Development of A Single-Axis Solar Tracker in Malaysia

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Abstract: The performance of solar photovoltaic systems can be improved if solar modules are kept perpendicular to the direction of solar radiation. Therefore, an accurate solar tracker system is important to continuously orientate solar modules to be always perpendicular to the solar radiation throughout the day. This paper presents the development and testing of a self-adjusting single-axis solar tracking system using two photovoltaic cells as photosensors. A prototype of the single-axis solar tracking system is built and tested based on continuous tracking method to the sun's position throughout the day. An Arduino UNO microcontroller, a servo motor, and photovoltaic cells are selected as the components of the prototype. As this is an active tracking system, the orientation of the tracker receiver surface depends on the feedback received from the photosensors. Outdoor tests were carried out under clear skies at Kota Damansara, Malaysia (3.1467512 N, 101.5740615 E). The tracking inaccuracy is less than 5% with the maximum being 4.12%.

Keywords: photovoltaic, active tracking, Arduino, solar energy, solar tracked

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1. Introduction

Over the years, researchers have developed solar trackers to maximize energy generation. Before the introduction of solar tracking methods, fixed solar modules were positioned with a reasonable tilted angle based on the latitude of the location (Helwa et al, 2000; Jacobson and Jadhav, 2018). In general, most solar photovoltaic (PV) farms around the world are installed with rows of solar modules in a fixed position. This is mainly due to lower cost and minimal maintenance at the site since there are no moving parts in the solar PV farm. As the earth revolves around the sun, a fixed solar module is unable to face the sun throughout the day (Chong K.K. et al, 2009; Sinha, Das and Singha, 2015). As a result, the solar module doesn't receive maximum daily insolation.

A solar tracking system continuously orients PV modules towards incident rays of the sun. A solar tracking system dynamically places PV modules in an optimal position which faces the sun, to receive maximum irradiance thus maximizing output power. The solar tracking system optimizes the angle of incidence to increase electrical energy output. Solar tracking systems are largely categorized in two groups due to the different principles of operations and are further divided into subgroups by the similarities and differences between the techniques. The two groups are passive and active tracking systems. Passive solar trackers depend primarily on solar thermal input for effective tracking without requiring external power supply (Amelia et al, 2019).

On the other hand, active solar trackers use an assembly of motors, sensors, drivers, and controllers to keep PV modules in sync with the trajectory of the sun (Suneetha Racharla and Rajan, 2017). An external power supply is necessary to operate the motors in active solar trackers. In active tracking or continuous tracking, the position of the sun in the sky during the day is continuously determined by sensors. The sensors will trigger the motor or actuator to move the mounting frame so that solar panels will always face the sun throughout the day. Active tracking systems could be primarily grouped into two, namely single axis and dual axis tracking systems. The former follows the sun in a single plane from east to west whereas, the later goes a step further tracks the sun in the north-south direction as well (Mustafa et al, 2018). To track the sun's movement accurately dual axis tracking system is necessary. The active/continuous tracking system tracks the sun for light intensity variation with precision. Hence, the power gain from this system is very high (Siaw and Chong, 2013). To achieve this power gain the system uses two motors continuously for two different axes. As a result, the system consumes extra power compared to time-based tracking system (Flores-Hernández et al, 2019).

To reduce power losses, a self-adjusting single-axis tracking system is proposed as a suitable alternative to this system to reduce the motor power consumption while tracking with acceptable accuracy. This study presents a single-axis tracking system that is controlled by an Arduino UNO microcontroller. The system is driven by a servo motor to keep and maintain the position of solar PV system throughout the day. A prototype is developed and evaluated under clear sky and cloudy conditions to verify the performance of the system.

2. Methodology

The main elements of a solar tracking system are the sensor unit, control unit, movement adjusting unit, and tracker frame. The proposed self-adjusting single-axis solar tracking system comprises of Arduino UNO microcontroller, servo motor, solar module that is installed on the tracker, and two solar cells as sensing devices (**Figure 1**). Microcontroller is the main control unit of the solar PV tracker. Output from the two solar cells will be channelled to the microcontroller as input signal and this determines the direction of movement for the tracker. The base programming language of the Arduino UNO microcontroller is C programming language and can be extended on C++ language compilers. The microcontroller ATmega328P is at the core of the Arduino UNO. The board has 14 digital input-output ports, labelled as 0 to 13. It also capable of accepting 6 analog inputs, which are labelled as A0 to A5.

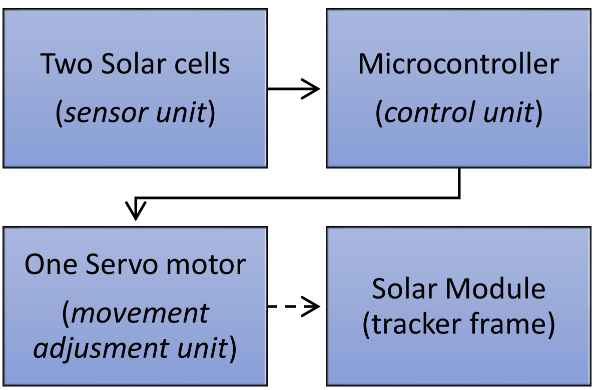

Figure 1. Block diagram of the single-axis solar tracker

Two solar cells are placed at the opposite ends of solar tracker frame to act as photosensors. They are used for measuring light intensity and generating corresponding analog voltage signals into the input pins of the analog to digital converter of the microcontroller. The voltage readings are taken continuously in real time and compared to check for differences. In the case when voltage readings are the same, it implies that solar irradiation is equally received on both opposite ends of the solar tracker. Therefore, motor operation will pause at that position until the next readings are received.

The motor used for this study is a micro servo with a simple potentiometer that functions as its position sensor. Apart from the potentiometer, other components of the servo set are a mini DC motor, gears and a simple control circuit. Servo motor is chosen due to its high precision and high torque characteristics which is achieved by the gears that are connected to the high-speed DC motor. In addition, the operating voltage of the motor is low and can be accommodated by the Arduino UNO without needing additional power supply. The output from microcontroller is sent to the motor driver which executes the proper sequence to turn the stepper motors in the required direction.

The initial position of the solar module horizontal, which is parallel to the base. This translates to a 90° neutral position of the motor. If the voltage of the sensor on the right is greater than for the solar sensor cell on the left, the motor would rotate in the clockwise direction heading towards 0° position (**Figure 2**). On the contrary, if the voltage of the left cell is higher than that of the right one, the module would be rotated counter- clockwise with the motor closing on to the 180° position.

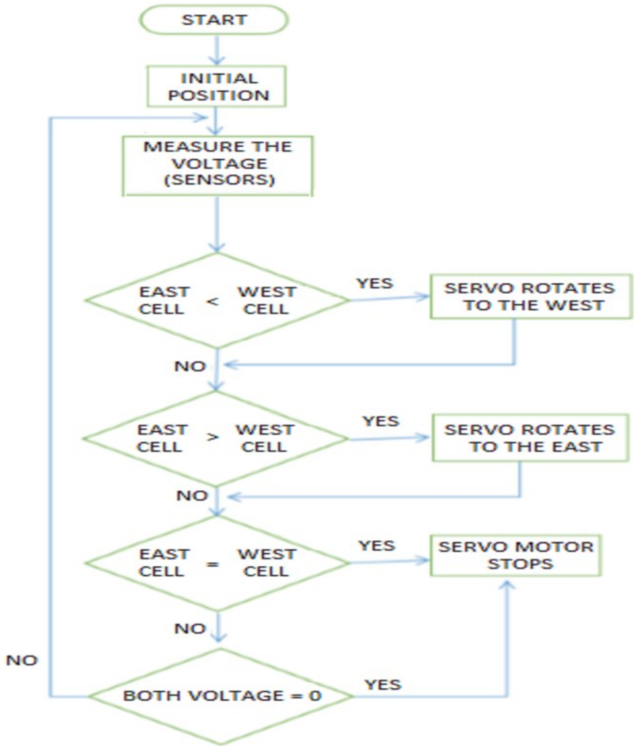

Figure 2. Flowchart of the software program

3. Results and discussion

Data collection is necessary to validate the performance of the single-axis solar tracking system. Firstly, the prototype is tested under artificial light in a controlled environment room. The artificial light source is placed at different angles and the corresponding incidence angle of the solar tracker receiver surface is measured.

Subsequently, the solar tracking system is taken outside to be tested under clear-sky condition. The prototype is placed away from any shadings of trees and buildings. Solar elevation angles and the position of the sun are recorded. The two angles, angle of the tracker receiver surface and the solar elevation angle are compared and analysed.

3.1. Indoor results

The prototype is placed below an artificial light source while all other light sources are switched off in a dark room. The artificial light source is positioned at a predetermined angle facing the tracker receiving surface. The servo motor rotates the tracker frame in accordance to the position of light source and the prototype's tracking angles is recorded (**Table 1**).

Table 1. Motor angle readings from indoor testing

Artificial Light Source Position	Target Motor Angle	Recorded Prototype Motor Angle			Average Prototype Motor Angle	Inaccuracy (%)
		A	B	C		
75°	165	165	165	166	165.3	0.18
60°	150	153	150	149	150.7	0.47
45°	135	133	136	134	134.3	0.52
30°	120	120	120	119	119.7	0.25

The angle values in the table above are all with respect to bearing due north of the centre of motor axle. The artificial light source only moves in a single plane, stopping at intervals of 15° to obtain the corresponding motor angle values. The artificial light source mimics the east to west directional axis of the sun, ignoring its seasonal north-south deviation. It is important to highlight that human influence is not negligible in indoor testing, due to physical limitation in positioning of the artificial light source and the method of obtaining the readings manually. This leads to a margin of error, and thus the testing is repeated thrice to increase its accuracy. From Table 1, the maximum percentage of inaccuracy is 0.52%.

3.2. Outdoor results

All outdoor experiments are conducted under clear skies at Kota Damansara, Malaysia (3.1467512 N, 101.5740615 E). The prototype of self-adjusting single-axis solar tracker is placed under the sun, away from obfuscations such as buildings or trees (**Figure 3**). The Arduino UNO microcontroller is powered by a laptop computer via a universal serial bus (USB) cable.

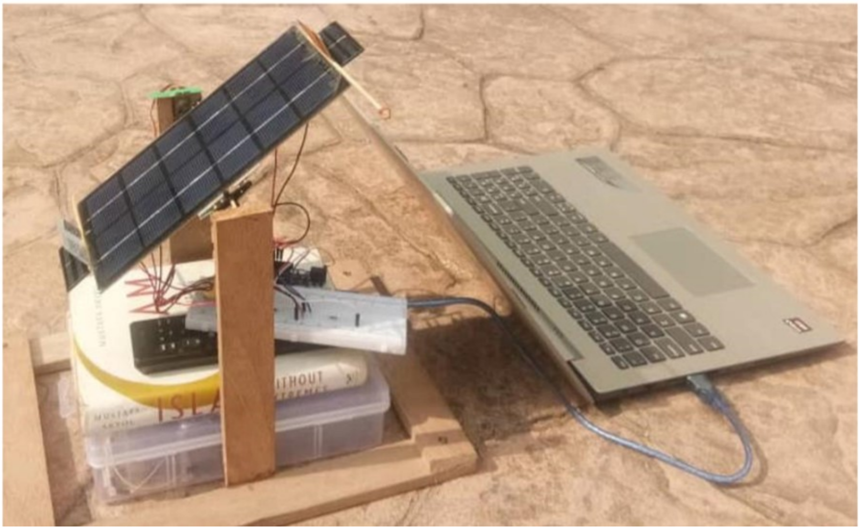

Figure 3. An implementation of single-axis solar tracker under outdoor condition

The angular tilt readings of solar module, mounted on the solar tracker receiving surface, is measured using Protractor App in a smart phone. The actual motor angle is compared to the ideal position at the time of measurement to validate the accuracy of the tracker. The ideal motor angles are calculated using azimuth and zenith angles obtained via a series of mathematical calculations. This is done by inputting parameters such as the location (latitude and longitude), date and time zone into an online Keisan Casio solar elevation angle calculator. The website produces a table consisting data of elevation angle against time, at intervals of 15 minutes. The outdoor tests were conducted on 8th of April 2019 from 15.00 to 18.00 hrs, at longitude 101.577 degrees East and latitude 3.148 degrees North which is in the 8th hour time zone. A comparison table of ideal motor angles and actual motor angles is presented in **Table 2**, and the two angles are compared to obtain the percentage error. The error increases as the sun proceeds to set and this could be attributed to the photovoltaic module in a more upright position, causing an uneven weight distribution that would in turn affect motor operation.

Table 2. A comparison table of ideal motor angles and actual motor angles

Hour: Minute	Elevation Angle (Degrees)	Azimuth Angle (Degrees)	Ideal Motor Angle (Degrees)	Actual Motor Angle (Degrees)	Percentage Error (%)
15:00	63.74	279.74	153.74	152.5	0.81
15:15	60.04	278.82	150.04	150.6	0.37
15:30	56.34	278.14	146.34	147.1	0.52
15:45	52.63	277.64	142.63	142.8	0.12
16:00	48.92	277.25	138.92	140.1	0.85
16:15	45.20	276.97	135.20	135.5	0.22
16:30	41.49	276.76	131.49	130.8	0.52
16:45	37.77	276.76	127.77	128.2	0.37
17:00	34.05	276.51	124.05	124.9	0.69
17:15	30.34	276.45	120.34	119.5	0.70
17:30	26.62	276.44	116.62	118.1	1.64
17:45	22.90	276.45	112.90	114.5	1.42
18:00	19.19	276.50	109.19	110.6	1.29

4. Conclusion

In this paper, the development and testing of a self-adjusting single-axis solar tracker is presented. The solar tracker has one servo motor that follows the trajectory of the sun in the azimuth axis, which is the East to West direction. An Arduino UNO microcontroller board, a servo motor, and photovoltaic cells are selected as the main components of the prototype. Two solar cells are installed on the tracker as sensing devices that would measure the solar irradiation received on opposite ends of the solar tracker. Voltage measurements from both sensors become input for the microcontroller. The microcontroller compares both input data and directs the servo motor to rotate towards the sun by minimizing the incident angle on the tracker receiver surface to zero degrees.

As this is an active tracking system, the orientation of the tracker receiver surface depends on the feedback received from the sensors. Therefore, the precision of the tracking system relies on the sensitivity of the solar cells. Since the prototype is relatively small, the deviation of voltage on the solar cells is minimal. Therefore, a cardboard obfuscation of similar dimension to the photovoltaic cells is fixed at an angle of 90° between the tracker receiver surface and each sensor. This increased the sensitivity of the solar cells and an overall improvement in reaction time of the tracking system.

In this study, indoor tests concentrated on the azimuth axis because the artificial light source moved in a single plane. On the other hand, outdoor tests were carried out under clear skies at Kota Damansara, Malaysia (3.1467512 N, 101.5740615 E). The tracking inaccuracy is below 5% with the maximum being 4.12% and minimum of 0.12%.

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