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Analysis of an Arduino based solar tracking system

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Abstract. The main purpose of this research is to develop and evaluate a solar tracking system which able to maximize the power output of the solar panel. The design of the solar tracking system consists of some electronic components such as an Arduino Uno R3 microcontroller, four light-dependent resistors (LDRs), two servo motors, and one solar panel. The Arduino microcontroller acts as the main controller of the whole system, light-dependent resistor is used as a light sensor to detect sunlight while the function of the servo motor is to rotate the solar panel to align with the sunlight. The prototype of the solar tracking system was build and tested. The data result obtained are tabulated and the comparison of performance between the static solar panel and solar tracking system is showed using the graphical method. As a result, solar panels with tracking mechanisms can generate more current, voltage, and power than static solar panels. The overall efficiency of the solar panel had increased after the implementation of the tracking system.

1. Introduction

Sun is one of the factors that allow all living creatures to live in this world. Due to the utilization of solar radiance from the Sun, solar energy is a renewable energy source that is pollution-free, eco-friendly, and requires minimal maintenance among all renewable sources. Two types of solar energy technologies are currently available, namely solar photovoltaic (PV) and solar thermal [1].

Photovoltaic solar technology is an elegant technology that directly converts sunlight into electricity using panels made of semiconductor cells. It is based on a natural phenomenon called the photoelectric effect, which is certain materials are absorbed incident radiation and emitted electrons to generate an electric current [2]. Photovoltaic solar panels are commonly installed on house rooftops as well as on solar farms.

Thermal solar power technology on the other hand centralizes sunlight using a receiver to heat transfer fluids such as gas, oil, or molten salt to a high temperature. After heated, the transfer fluid turns into steam, then convert into the form of mechanical energy by a turbine. The rotation of the shaft of the generator then produces electricity. This technology is suitable to those countries where has high solar irradiance level, such as Malaysia [3].

Although there has been significant development around solar energy technologies in recent years, there is still plenty of room for performance improvement in both design and applications aspects. As the position of the Sun keeps changing from east to west direction as the day progresses, stationary solar panels with fixed inclination angles have a limited performance since the power generation is relatively low since these solar panel surfaces are not perpendicular to the Sun most of the time. For these reasons,

the researchers are keen to develop a solar tracking system to optimize the performance of the photovoltaic system by assuring the tilt angle of a solar panel is always perpendicular to the Sun.

2. Methodology

2.1. Hardware implementation

This step involves material and component selection, hardware installation, and prototyping design. This project consists of using several electronic components to build up the solar tracking mechanism. The main components used are Arduino UNO R3, light-dependent resistor (LDR), servo motor, and solar panel. This section discusses the specifications of components used.

2.1.1. Arduino Uno R3

Arduino Uno R3 is based on the ATmega 328p microcontroller that can execute instructions in a single clock cycle, and the ATmega16U microcontroller that is managing the USB connection and ICSP bootloader. Arduino UNO R3 consists of 14 digital pins and 6 analog pins where there are 6 pins are used as Pulse Width Modulation (PWM) pins to control the speed of the motor.

2.1.2. Light-Dependent Resistor (LDR)

This device is commonly used in electronic circuit design where it can detect the presence of light. LDR is made from semiconductor materials such as cadmium sulfide (CdS) and lead sulfide, PbS [4]. It works on the principle of photoconductivity, where the resistance of LDR will be changed when detecting light. A significant drop in the resistance will occur when the level of light intensity increases [3].

2.1.3. Solar panel

The solar panel is an electrical device that can convert light energy from the Sun into electricity by the photovoltaic effect. Electrical parameters such as voltage, current, and resistance will be varying when the solar cell is exposed to sunlight.

Table 1. Specification of solar cell

Parameter	Detail
Type	0.33W 5.5V solar panel
Solar cell	Poly-crystalline solar cell
No. of cell	10 cells
Maximum power	0.33W
Voltage at maximum power	5.5V
Current at maximum power	80mA
Open circuit voltage	6.283V
Dimensions	60mm X 60mm X 3.0mm
Weight	10g

2.1.4. Servo motor

Servo motor is a type of motor that can rotate with high accuracy. It consists of a control circuit that provides feedback on the current position of the motor shaft, this feedback allows the servo motors to rotate with great precision. SG90 servo motor is selected to work in this project as it is relatively cheap

and able to be controlled by pulse-width modulation (PWM) pulse which is provided by the microcontroller.

Servo motor consists of 3 wires; two wires will be used for the power supply while one wire used for the signal that is to be sent from the motor control unit. Servo motor able manipulates with 5V to 6V power supply, it is normally able to give accurate control angle of 45º, 90º and 180º.

2.2. Hardware design

The solar tracking system is done by first receiving analog input values from LDRs. Input values received from the sensors are then processed by the Arduino UNO R3 microcontroller, where it will convert the analog values into digital signals using an internal Analog to Digital converter.

The digital PWM pulse is applied to move the servo motor and it will change the direction of the solar panel to the position of LDR which captured maximum light intensity. The position of LDR is divided into four positions, which are top-left, top-right, bottom-left, and bottom-right. Figure 1 shows the block diagram for the solar tracking system.
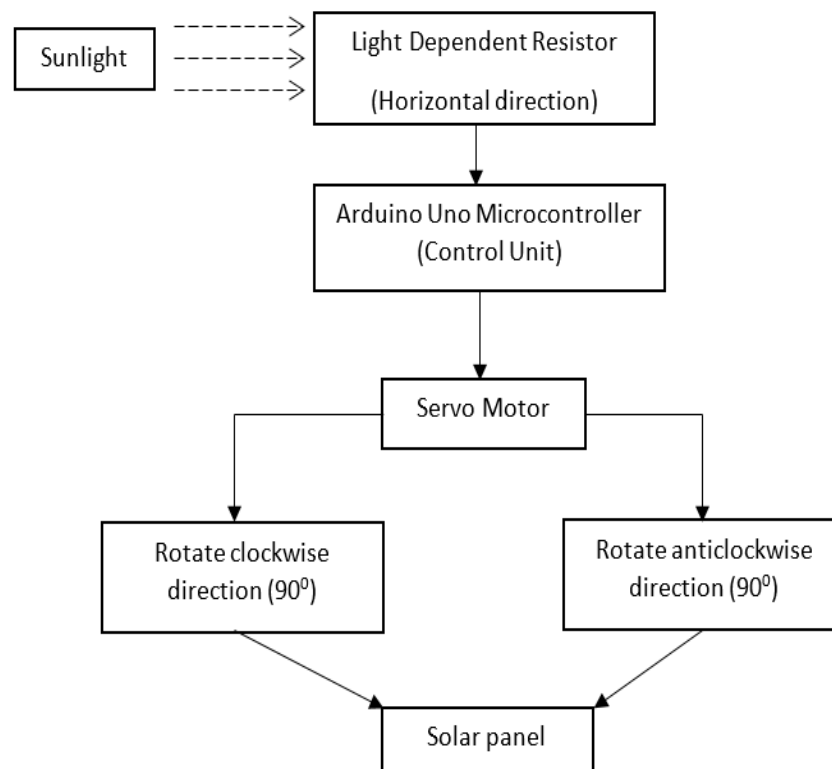

Figure 1. Block diagram for the solar tracking system

2.3. Software implementation

After the completion of hardware design, this project proceeds with software implementation. This section explained the circuit design of the solar tracking system by using LDR inputs to control the rotation of the servo motor. As mentioned earlier, this circuit consists of an Arduino UNO R3 microcontroller, 4 units of LDR, 4 units of 10 kΩ resistors, and 2 servo motors.

2.3.1. Algorithm of solar tracking system

The algorithm is constructed using Arduino programming. After the microcontroller receives the digital signals from ADC, then it will proceed to compute the average voltage of the corresponding LDR pairs.

The average value computed is used to determine what control signal send to the servo motor. Equations 1 until 4 show the average method that needs to be utilized.

$$The\ average\ value\ of\ the\ top\ part,\ Avg1 = \frac{Top\ left + Top\ right}{2} \tag{1}$$

$$The\ average\ value\ of\ the\ bottom\ part,\ Avg2 = \frac{Bottom\ left + Bottom\ right}{2} \tag{2}$$

$$The\ average\ value\ of\ the\ left\ part,\ Avg3 = \frac{Top\ left + Bottom\ left}{2} \tag{3}$$

$$The\ average\ value\ of\ the\ right\ part,\ Avg4 = \frac{Top\ right + Bottom\ right}{2} \tag{4}$$

2.4. Experimental setup

This section is explained about experimental setup and the mathematical method used to obtain the parameter of the solar panel. To improve the accuracy of the result, this experiment is held on outdoor and the venue to experiment must be a wide-open area. Thus, there would be no obstacles blocking the irradiance of sunlight. Furthermore, this experiment is conducted start from 9 a.m. to 6 p.m. to observe the performance of solar panels in different periods. After done with the experiment setup, the experiment is then started to collect data for analysis.

To discriminate the performance, power output, solar irradiance, and efficiency of the overall system will be determined in this experiment. The parameters of the solar panel such as voltage and current flow are measured using digital multimeters. For an electric element, the electric power is defined as the potential difference across the electric element multiple by current flow. Therefore, the power of solar panels is determined by using Equation 5:

$$P = VI \tag{5}$$

where P is the electric power of the solar panel, V is the voltage output, and I is the value of current.

Solar irradiance is known as the measurement of solar power and it is defined as the amount of electromagnetic radiation received from the sun per unit area [8]. Solar irradiance of solar panel can be calculated using Equation 6 below:

$$E = \frac{P}{A} \tag{6}$$

where E is the solar irradiance, P is the electric power of the solar panel and A is the surface area of the solar panel.

To compare the performance of the solar tracking prototype with the tracking mechanism and without the tracking mechanism, the efficiency of the overall system will be calculated using Equation 7 below [6].

$$\eta = \frac{Average\ Power\ (T) - Average\ Power\ (S)}{Average\ Power\ (S)} \times 100\% \tag{7}$$

Where η is the efficiency of the overall system, *Average Power (T)* is the average power of solar panels with solar tracking system and *Average Power (S)* is the average power of a static panel.

3. Results and Discussion

This section discusses the result that obtained from the conducted experiments. The experiments had done to compare the result between the static solar panel and solar panel with a tracking mechanism

towards the sunlight. The location for experiments is at the area of Universiti Malaysia Perlis main campus, which is located at latitude 6.46, longitude 100.35. The experiments were carried out on 29 May 2021 and 30 May 2021. All data and results are taken from 0900 hours until 1800 hours and the weather is in good condition.

3.1. Comparison results
This section discusses the comparison results obtained by the outdoor experiments. The voltages, currents, power outputs, solar irradiance, and the overall efficiency between the static solar panel and solar with tracking mechanism are tabulated and plotted in the time graph. The data recorded and calculated is given in Table 2.

Table 2. Comparison of output values between the static solar panel and solar panel with a tracking mechanism

Time (Hours)	Static Solar Panel				Solar Panel with a tracking mechanism			
	Voltage (V)	Current (A)	Power (W)	Solar Irradiance (W/m²)	Voltage (V)	Current (A)	Power (W)	Solar Irradiance (W/m²)
9.00am	4.30	0.025	0.11	29.86	4.80	0.050	0.24	66.67
10.00am	4.90	0.053	0.26	72.14	5.30	0.060	0.32	88.33
11.00am	5.57	0.057	0.32	88.19	5.56	0.058	0.32	89.58
12.00pm	6.17	0.050	0.31	85.69	6.17	0.050	0.31	85.69
1.00pm	6.03	0.049	0.30	82.08	6.03	0.051	0.31	85.43
2.00pm	5.98	0.042	0.25	69.77	5.98	0.043	0.26	71.43
3.00pm	5.29	0.021	0.11	30.86	5.91	0.042	0.25	68.95
4.00pm	4.21	0.019	0.08	22.22	5.36	0.043	0.23	64.02
5.00pm	4.03	0.015	0.06	16.79	4.63	0.039	0.18	50.16
6.00pm	2.14	0.003	0.007	1.78	3.66	0.016	0.06	16.27
	Total Power		1.82		**Total Power**		2.47	
	Average Power		0.18		**Average Power**		0.25	

Figures 2 and Figure 3 show some of the comparisons on the performance of the static solar panel and the solar panel with a tracking mechanism.
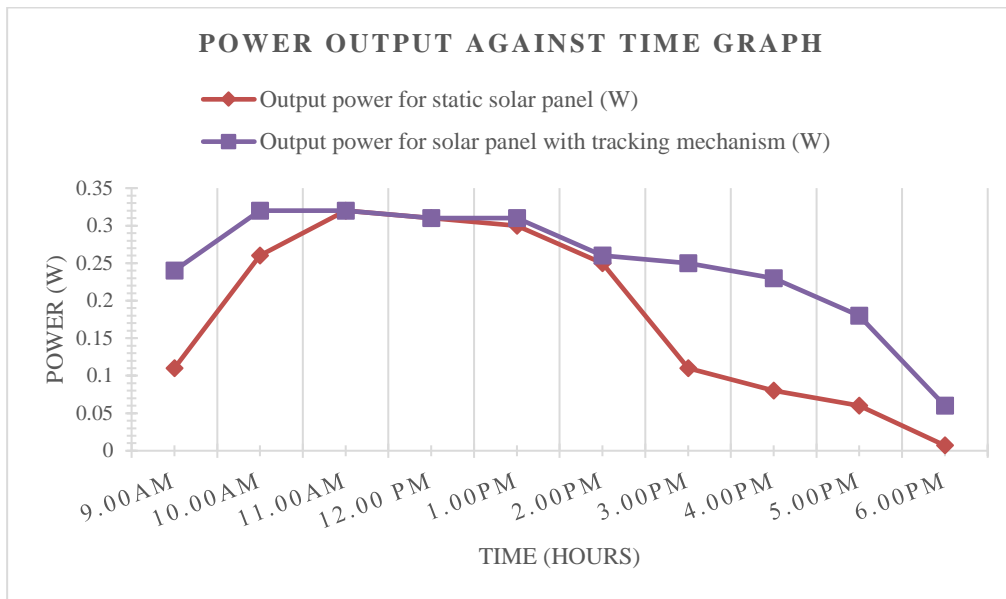
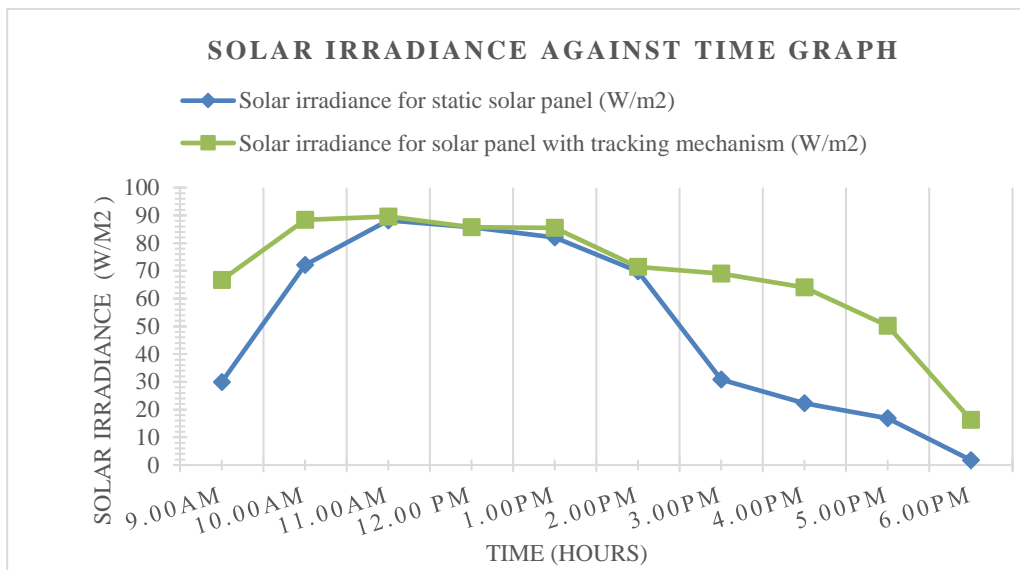**Figure 2.** Power output versus time comparison graph

Figure 3. Solar irradiance versus time comparison graph

3.2. Discussion

Based on the comparison graphs, solar panel with solar tracking mechanism has higher performance than static solar panel while there is a similar value from 11.00 am until 2.00 pm due to both solar panels are position horizontally, facing vertically upward and receive the same amount of radiation from the sunlight.

While conducting an outdoor experiment, some disturbances will affect the performance of the solar panel, one of the factors will be the weather condition during the time to collect data. There are different weather conditions such as rainy days, cloudy days, and sunny days in Malaysia. The performance of the solar panel would be affected on cloudy days, as the beam radiation of sunlight will be blocked by cloud and the solar panel may not be able to directly received diffused radiation from the Sun. This is

in agreement with what had been done by Lee et al. [7] and Vieira et al. [5], in which experimental studies had been conducted.

To compare the performance of solar panels with a tracking mechanism and static solar panel, a solar tracking prototype that was controlled by Arduino had been built. The hardware modeling of the solar tracking mechanism is referenced to the construction of the solar tracking structure discussed by Sujatha et al. [2]. An outdoor experiment had been conducted to measure the solar parameters and the result obtained is validated by comparing it with the previous model. Although the value compared is different, but comparison graph had demonstrated a similar trend which indicates the measured value is obtained in a correct path.

4. Conclusion

In this paper, a real-life prototype of a solar tracking system had built by using Arduino based controller. The design modeling is referenced to the mechanical construction of the solar tracking structure discussed by previous research. The prototype consists of a control system from the Arduino board, light-sensing from the light sensor, rotate mechanism from the servo motor, and a solar panel as the main component. To achieve the objective, an outdoor experiment is conducted to measure the parameter of solar panels and compare the performance of solar panels with a tracking mechanism and static solar panel.

Based on the result obtained, the performance of solar panels had an increased efficiency of 38.89% after being implemented with a solar tracking mechanism. It is proved the advantage of a solar tracking mechanism throughout the day as it can track the Sun's position compared with static solar panels. This allows the solar panel to absorb more solar irradiance to generate electricity, result in reducing the cost of electricity.

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