은 따라서 태양지도, 태양 아틀라스 또는 지리 정보 시스템 (GIS)에 통합 할 수 있습니다. 이러한 모델은 Matlab과 Simulink 및 같은 또는 작성할 때 선형 또는 다중 목적 최적화 알고리즘 플랫폼에서 시뮬레이션 및 합성 플랫폼에서 CSP 시스템의 태양 광 다른 태양의 평가의 측면에서 도움이 될 수있는 특정 지역에 대한 지역의 매개 변수를 정의 할 수 있습니다 , EnergyPLAN 또는 DER-CAM.

이중 축 태양 광 추적 및 단일 축 태양 광 추적 장치는 태양 접시, 태양 전지 패널 배열, heliostat 배열, 태양 광 패널, 태양 안테나 또는 적외선 태양 nantenna를 배치하는 일 추적기 프로그램이나 태양 추적 알고리즘을 사용할 수 있습니다.자동 추적 태양 집중 태양 벡터를 계산하여 자동 태양 추적을 수행한다. 태양 위치 알고리즘 (트윈 캣은 SPA 또는 PSA 알고리즘)은 태양의 위치를 계산하는 알고리즘을 사용 천문. 그것은 하루 중 언제든지 땅에있는 각 위치의 하늘에서 태양의 위치를 계산하는 태양 추적을위한 천문 소프트웨어 알고리즘 및 방정식을 사용합니다. 태양이 하루 종일 진행되는 광 태양 망원경처럼, 태양의 위치 상 태양과 잠금의 태양 위치 알고리즘 핀 포인트 태양 반사경은 하늘을 가로 질러 태양을 추적 할 수 있습니다. 포토 다이오드와 같은 광 센서는 빛에 의존하는 - 저항 (LDR) 또는 photoresistors 광학 정확도 피드백 장치로 사용된다. 최근 우리는 또한 Wii 리모콘 또는 Wiimote의 목록 PixArt 닌텐도 적외선 카메라는 적외선 태양 추적 애플리케이션에서 사용될 수있는 방법 (마이크로 코드에 링크) 책의 부분을 포함.

태양으로부터 자유 에너지를 수확하기 위해, 일부 태양 자동 위치 결정 시스템은 태양 광 추적 장치를 지시하는 광학 수단을 사용한다. 이러한 태양 추적 전략을 결정하기 위해 X 실리콘 또는 CMOS 기판 상에 직접 태양 광선에 이러한 일 센서 수단으로서 광 추적 기술을 사용하고 Y는 태양의 위치 좌표.일 태양의 MEMS 센서 장치에있어서, 입사 광선은 광이 실리콘 기판에 노출되는 마스크 판의 작은 구멍을 통해 핀

태양 센서 들어간다. 웹 카메라 또는 카메라 이미지 처리 태양 추적 및 일 다음과 같은 방법에서 객체 추적 소프트웨어는 다중 객체 추적 또는 이동 물체 추적 방법을 수행합니다.태양 물체 추적 기법에서, 화상 처리 소프트웨어는 태양 현지화 태양 벡터 좌표를 결정하기 위해 에지 검출 알고리즘을 수행하는 동안, 촬영 한 화상 프레임 내의 겉보기 태양 디스크 또는 태양 블롭의 개략 상자 수학적 처리를 수행한다.

자동 위치 추적 시스템은 태양 에너지를 활용하는 태양 광 추적 제어를 통해 태양 광 발전소의 생산량을 극대화 할 수 있도록 도움을줍니다. 신 재생 에너지 시스템에있어서, 태양 전지 패널 측위 시스템은 태양 추적 기법과 광 시스템의 위치 결정 PV 패널의 태양 각도 계산기 및 농축 광전지 CPV 시스템을 사용한다.PV 태양 추적 시스템의 자동 온 - 축 태양 추적은 이중 축 태양 추적 또는 단일 축 태양 추적 일 수있다. 이는 태양 광 패널 추적기 증가 에너지 수율로 전동 측위 시스템은 심지어 단일 축 태양 추적 구성에서, 전력 출력을 증가 보장하는 것이 알려져있다. 이러한 로봇 태양 광 추적 장치 나 로봇 형 태양 광 추적 시스템과 같은 다른 응용 프로그램은 로봇 추적 시스템을 통해 태양 수확의 에너지 생산량의 제어 최적화 인공 지능 robotica를 사용합니다.

태양 추적 설계에서 자동 포지셔닝 시스템은 또한, 농축 태양열 전력 CSP와 접시 스털링 시스템과 같은 다른 자유 에너지 발생기에 사용되고있다.태양 집중 장치 나 태양열 집열기에서 태양열 집열기의 태양 추적 장치와 같은 포물선 거울이 될 수 태양 추적, 이중 축 태양 추적기 어시스트 광 태양열 집열기를 통해 태양 에너지를 활용하기에 축 수행, 포물선 리플렉터, 프레 넬 렌즈 또는 거울 어레이 / 매트릭스.포물선 접시 또는 반사기 동적 전송 시스템을 사용하여 조향하거나 태양 추적 슬루 드라이브 의미한다.일 대향 접시 스티어링에서, 전력 요리 액츄에이터 구동 광학적 포물선 접시 시스템 수단 포물선 접시 또는 태양열 집중 수단의 초점에 태양 에너지를 집중한다.스터링 엔진, 태양열 파이프 thermosyphin 태양 상 변화 재료 PCM 수신기, 또는 광섬유 햇빛 수신기 태양 농축기의 초점에 위치되는 것을 의미한다.접시 스털링 엔진 구성은 접시 스털링 스털링 시스템 또는 발전 시스템이라한다. (바이오 가스, 바이오 연료, 가솔린, 에탄올, 디젤, 천연 가스 또는 PNG와 병용) 하이브리드 태양 광 발전 시스템은 활용 및 기억 매체에 태양 에너지를 저장하기 위해 전원의 조합을 사용한다. 에너지 원 중 다수는 제어기의 사용 및 배터리에 저장된 에너지, 상 변화 물질, 열 축열을 통해 결합 될 수 있으며, 열병합 발전에 폼 (열역학적 싸이클을 사용하여 필요한 전력으로 변환 유기 순위, 브 레이튼 사이클, 마이크로 터빈, 인버터 및 충전 컨트롤러와 스털링).

Abstract for Google Translate in Dutch
Dit boek beschrijft Automatische Zonne-Tracking, Sun-Tracking-systemen, zonne-Trackers en Sun Tracker Systems. Een intelligente automatische solar tracker is een apparaat dat een lading in de richting van de zon oriënteert. Dergelijke programmeerbare computer gebaseerd zonnevolg inrichting omvat beginselen van zonnevolg, zonnevolg systemen en microcontroller, microprocessor en / of PC gebaseerde zonnevolg control zonne reflectoren, zonne lenzen, fotovoltaïsche panelen of andere optische configuraties oriënteren naar de zon. Gemotoriseerde ruimte frames en kinematische systemen zorgen voor beweging en dynamiek in dienst aandrijftechniek en gearing principes om optische configuraties zoals Mangin, parabolische, conische of cassegrain zonnecollectoren naar de zon en het continu volgen van de beweging van de zon contour sturen.

In het benutten van energie van de zon door een zonne-tracker of praktische solar tracking systeem, hernieuwbare energie controle automatiseringssystemen vereisen automatische solar tracking software en zonne-positie algoritmen om dynamische motion control met controle-automatisering architectuur, printplaten en hardware te bereiken. On-as zon volgsysteem zoals de hoogte-azimuth dubbele as of meerdere assen solar tracker systemen maken gebruik van een zon volgen algoritme of ray tracing sensoren of software om de passage van de zon langs de hemel te verzekeren wordt opgespoord met een hoge precisie in geautomatiseerde solar tracker toepassingen , dwars door zomerzonnewende, zonne-equinox en de winter zonnewende. Een hoge precisie zonligging rekenmachine of zonligging algoritme maakt gebruik van een software programma routine om de zonne-tracker om de zon af te stemmen en is een belangrijk onderdeel in het ontwerp en de bouw van een automatische solar tracking systeem.

Van zon tracing software perspectief, het sonnet Tracing The Sun heeft een letterlijke betekenis. In het kader van de zon track and trace, dit boek legt uit dat de zon dagelijks pad langs de hemel is geregisseerd door relatief eenvoudige principes, en als begrepen / begrijpen, dan is het relatief eenvoudig om de zon met volgende software op te sporen. Zonligging software voor het opsporen van de zon zijn beschikbaar als open source-code, bronnen die worden vermeld in dit boek. Ironisch genoeg was er zelfs een systeem genaamd zon chaser, zei een zonne klepstandsteller systeem dat bekend staat voor het achtervolgen van de zon gedurende de dag te zijn geweest.

Met behulp van zonne-vergelijkingen in een elektronisch circuit voor automatische solar tracking is vrij eenvoudig, zelfs als je een beginner, maar wiskundige zonne vergelijkingen worden dan bemoeilijkt door academische experts en professoren in tekst-boeken, tijdschriftartikelen en internet websites. Op het vlak van zonne-hobby's, wetenschappers, studenten en hobbyist's kijken naar zonne-volgsysteem elektronica of PC-programma voor zonne-volgsysteem worden meestal opgelost door de enorme hoeveelheid wetenschappelijk materiaal en internetbronnen, waar veel ontwikkelaars bladeren in frustratie bij het zoeken naar eenvoudige experimentele zonnevolg bron -Code voor hun on-as zon-tracking systemen. Dit boekje zal de zoektocht naar de mystieke zon volgen formules voor uw zon tracker innovatie vereenvoudigen en u helpen uw eigen autonome zonne volgen controller te ontwikkelen.

Door de leiding van de zonnecollector direct in de zon, een zonne oogsten betekent of apparaat kan zonlicht of thermische warmte te benutten. Om de zon als de aarde draait volgen (of als de zon beweegt langs de hemel) de hulp van de zon hoek formules, zonne-hoek formules of zonne volgen procedures nodig voor de berekening van de positie van de zon in de hemel. Automatisch zon volgsysteem software bevat algoritmes voor zonne hoogte azimuthoek berekeningen die nodig zijn in het volgen van de zon langs de hemel. Bij het gebruik van de lengte, breedte GPS-coördinaten van de zonne-tracker locatie, deze zon tracking software gereedschappen ondersteunt precisie zonne volgen door het bepalen van de hoogte van zonne-azimuth coördineert voor de zon traject in hoogte-azimuth volgen op de tracker locatie, het gebruik van bepaalde zon hoek formules in zon vector berekeningen. In plaats van het volgen zon software, een zon tracking-sensor, zoals een zonnecel of webcam of videocamera met visie gebaseerde zon volgende beeldverwerking software kan ook worden gebruikt om de positie van de zon optisch bepalen. Dergelijke optische feedback apparaten worden vaak gebruikt in zonnepanelen volgsystemen en gerecht volgsystemen.

Dynamische zon tracing wordt ook gebruikt in zonne-landmeten, DNI analyzer en zon landmeetkundige systemen die zonne infographics kaarten met zonne-straling, instraling en DNI modellen voor GIS (geografisch informatiesysteem) te bouwen. Op deze manier geospatiale methoden op zonne / interactie omgeving maakt gebruik gebruik van geospatiale technologie (GIS, Remote Sensing en Cartografie).
Klimatologische gegevens en het weerstation of het weer het centrum van gegevens, maar ook vragen van hemel servers en zonne resource database-systemen (dwz op DB2, Sybase, Oracle, SQL, MySQL) kan ook worden geassocieerd met zonne-GIS-kaarten. In dergelijke zonne resource modellering systemen wordt een pyranometer of solarimeter normaal gebruikt in aanvulling op de directe en indirecte, verstrooid, verspreid, reflecterende straling te meten voor een specifieke geografische locatie. Zonlicht analyse is belangrijk bij flitsfotografie waar fotografische verlichting belangrijk zijn voor fotografen. GIS-systemen worden gebruikt door architecten die toe zon schaduw applets tot architectonische schaduw of zon schaduw analyse, zonneflux berekeningen, optische modellering studeren of om weermodellen voeren. Zulke systemen vaak gebruik van een computer bediend soort telescoop mechanisme met ray tracing programma software als een zonne-navigator of zon tracer die de zonne-positie en de intensiteit bepaalt.

Het doel van dit boekje is om ontwikkelaars te traceren en te volgen geschikte source-code en zonne volgen algoritmes voor hun toepassing, of een hobbyist, wetenschapper, technicus of ingenieur te helpen. Veel open-source zon volgen en bijhouden van algoritmes en source-code voor zonne-opsporingsprogramma's en modules zijn vrij beschikbaar om te downloaden op het internet vandaag. Bepaalde merkgebonden solar tracker kits en zonnevolg controllers zijn voorzien van een software development kit SDK voor de application programming interface API attributen (Pebble). Widget bibliotheken, widget toolkits, GUI toolkit en UX bibliotheken met grafische controle-elementen zijn ook beschikbaar voor de grafische gebruikersinterface (GUI) te bouwen voor uw zonne-volgsysteem of zonne-energie monitoringsprogramma.

De zonne-bibliotheek die wordt gebruikt door zonne-positie rekenmachines, zonne-simulatiesoftware en zonne-contour rekenmachines bevatten machine programmacode voor de zonne-hardware controller die software geprogrammeerd in Micro-controllers, Programmable Logic Controllers PLC, programmable gate arrays, Arduino processor of PIC-processor zijn. PC-gebaseerde zonne-tracking is ook hoog in de vraag met behulp van C ++, Visual Basic VB, evenals MS Windows, Linux en Apple Mac-besturingssystemen voor zon pad tafels op Matlab, Excel. Sommige boeken en internet webpagina's gebruiken andere termen, zoals: zon hoek rekenmachine, zonligging rekenmachine of zonne-hoek rekenmachine. Zoals gezegd, dergelijke software code berekenen van de zonne-azimuth hoek, zonne hoogte hoek, zonne elevatiehoek of de zonne-Zenith hoek (Zenith zonne-hoek wordt gewoon verwezen vanuit verticale vlak, de spiegel van de elevatie hoek gemeten vanaf de horizontale of maaiveld-niveau) . Vergelijkbare software code wordt ook gebruikt in zonne-rekenmachine apps of de zonne-energie rekenmachine apps voor iOS en Android smartphones. De meeste van deze smartphone zonne mobiele apps tonen de zon weg en zon-hoeken voor elke locatie en datum over een periode van 24 uur. Sommige smartphones bevatten augmented reality features waar je fysiek kunt zien en kijken naar de zonne-pad via uw mobiele telefoon camera of mobiele telefoon met camera op specifieke GPS-locatie van de telefoon.

In het programmeren van computers en digitale signaalverwerking (DSP) milieu, (gratis / open source) programma-code zijn beschikbaar voor Gambas, VB, NET, Delphi, Python, C, C +, C ++, PHP, Swift, ADM, F, Flash , Basic, QBasic, GBasic, KBasic, SIMPL taal, Eekhoorn, Solaris, assembler op besturingssystemen zoals MS Windows, Apple Mac, DOS, Unix of Linux OS. Software-algoritmen voorspellen positie van de zon aan de hemel zijn algemeen beschikbaar als grafische programmering platforms zoals Matlab (Mathworks), Simulink modellen, Java applets, TRNSYS simulaties, Scada systeem apps, Labview-module, Beckhoff TwinCAT (Visual Studio), Siemens SPA, mobiele en iPhone apps, Android of iOS tablet apps, enzovoort. Op hetzelfde moment, kan PLC-software code voor een reeks van de zon volgen automatiseringstechniek het profiel van de zon te volgen in de hemel voor Siemens, HP, Panasonic, ABB, Allan Bradley, Omron, SEW, Festo, Beckhoff, Rockwell, Schneider, Endress Hauser , Fudji elektrisch. Honeywell, Fuchs, Yokonawa of Muthibishi platforms. Zon pad projectie software zijn ook beschikbaar voor een reeks modulaire IPC ingebedde moederborden, industriële PC, PLC (Programmable Logic Controller) en PAC (Programmable Automation Controller), zoals de Siemens S7-1200 of Siemens Logo, Beckhoff IPC of CX-serie, OMRON PLC, Ercam PLC, AC500plc ABB, National Instruments NI PXI of NI cRIO, PIC-processor, Intel 8051/8085, IBM (Cell, Power, Brain of TrueNorth serie), FPGA (Xilinx Altera Nios), Intel, Xeon, Atmel megaAVR , MPU, esdoorn, Teensy, MSP, XMOS, Xbee, ARM, Raspberry Pi, Eagle, Arduino of Arduino AtMega microcontroller, met servomotor, stappenmotor, gelijkstroom DC pulse width modulation PWM (huidige bestuurder) of wisselstroom AC SPS of IPC variabele frequentie VFD motor drives (ook wel instelbare frequentie rijden, variabele snelheid rijden, AC aandrijving, micro-station of een frequentieregelaar) voor elektrische, mechatronische, pneumatisch of hydraulisch zonnevolg actuatoren.

Bovenstaande motion control en robotbesturing omvatten analoge of digitale interface poorten op de processors om voor tracker hoekoriëntatie terugkoppeling via een of een combinatie van hoeksensor of angle encoder, encoder, precisie encoder, optische encoder, magnetische encoder richting encoder, rotatie encoder, encoder chip, tilt sensor, hellingshoek sensor, of pitch sensor. Merk op dat verhoging of zenith as hoek van de tracker kan gemeten met een hoogte hoek-, hoek-declinatie, inclinatie hoek-, pitch hoek-of verticale hoek-, zenith hoek-sensor of inclinometer. Op dezelfde azimuth-as hoek van de tracker's worden gemeten met een azimuth hoek-, horizontale hoek-of roll hoek-sensor. Chip geïntegreerde accelerometer magnetometer Type gyroscoop hoeksensoren kan ook gebruikt worden om vervorming meten. Andere opties zijn het gebruik van thermische beeldvormende systemen, zoals een warmtebeeldcamera van Fluke, of robot of visie op basis van zonne tracker systemen die face tracking, hoofd bijhouden, met de hand bijhouden, eye tracking en autovolging principes hanteren in zonne-tracking.

Met onbeheerd gedecentraliseerde landelijke, insulaire, geïsoleerde, of autonome off-grid-installaties, afstandsbediening, monitoring, data-acquisitie, digitale datalogging en online meting en controle-apparatuur wordt van cruciaal belang. Het helpt de gebruiker met toezichthoudende controle toezien op de efficiëntie van externe bronnen en systemen op duurzame energie en waardevolle webgebaseerde feedback in termen van CO2 en mechanisme voor schone ontwikkeling (CDM) rapportage. Een power quality analyzer voor diagnostiek via internet, WiFi en cellulaire mobiele verbindingen is het meest waardevolle in de frontlinie het oplossen van problemen en predictief onderhoud, waar een snelle diagnostische analyse is nodig om te detecteren en power quality problemen te voorkomen.

Solar tracker toepassingen bestrijken een breed spectrum van toepassingen van zonne-en zonne-ondersteunde toepassing, met inbegrip van geconcentreerde zonne-energie opwekking, zonne-ontzilting, zonne waterzuivering, zonne stoom generatie, zonne-energie opwekking van elektriciteit, zonne-industriële proceswarmte, thermische zonne-warmte-opslag, zonne-energie voedsel drogers, zonnewaterpompen, productie van waterstof uit methaan of de productie van waterstof en zuurstof uit water (HHO) door middel van elektrolyse. Veel gepatenteerd of niet-gepatenteerde solar apparaten omvatten het bijhouden van in zonne-apparatuur voor zonne-elektrische generator, zonne ontzilter, zonne stoommachine, zonne ijsblokjesmachine, zonne waterzuiveraar, zonne-koeling, zonne-koeling, USB zonne-lader, zonne-energie telefoon opladen, draagbare zonne-energie opladen tracker, zonne koffiezetsysteem, solar cooking of zonne stervende middelen. Uw project kan de volgende doorbraak of octrooi zijn, maar uw uitvinding wordt tegengehouden door frustratie op zoek naar de zon tracker u nodig heeft voor uw zonne-energie aangedreven toestel, zonne-generator, zonne-tracker robot, zonne-vriescombinatie, solar cooker, zonne-droger, zonne-pomp , zonne-vriezer, of zonnedroger project. Of uw zonne elektronische schakelschema onder andere een vereenvoudigde zonne-controller design in een zonne-energie project, zonne-energie kit, zonne-hobby-kit, zonne-stoomgenerator, solar warm water systeem, zonne-ijsblokjesmachine, zonne ontzilter, hobbyist zonnepanelen, hobby robot, of als je de ontwikkeling van professionele of hobby elektronica voor een zonne-hulpprogramma of micro schaal zonne-krachtbron voor uw eigen zonne-boerderij of zonne-landbouw, kan deze publicatie helpen bij het versnellen van de ontwikkeling van uw zonne-volgsysteem innovatie.

De laatste tijd, zonne polygeneratie, zonne trigeneration (zonne triple generatie), en zonne-quad generatie (het toevoegen van de levering van stoom, vloeibare / gasvormige brandstof, of te vangen food-grade CO $ _2 $) systemen zijn nodig voor de automatische solar tracking. Deze systemen zijn bekend voor significant verbeterde efficiëntie van de energie-opbrengst als gevolg van de integratie en hergebruik van afval of restwarmte en geschikt voor compact verpakte micro solar elektriciteitscentrales die kunnen worden geproduceerd en getransporteerd in kit-vorm en werken op een plug -en play basis. Typische hybride zonne-energie systemen zijn compact en verpakt zonne micro warmtekrachtkoppeling (WKK of MChP) of zonne-micro gecombineerd, koeling, verwarming en stroom (CCHP, WKKC, mCCHP of mCHPC) systemen die worden gebruikt in gedistribueerde energieopwekking. Deze systemen worden vaak gecombineerd in geconcentreerde zonne CSP en CPV slimme microgrid configuraties voor off-grid landelijk, eiland of geïsoleerde microgrid, Minigrid en gedistribueerde energie hernieuwbare energie systemen. Zonnevolg algoritmen worden ook gebruikt in het modelleren van trigeneration systemen met behulp van Matlab Simulink (Modelica of TRNSYS) platform, alsmede in automatisering en controle van hernieuwbare energiesystemen door middel van intelligente parsing, multi-objective, adaptief leren en controlepaneel optimalisatie strategieën.

Zonnevolg algoritmen toepassing bij de ontwikkeling van zonne-modellen voor het land of de locatie specifieke zonne-studies, bijvoorbeeld op het gebied van het meten en analyseren van de schommelingen van de zonnestraling ook vinden (dwz directe en diffuse straling) in een bepaald gebied. Solar DNI, zonnestraling en atmosferische informatie en modellen kan dus worden geïntegreerd in een zonne-kaart, zonne-atlas of geografische informatiesystemen (GIS). Dergelijke modellen zorgt voor het definiëren van de lokale parameters voor specifieke regio's die waardevol kan zijn in termen van de evaluatie van de verschillende zonne in fotovoltaïsche van CSP-systemen op simulatie en synthese platforms zoals Matlab en Simulink of in lineaire of multi-objective optimalisatie algoritme platforms zoals COMPOSE , EnergyPLAN of DER-cAM.

Een dual-as solar tracker en single-as solar tracker kan een zon tracker programma of zon tracker algoritmes gebruiken om een zonne-schotel, zonnepaneel array, heliostat array, PV-paneel, zonne-antenne of infrarood zonne nAntennekabel positioneren. Een zelfsporende solar concentrator voert automatische zonne volgen door het berekenen van de zonne-vector. Solar positie algoritmen (TwinCAT, SPA, of PSA Algoritmes) maken gebruik van een astronomische algoritme om de positie van de zon te berekenen. Het maakt gebruik van astronomische software algoritmes en vergelijkingen voor zonne volgen in de berekening van de positie van de zon in de hemel voor elke locatie op aarde op elk moment van de dag. Zoals een optische zonne-telescoop, de zonne-positie algoritme pin-points de zonne-reflector aan de zon en sluizen op de positie van de zon aan de zon langs de hemel volgen als de zon gedurende de dag vordert. Optische sensoren zoals fotodiodes, zijn licht-afhankelijke weerstanden (LDR) of fotoweerstanden gebruikt als optische precisie feedback apparaten. De laatste tijd opgenomen we ook een sectie in het boek (met links naar microprocessor-code) over de manier waarop de pixart Wii infraroodcamera in de Wii-afstandsbediening of Wii-afstandsbediening kan worden gebruikt in de infrarood zonnevolg toepassingen.

Om vrije energie te oogsten van de zon, een aantal automatische zonne-positioning systemen maken gebruik van een optische middelen om de zonne-tracking-apparaat te sturen. Deze zonne-energie volgen strategieën te gebruiken optische tracking technieken, zoals een zon sensor middel, om directe zonnestralen op een silicium of CMOS substraat om de X te bepalen en Y-coördinaten van de positie van de zon. In een zonne MEMS zon-sensorinrichting, invallend zonlicht komt de zonnecel door een klein pin-hole in een maskerplaat waar het licht wordt blootgesteld aan een silicium substraat. In een web-camera of camera beeldverwerking volgen van de zon en de zon volgende middelen, voert object tracking software multi-object volgen of een bewegend voorwerp volgen methoden. In een zonnevolg object techniek beeldverwerking software voert rekenkundige bewerking om de omtrek van het zichtbare zonneschijf of zon blob in de opname lijst box, terwijl zon-lokalisatie wordt uitgevoerd met een randdetectie-algoritme om de zonne vector coördinaten bepalen.

Een geautomatiseerd positioneringssysteem helpen maximaliseren van de opbrengsten van zonne-energiecentrales door zonne-tracking-instelling om energie zon te benutten. In dergelijke systemen voor hernieuwbare energie, het zonnepaneel positionering systeem maakt gebruik van een zon volgen technieken en een zonne-hoek rekenmachine in de positionering van PV-panelen in fotovoltaïsche systemen en geconcentreerde fotovoltaïsche CPV-systemen. Automatisch op-as solar bijhouden in een PV zonne-tracking systeem kan twee-assige volgen van de zon of single-as zon zonne volgen zijn. Het is bekend dat een gemotoriseerd positioneersysteem in een fotovoltaïsch paneel tracker toename energieopbrengst en zorgt voor meer vermogen, zelfs in een enkele as zonnevolg configuratie. Andere toepassingen zoals robot solar tracker of robotic zonnevolg maakt gebruik van robotica met kunstmatige intelligentie in de controle optimaliseren van de energie opbrengst zonne oogst door een robot volgsysteem.

Automatische systemen voor plaatsbepaling in zonnevolg ontwerpen worden ook gebruikt in andere vrije energie generatoren, zoals geconcentreerde zonne-thermische energie CSP en gerecht Stirling systemen. De zon tracking device in een zonnecollector in een solar concentrator of zonnecollector Zo'n presteert op-as solar tracking, een dual-as solar tracker helpt om energie te benutten van de zon door middel van een optische zonnecollector, die een parabolische spiegel kan zijn, parabolische reflector, Fresnel-lens of spiegel-array / matrix. Een parabolische schotel of reflector wordt dynamisch gestuurde behulp van een transmissiesysteem of zonnevolg hoop rijden betekenen. Bij het sturen van de schotel naar de zon, de kracht gerecht aandrijving en bediening betekent in een parabolische schotel systeem optisch richt de energie van de zon op het brandpunt van een parabolische schotel of zonne concentreren middelen. Een Stirlingmotor, zonne-heat pipe, thermosyphin, zonne faseovergangsmateriaal PCM-ontvanger, of een glasvezel zonlicht ontvanger betekent ligt in het brandpunt van de zonne-concentrator. De schotel Stirling motor configuratie wordt aangeduid als een schotel Stirlingsysteem of Stirling stroomopwekking. Hybride zonne-energie systemen (gebruikt in combinatie met biogas, biobrandstof, benzine, ethanol, benzine, aardgas of PNG) maken gebruik van een combinatie van energiebronnen aan te wenden en op te slaan zonne-energie op een opslagmedium. Elke veelheid van energiebronnen kan worden gecombineerd door het gebruik van controllers en de energie opgeslagen in batterijen, faseovergangsmateriaal, aardwarmte opslag en in warmtekrachtkoppeling vorm omgezet in de gewenste stroom met thermodynamische cycli (organische Rankin, Brayton cyclus, micro turbine, Stirling) met een omvormer en laadregelaar.