# GPS based portable dual-axis solar tracking system using astronomical equation

**Article** · March 2015

DOI: 10.1109/PECON.2014.7062450



**7 authors**, including:

W. Z. Wan Hasan
Universiti Putra Malaysia


Zainal Kadir
Universiti Putra Malaysia


Suhaidi Shafie
Universiti Putra Malaysia


Mohd Amran Mohd Radzi
Universiti Putra Malaysia

# GPS Based Portable Dual-Axis Solar Tracking System Using Astronomical Equation

M.H.M Sidek, W.Z.W Hasan, M.Z.A.Ab. Kadir, S.Shafie, M.A.M.Radzi, S.A.Ahmad, M.H.Marhaban
Department of Electric and Electronic Engineering
Universiti Putra Malaysia
Serdang, Malaysia
*wanzuha@upm.edu.my

***Abstract*— The overall objective of this study is to design and develop a portable dual-axis solar tracking system that focuses on portable and mobility purpose. This paper discusses the design, electronic control system and the algorithm based on the astronomical equation. The tracking system utilizes the GPS module and a digital compass sensor for determining the location and the heading feedback of the system respectively. Moreover, the microcontroller based tracking system is embedded with a PID controller for which will increase the PV positioning accuracy based from the feedback signal of the absolute encoder. Furthermore, this paper also analyses and compares the performance between the fixed-tilted PV panel and the developed portable solar tracking system.**

***Keywords*— *portable solar tracker; dual-axis; GPS system; PID controller.***

## I. INTRODUCTION

In the years ahead the demand for energy will escalate, whereas the conventional fossil fuel energy will deplete in a rapid pace. Henceforth, harvesting the power from a renewable energy source is vital in order to fulfil the growing energy needs. Among all the available renewable energy sources, solar energy is the most abundant and available all year-round. In solar technology, the sun's energy is captured by using photovoltaic (PV) panel and converts the solar radiation into electricity. Additionally, PV technology is a fast growing technological progress that requiring very little maintenance with zero carbon foot-print. The performance of a PV panel is not only dependent upon the solar irradiance power, whether condition and the ambient temperature, but it also depends on the solar radiation's incidence angle to the PV panel [1].

During the day, the sun appears to move through the sky from east to west, therefore the angle between sun and a fixed PV surface is continually changing. Thus, the power density on a fixed PV module is less than that of the incident sunlight. Lately, there are many works have been taken in order to maximize the power extraction from the PV panel. Solar tracking system offers a practical technology solution to improve the power efficiency generated by the PV panel. Extensive research and experiment have shown that by maintaining consistent direct exposure from the sun to the PV module, the tracking system able to produce up to 40 percent more power over a fixed-tilted (non-tracking) PV panel [2].

Generally, solar tracker is device used for aligning a PV panel towards the sun. In this context, there are three types of solar tracking system, namely passive tracker, active tracker and open-loop tracker. Passive tracker uses two canisters filled with compressed gas fluid that placed each in the east and west of the tracking. However, this gas tracker rarely point the PV panel direct to the sun due to the unpredictable ambient temperature. Yet, as the advancement of sensor technology, light sensor is used in the active sun tracker system and it is placed at various locations at the tracker to determine the best sun position, which is done by tilting the PV panel using actuators. Nevertheless, cloud and shadow effect are the major drawback of the system. This consequence bring disadvantages because power is wasted to drive the tilting actuator back and forth for during its searching mode. Other than that, open-loop tracker is also commonly used for tracking the sun path as in Fig. 1. The tracker uses pre-determined astronomical database to determine the sun position for any given time and location's coordinate by using micro-controller or PLC. In addition, the open-loop tracker is based on the altitude and the azimuth position of the sun, therefore, this system is not dependant to the ambient temperature and weather. This circumstances gives great advantages, such that it will not eliminates unwanted power dissipation and complexity. Conversely, the open-loop tracker also has demerits that could reduce the efficiency output, as an instance, tracker's misalignment during setup due to human error. Besides, before the deployment of the solar tracker, solar path database is set manually by the supplier or contractor. As we all know, every location has its unique solar path, thereupon, it will involve extra man power that will increase the installation or setup cost.

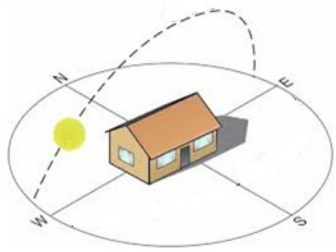


Fig. 1. Sun path trajectory.

Also, the mechanical system design will varies. Typically, some may use a simple single-axis tracker 20 percent that has better energy gain than the non-tracking PV panel [3].

Likewise, some may even use the dual-axes tracker system that gives clearly 70 percent better energy gain compared to the non-tracking PV panel [4].

This research aims to design and develop a global dual-axes solar tracking system based on open-loop astronomical equations. The research will emphasize on the algorithm to generate a solar path trajectory database by utilizing the information acknowledge from the Global Positioning System (GPS) sensor module. Moreover, the algorithm will also cater all location, season and environment globally. PID control algorithm for positioning the PV panel is also intensively highlighted. On top of that, the research will fuse and combine all the developed sub-system into a single free-interface and easy to set-up solar tracking system controller board. This research also compares the power efficiency of the developed solar tracking system controller board and a non-tracking system under the same location and environment.

## II. Solar Tracking Angles

The main objective of the research is to maximize the PV power generation; this can be archived by minimizing the solar radiation's incidence angle to the PV panel. Due to this factor, the solar tracker needs to follow the sun accordingly to maintain the incidence angle to ideally zero degree. It is a common knowledge that the sun position in the sky changes from day to day and from hour to hour. For that reason, the exact location of the sun in the sky is specified by two angles; the altitude angle and azimuth angle as in Fig. 2.

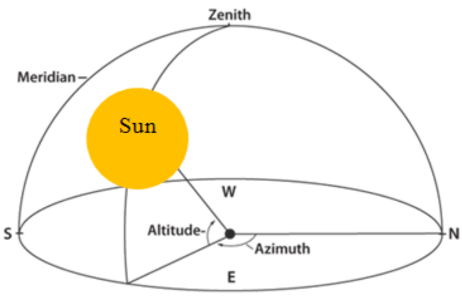


Fig. 2. Azimuth and altitude angle.

The altitude angle is defined as the angle from the horizon of the observer to the sun, perpendicular to the horizontal plane. The value is 0 degree and 180 degree at sunrise and sunset respectively. Whereas, the Azimuth angle is measured clockwise from true north to the point on the horizon directly below the sun.

## III. Solar Position Geometry

In this work, the solar tracking system tracks the sun based on astronomical equations, or in other word, the tracker does not actively find the sun's position but instead determines the position of the sun as in (1) and (2). The sun position which is described in terms of its altitude and azimuth angle that is depends on the day number, d (from 1st January) in (3) and the time of day, T in (9) that is derived from the following equation.

$$Azimuth = \cos^{-1}((\sin\delta.\cos\emptyset - \cos\delta.\sin\emptyset.\cos\partial)/\cos\alpha) \quad (1)$$

$$Altitude = \sin^{-1}(\sin\delta.\sin\varphi+\cos\delta.\cos\varphi.\cos\partial) \quad (2)$$

$$B = 360/365\ .\ (d - 81) \quad (3)$$

$$\delta = 23.45°.\ \sin B \quad (4)$$

$$\partial = 15°.\ (LST - 12) \quad (5)$$

$$LST = LT + TC/60 \quad (6)$$

$$TC = 4(Longitude - LSTM) + EoT \quad (7)$$

$$Eot = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B) \quad (8)$$

$$LSTM = 15°.\ \Delta T_{GMT} \quad (9)$$

The azimuth angle of the system is based on the true north bearing system for its heading reference. Nonetheless, the tracking system utilize digital compass sensor which is using magnetic north bearing system. The difference angle between the true north and the magnetic north is called the magnetic declination angle that varies from place to place. In order to get the true north direction for the system's heading reference; the raw data must be added with the location's declination angle as in (10). The global declination angle information is provided from a database generated from the National Geographical Data Centre that has been embedded in the solar tracking system.

$$TrueNorth = MagneticNorth + DeclinationAngle \quad (10)$$

## IV. Solar Tracker Design

The position of the PV panel is controlled using the solar tracking system for maximizing the energy harvested from the sun anywhere. The solar tracker is the integration between mechanical, electronic control system and its algorithm.

### *A. Mechanical Structure*

In order to test and evaluate the algorithm and controller performance, a tracking mechanism design has been modelled first using mechanical design software, SolidWorks. The overall structural design of the biaxial solar tracking system is shown in Fig. 3. The design of the solar tracker incorporated several distinctive features: easy to assemble and dismantle, lightweight and manually portable. The overall weight of the tracking part excluding the solar panel is only 5.83 kg.

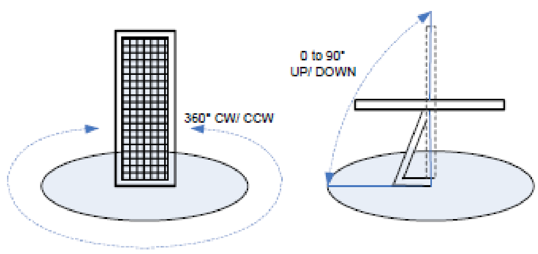


Fig. 3. Structure of the solar tracker

Two actuators are placed at the edge of circumference for azimuth and altitude tracking that can rotate 360 degree and tilting 90 degree respectively. For azimuth and altitude angular feedback, two 10-bit absolute encoders are mounted at the azimuth and altitude's rotation centre. Unlike other position sensor such as linear encoder and potentiometer, the absolute encoder gives advantage because it requires no previous traverse to provide the current position value and rotate freely in 360 degree range. Single turn encoders provide the current angular position value within one revolution.

### *B. Control System Design*

Electronic control system is design to give an accurate control signal to the mechanical system in order to get maximum power generation from the solar PV, and it is reliable with low power consumption. The electronic control system is shown in Fig. 4.

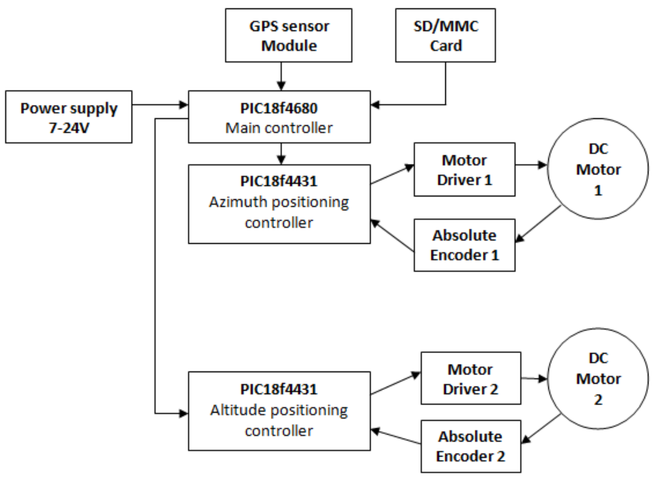


Fig. 4. Electronic control system block diagram of the solar tracking system.

The solar PV movement is control by using a PIC18f4680 microcontroller that act as the system's main brain. The main system is designed to complete the calculation and generate the database of the sun's path trajectory throughout the year for a particular site. Here, the generated sun position database is stored in a non-volatile 2GB memory card. The location of the solar tracker is determined by using a global positioning system receiver module (GPS), which uses multiple orbiting satellites to calculate its position. The GPS module is connected to the microcontroller via a standard serial RS-232 port, that continuously sends to the microcontroller sentences which contain a string of characters. These sentences mainly include longitude, latitude, altitude, date and time for current location to be used for the database generation. Moreover, a digital compass sensor module also interfaced to the main microcontroller via the two wired I2C communication protocol. The compass sensor measures the earth's magnetic field and outputs a value that provides a feedback on the heading of the solar tracker with respect to the magnetic north.

Additionally, two more PIC18f4431 microcontrollers are also implanted in the solar tracker electronic circuit. These two slave microcontroller is used to control the PV's azimuth and altitude angular movement independently. The position of the PV is control based from the information or the set point which is sent from the main microcontroller by utilizing the I2C communication protocol. In addition, these slave microcontrollers are also embedded with a PID controller, which will increase the PV positioning accuracy based from the feedback signal of the absolute encoder. The absolute encoder is interfaced to both slave microcontrollers via 10-bit grey-code digital parallel port.

### *C. Tracking System Algorithm*

In this context, the developed sun tracking algorithm allows determination of sun angles and times for solar noon, sunrise, and sunset with high-precision year-round. The calculation of the sun angles with the sun tracking algorithm software requires the specification of the date, time and precise longitude and latitude of the location by using the GPS module. During the deployment of the solar tracker, the tracking system will initialized its heading with respect to the true north using the compass sensor. Then, the system will take the GPS information to calculate and tabulate the database for the sun position coordinate on the sky for the whole year. Next, the tracking system will control the PV position based on the tabulated database of the sun angular movement. This algorithm allows the tracker to follow the sun movement closely in one degree of difference for both altitude and azimuth angle during the day. For the altitude motion control, the motor will actuate the panel up from sunrise until noon, and bring the panel down to the original position in the sunset. At the same time, the azimuth motion control will rotate the panel either in clockwise or counter-clockwise. Contrary to this, at night, the electronic system will be in a sleep mode that allows the reduction of the power consumption. Fig. 5 shows the tracking system's algorithm summary.

PID controller is also implemented into the system algorithm that is embedded in both slave microcontrollers. The PID controller makes the PV panel rotates to its desired set point with fast response and high accuracy. The value of $k_p$, $k_i$ and $k_d$ is ascertain by using trial and error method.

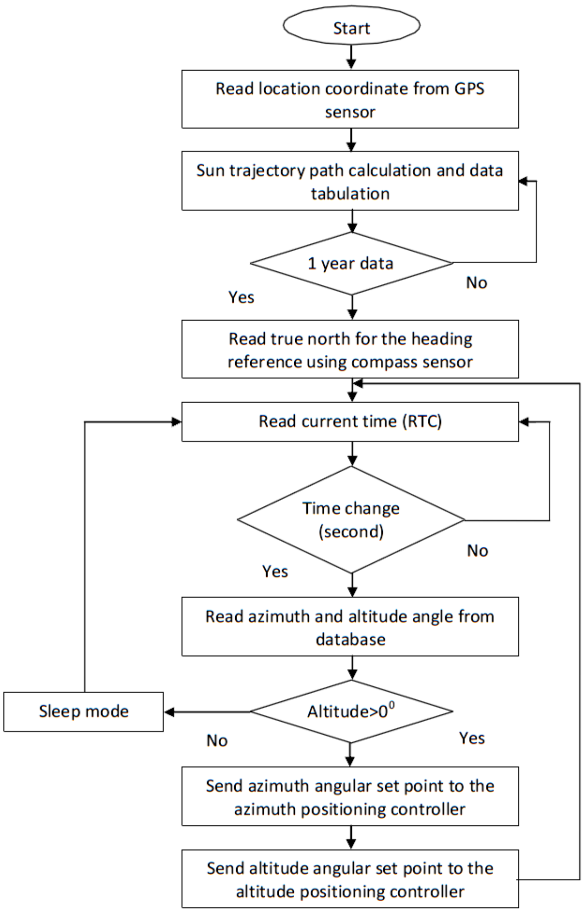


Fig. 5. Flow chart of the solar tracking system algorithm.

## V. EXPERIMENTAL SETUP

The performance of the solar tracker is assessed by comparing the power generated between the fixed-tilted PV panel and the developed solar tracking system as in Fig. 6. The fixed-tilted PV panel is set to the position that will generate the maximum power of the specific day. The maximum power is generated during the solar noon whereas the sun is located at the highest positions above the horizon on the day. Both systems are deployed at an open area in Serdang with the coordinate of 3.00 North and 101.72 East. The power generated from both systems is recorded using a data logger simultaneously for every minute from 7am to 8pm.

Fig. 6. Data collection setup of two systems.

Fig. 7 and Fig. 8 shows the daily variation of the PV panel output power generated for the fixed-tilted and the tracking system. The data recorded on the Fig. 7 proved that the solar tracking system produced 27% more energy than the fixed-tilted PV panel during a mostly clear day. During a cloudy day, the tracking system also produced more energy than the fixed-tilted PV about 19% as in Fig. 8. Henceforward, the tracking system gives very significant difference in power generation during morning and evening if compared to the fixed-tilted system.

Obviously, the power generated from both tracking and non-tracking is reduce during the cloudy condition that block the sun irradiation. This is because the amount of power produces is directly dependent on the received level of light.

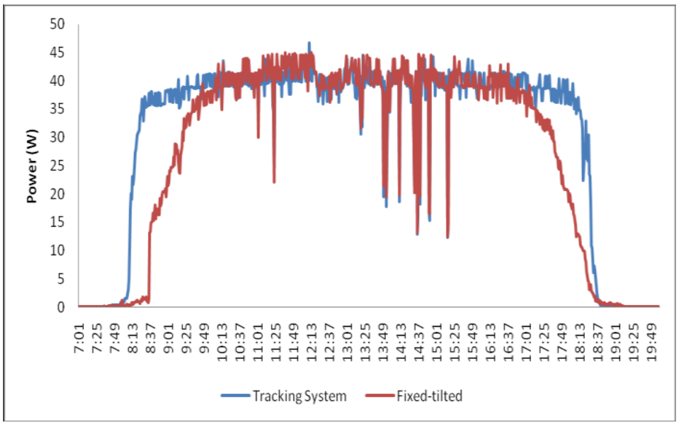


Fig. 7. Power generation on mostly clear day.

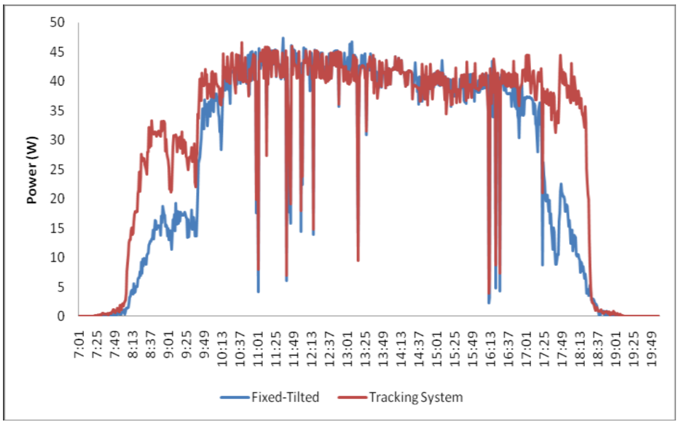


Fig. 8. Power generation on a cloudy day.

## VI. CONCLUSION

In conclusion, it is clear that the solar tracking system plays an important role to guarantee the maximum solar energy generation from dawn until dusk. The solar tracker's control system successfully calculates and generates the sun's trajectory path through the year. Moreover, the tracker also capable to position the PV panel towards the sun automatically during deployment or initial set up. In addition, the embedded PID positioning system will improve the tracking angle accuracy in locating the elevation and azimuth angle up to ± 0.2 degrees.

The simplicity, practical, and the effectiveness of the solar tracking system provides a lucrative solution mobile solar power generation purpose that can be deployed anywhere on the surface of the earth.

## References

[1] J. Shi, W.J. Lee, Y. Liu, Y. Yang, W. Peng, “Forecasting Power Output of Photovoltaic Systems Based on Weather Classification and Support Vector Machines,” in IEEE Transactions on Industry Applications, Jun. 2012, Volume: 48, Issue: 3, pp. 1064–1069.

[2] C. Sungur, “Multi-axes sun-tracking system with PLC control for photovoltaic panels in Turkey,” Renewable Energy, vol. 34, pp. 1119-1125, 2009.

[3] A. Al-Mohamad, “Efficiency improvements of photo-voltaic panels using a Sun-tracking system,” Applied Energy, vol. 79, pp. 345-354, 2004

[4] A.N. Khalifa, S.S. Al-Mutawalli. Effect of two-axis sun tracking on the performance of compound parabolic concentrators. Energy Conversion and Management, vol. 39, pp. 1073- 1079, 1998