Effective and Low-Cost Arduino based Dual-Axis Solar Tracker

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Abstract. This paper presents research on dual-axis solar tracker utilizing solar irradiance most efficiently. The high cost is the main challenge in effectively harnessing solar technology due to the higher cost of materials and equipment for the system since the solar tracking device needs more equipment to manage the control system. The objective of this research is to design a dual-axis solar tracker using Arduino as the main component in the control system. In order to maximize the effectiveness of this work, the structure of the tracker is designed to accommodate the solar panels with minimal power consumption and cost. This research is focused on improving the full collection of output power from the solar panel using a tracking system. The experiment shows the performance comparison between the dual-axis solar tracker and a fixed tilted solar panel.

1. Introduction

Solar photovoltaic (PV) system is a system to convert the solar irradiance from the sun into electrical power. The solar panel, also known as PV panel, is made up from commonly silicon semiconductor material used to convert the solar energy from the sun into direct current. The output power of the solar panels depends on the angle of incidence of the sunlight. For a fixed system, there is an optimal tilt angle that can be applied for the output power to be optimum [1-3]. Since the position of the sun varies throughout the day, the angle of incidence changes which affects the performance of the solar panel. Maximum power can be produced if the sun rays are perpendicular to the solar panel’s surface. Therefore, to align the panel perpendicularly to sunlight, the necessary setup has been carried out in the designed solar tracker system.

Basically, the solar tracker is a device used to track the sun irradiation so that it is aligned perpendicularly to the solar panel as the sun moves across the sky during the day from the sunrise until sunset. There are two angles involved, the azimuth and elevation angle which indeed corresponds to the dual-axis tracking method, while the system that involved single tracking only involved the elevation
angle only. The azimuth angle is given in Equation 1 \[4\] and elevation angle is shown in Equation 2 \[4\], where \(\theta\) is the hour angle, \(\phi\) is the latitude of the location and \(\delta\) represents the solar declination angle. Moreover, throughout the year, the sun’s position changes based on seasonal changes. Therefore, the position of the panel at noon in January will not be the same with noon in June. However, Malaysia, as a tropical country, receives abundant solar irradiation all year round and does not experience obvious four seasons, which indeed the position of the sun varies slightly at noon throughout the year. Figure 1 shows the sun chart of sun trajectory from December until June in Perlis.

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\text{Azimuth angle} = \tan^{-1}\left(\frac{\sin \theta}{(\cos \theta \sin \varphi - (\tan \delta \cos \varphi)}\right) \tag{1}
\]

\[
\text{Elevation angle} = \sin^{-1}[\sin \delta \sin \varphi + \cos \delta \cos \varphi \cos \theta] \tag{2}
\]

**Fig 1:** Sun Chart diagram for December until June in Kangar, Perlis [5]

2. Dual-Axis Solar Tracker

This project focused on the development of dual-axis solar tracker, which uses the Light Dependent Resistor (LDR) sensors as a tracking mechanism to follow the sun’s position called the closed-loop system [6]. Another method uses mathematical computation using the sun’s trajectory is called the open-loop tracking system [7-11]. This dual-axis solar tracker is more efficient from a single axis tracker in terms of collecting solar irradiation. This system uses a combination of resistors, capacitors, diodes and transistor to form a complete circuit. The output voltage from the circuit will supply power to the circuit that controls the motor movements and direction change based on which sensor receives a higher amount of solar irradiance and align the solar panel perpendicularly to the sunrays. In this work, the Arduino (ATmega328p) microcontroller programming will control the rotation of servo motor using a closed-loop tracking system that depends on the voltage differences between the LDR sensor based on the intensity of the solar irradiance.
2.1. Closed-Loop Tracking System

A sun-tracking system which generally uses sensors to detect the sun’s trajectory is called a closed-loop tracking system. The signal receives from the sensors is sent to the controller to drive the motor to the turning angle to collect the solar irradiance at the most optimal angle. By using a closed-loop tracking system, a stand-alone single-axis solar tracker can be designed by using the MATLAB/Simulink. Using MATLAB, this research is represented in the modelling and simulation of the photovoltaic system under a constant load. The PV stand-alone system consisted of a PV panel, servo motor, battery, light-dependent resistor (LDR) sensors, charger, load and a microcontroller. This tracker is designed to have a single axis rotation (East-West). The servo motor is mounted so that the tracker system can rotate freely. The intensity of solar irradiance would be sensed by the LDR sensors which would send the signal to the microcontroller to command the rotation of servo motor. This solar tracker is powered by the lead-acid battery, which has been powered up by the generated electrical energy from the PV panels using the charge controller [12].

Moreover, one axis with three positions of sun-tracking PV panel also can be built by using a closed-loop system which can be mounted on the wall of a building easily. This solar tracker is created to operate at three different angles. The solar tracker had involved with simple structural design and a DC motor to turn the photovoltaic mounting frame. Basically, the solar tracker could easily move as the IC timer was installed to provide time information signal in which would trigger the motor to turn at a turning angle. All the measuring features for this solar tracker motion and control algorithms were implemented using microcontroller PIC18f452 [13].

3. Method

3.1. Tracking System

The main working principle of this dual-axis solar tracker system is the orientation of the system. The tracking system uses the components as given in Figure 2, where the solar panel is aligned with the sun by controlling the servo motor using the signal from the Arduino as the main controller which receives input from the LDR.

![Fig 2: Block Diagram of the Solar Tracker System](image)

Initially, as the sun detected, the LDRs produce an analogue signal that will eventually send to Arduino Uno to be interpreted in digital signal form. This signal is then sent to the servo motor. The servo motor will act as the primary mechanism to decode the signal received from the Arduino by moving the solar panel perpendicularly to the sun. Figure 3 shows the flowchart of the program.
3.2. Structure Design

The structure design for the dual-axis solar tracker is made using inexpensive materials and equipment. Basically, the design of this structure proposed is to reduce the load that will be carried by the servo motor. This dual-axis solar tracker is divided into several parts. Each part will be permanently joined with light, inexpensive and durable metal holder. The base of the project is made out from a reusable plastic box which has a lowered centre of gravity to give more stability to the tracker. The solar panel is attached to a metal holder using a metal-carbon rod which has high durability and long-lasting. The metal holder is connected to the cylindrical plane in which is linked with motor 1 using metal screws. Motor 1 is attached to the cylindrical plan by making a 5 mm hole to place the motor gear. Motor 1 and motor 2 are responsible for controlling the movement of the tracker according to the solar irradiance obtained by the LDR sensors. The complete assembled dual-axis solar tracker is given in Figure 4.
3.3. Circuit

For the circuit of the tracker, four LDRs are used and connected to a 10 kΩ adjustable variable resistor. The connected load is connected to port A0, A1, A2 and A3 as given in Figure 5. below shows the circuitry design of this project. As the LDR sensors detect the solar irradiance from the sun, it will send the signal to the Arduino. The Arduino will analyze the signal as it sends the command to the motor 1 and motor 2 in which the data cables were connected at port 9 and port 10. The positive cable of the motor is connected to Vcc as the negative cable is grounded. The Arduino is installed in the control box and can be powered either using 6 V battery or external cable.
4. Results and Discussion

In comparison to a fixed tilted solar panel and dual-axis solar tracker using Arduino, the cost of tracking using Arduino is 20% higher than the fixed panel. For a tracker using other controllers, the price range could be much higher with the same performance. Therefore, solar tracker using Arduino is an effective and low-cost solution yet affordable dual-axis solar tracking. From the result, it is shown that dual-axis tracking shows better performance than a tilted panel. The experiments are done in May, in Universiti Malaysia Perlis, Pauh with the latitude of 6.45° and longitude of 100.34°. All recorded data are collected from 7.00 am until 7.00 pm.

The comparison between the fixed tilted and dual-axis solar tracker are given in Figure 6, Figure 7 and Figure 8, while the percentage difference of the power collected from both systems are shown in Table 1.

![Graph showing comparison between fixed tracker and dual-axis tracker](image)

**Fig 6:** Comparison Output Power vs Time Day 1

For Day 1 and Day 2, these days experienced clear day throughout the day. But, Day 3 experienced slight cloudy during the day. Therefore, it is observed that the graph of power collected in Day 3 experienced many power drops. However, when compared to the fixed tilted, the dual-axis tracking shows better improvement than the fixed tilted by 53.275%. Meanwhile, during the clear day in Day 1 and Day 2, the power collected are very high for both panel, which displays a small improvement for dual-axis tracker of 15.934% and 21.646%, respectively as given in Table 1. This scenario shows that dual-axis tracking is more useful during cloudy days.
Fig 7: Comparison Output Power vs Time Day 2

Fig 8: Comparison Output Power vs Time Day 3
Table 1. Power collected for both systems

|                  | Power (Wh) collected |        |        |
|------------------|----------------------|--------|--------|
|                  | Day 1                | Day 2  | Day 3  |
| Fixed tilted     | 65.971               | 60.124 | 34.044 |
| Dual-axis tracker| 76.483               | 73.139 | 52.181 |
| Percentage difference | 15.934%   | 21.646%| 53.275%|

5. Conclusions
In conclusion, the cost of dual-axis solar tracker is affordable and can be easily implemented. From the obtained information, the price for the dual-axis solar tracker is slightly high from the fixed tilted solar panel. However, the collection of the output power for the solar tracker is more efficient than a fixed tilted solar panel. Overall, the average output power generated from the solar tracker is 5.2724 W per hour. From the collected data, the output power from dual-axis solar tracker is nearly 16% better than the fixed tilted solar panel on a clear day. In contrast, during cloudy days, the improvement percentage is higher, with approximately 53%. Therefore, dual-axis solar tracker using Arduino could be the preferable method compared to the fixed tilted solar panel as the solar tracking system can effectively capture solar energy.

Acknowledgements
The authors would like to acknowledge and thank the Faculty of Electrical Engineering Technology (FTKE), Universiti Malaysia Perlis for the funding of this publication.

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