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Research Article

An Experimental Monitoring and Comparative Performance Evaluation of a Solar Tracking-Fixed System

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ABSTRACT

Solar technology has been widely used nowadays because the source of sunlight can be converted into electricity and used by humans on the surface of the earth. The National Energy Policy (NEB) acknowledges the increase in oil prices in 2015 and the global electricity crisis adversely affecting Malaysia, which is solely dependent on oil. In general, when harvesting solar energy can be done, another challenge that will be faced is the inefficiency of solar panel arrays, and insufficient sunlight sources due to weather factors to generate more electricity. To solve this problem, another approach is to build an automatic system that consists of solar panel tracking, Light Dependent Resistors (LDRs), microcontrollers, and servo motors that are used to detect sunlight throughout the day to allow the system to generate maximum electricity. It was found that the voltage output from the solar panel detection approach is higher when compared to the horizontal method which is a fixed solar panel. Therefore, the output generated from the built system will be distributed to the rural population for daily use.

Keywords: Light Dependent Resistors, Microcontrollers, Servo Motor, Tracking System

INTRODUCTION

The main purpose of this study is to find a solution to improve the performance of solar array panels by using solar trackers. The most important part of this study is the tracking mechanism that allows the movement and position of the solar array to increase the power output and reduce the losses in terms of cost. Electricity is a much-needed energy in any developing country in the world. From existing statistics as much as 85% of energy is taken from fossil sources. The effects of excessive use of fossil fuels will cause the world to heat up rapidly due to the release of gases into the atmosphere. Other sources such as solar, wind, and Bio-mass are still not popular to produce electricity in Malaysia. In the past five years ago, Malaysia has made strides in popularizing solar energy converted into electricity by using solar panels or Photovoltaic (PV) as shown in Fig.1

The solar efficiency of this panel will exceed 24% if the position of the solar panel is a high place. Not all solar panels can be placed in high locations due to geographical problems and installation costs. Therefore, solar tracking panels are recommended to track sunlight from sunrise to sunset. The solar panel tracking model is shown in Fig.2 to illustrate the operation of solar panel tracking.

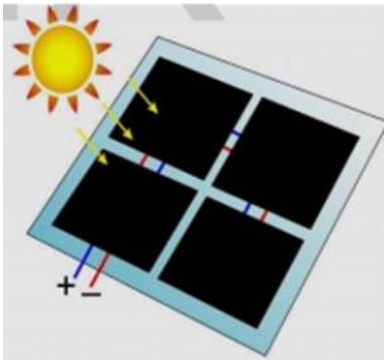


Figure. 1 Solar Panel

Based on this approach, it was found that solar panel efficiency can be optimized to 30% to 60% to generate electricity. Many parts will be used in designing the solar tracking systems such as LDR sensor, Microcontroller, and servo motor compared with the conventional approach, which is horizontal solar panels in a fixed state. Through this system, the solar panel will track the sunlight automatically throughout the day to produce more output voltage.

With the development of this system, this system can be installed in rural areas that do not have enough electricity. In general, solar panels that are placed permanently cannot generate much power because solar panels do not receive the full amount of sunlight compared to tracking solar panels. In this section, a summary of the scientific study from the main reference is explained below.

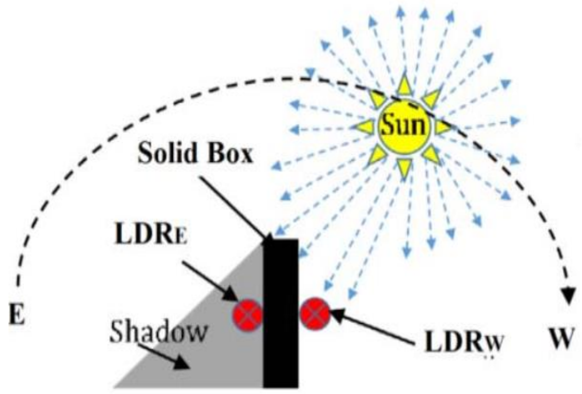


Figure. 2 Solar Tracking System Model

LITERATURE REVIEW

Prototype

The paper has described the experimental results for solar detector panels compared to fixed panels using microcontroller and LDR. The experimental readings were taken in different weather and days. Experimental results show that the efficiency of the detection system is better than the fixed system by 12.3% on sunny days and 4.9% on partly cloudy days. Unfortunately, there is a sharp drop in readings during cloudy weather. In terms of the total power output during clear weather, the total power output through solar tracking is more than 10.96% of the fixed system. The reading for total power output on a cloudy day is 4.63% higher than a regular system. Meanwhile, for cloudy days, the total power output is 3.4% less than the regular system. Therefore, the developed system is suitable for detecting sunlight in generating electricity. All the works were based on hardware where the circuits consist of microcontroller Arduino and LDR [1].

A Prototype Solar Tracking System Design and Implementation

This paper has described the experimental results for solar detector panels compared to fixed panels using micro control and LDR. The experimental readings were taken in different weather and days. Experimental results show that the efficiency of the detection system is better than the fixed system by 12.3% on sunny days and 4.9% on partly cloudy days. Unfortunately, there is a sharp drop in readings during cloudy weather. In terms of the total power output during clear weather, the total power output through solar tracking is more than 10.96% of the fixed system. The reading for total power output on a cloudy day is 4.63% higher than a regular system. Meanwhile, for cloudy days, the total power output is 3.4% less than the regular system. Therefore, the developed system is suitable for detecting sunlight in generating electricity. All the works were based on hardware where the circuits consist of microcontroller Arduino and LDR [1].

A Design and Implementation of Solar Tracking System using LDR Sensor

This paper presents solar energy as one of the renewable energy sources that can produce electricity. Solar energy conversion is better than others because of its clean, silent, and reliable features, which require low maintenance costs. One way to increase their efficiency is to maximize the capture of sunlight on solar panels, to increase power output. Solar tracking methods can increase the electricity production of PV systems. The approach in the design of this system consists of an automatic dual-axis solar detector connected to a mechanical structure with a controller, a DC motor, and an LDR. The controller can be done with an Arduino Uno, a DC motor to move the solar panel up and down, and an LDR sensor to detect the presence of light. For this purpose, a complete circuit will be developed and fully operational to produce more electricity based on the correct position of the sun.

This paper shows that the voltage output from the system gradually increases to a maximum between 11.00 am and 1.00 pm. The output voltage reading at that time was between 10.9V to 11.9V. Next, the output voltage drops significantly from 11.8V to 1.5V from 2.00 pm to 6.00 pm due to less sunlight [2].

Automatic Solar Tracking System

This paper describes the design and construction of a microcontroller-based solar panel detection system. Solar is a non-conventional source of energy. Experiments have been done to generate electricity from solar sources [3]. But due to the revolution of the earth's solar resources, for example, the sun cannot face the panel continuously, so the effect is that less energy is produced. This problem can be solved by using a system to detect solar energy automatically. The system will be connected to the LDR sensor to detect the maximum solar power and fed to the Microcontroller through the ADC. Next, the controller will act according to the algorithm as set before. The inclination of the solar tracker of the panel towards maximum energy depends on the response of the LDR with the help of a DC Motor.

A smart Control Based on Microcontroller for Solar Tracking System

This paper outlines a method for developing a system aimed at enhancing electricity generation to minimize reliance on fossil fuels. The system incorporates an AT-MAGA328P microcontroller, a servo motor, and an LDR sensor. The AT-MAGA328P microcontroller governs the movement of a dual-axis solar panel via servo motors. Solar energy, being a cost-effective and potentially clean source of power, is influenced by the light intensity and the angle of solar radiation due to the Earth's rotation. Consequently, the developed system ensures optimal sunlight alignment with the solar cell, which is the central focus of this research to create a smart, affordable, and efficient solution.

Moreover, the paper illustrates that the system's response varies with light intensity, especially during sunrise, with motor movement decreasing during the day when light intensity is higher, thereby enhancing efficiency and low-cost electricity production. The findings clearly demonstrate that solar tracking systems perform better compared to fixed solar systems or traditional methods [4].].

Active Solar Tracking System Using Node MCU

This paper details the design and implementation of an automatic single-axis active solar tracking system using the Node MCU ESP8266 module as the controller. This prototype serves as an alternative power generation source with high-power solar panels, demonstrated with a 5-watt solar panel in experiments. Data sets were collected under various weather conditions, such as sunny and cloudy days. The project extends to a dual-axis solar tracker with additional IoT functionality, allowing for remote monitoring of the system. Solar tracking is categorized into three types:

a. Active solar trackers, where the sensor and controller work together to follow the sun's path and maximize sunlight absorption. These can be single-axis or dual-axis trackers.
b. Passive solar trackers, which rely on the Earth's rotation and geographical variations.
c. Single-axis and dual-axis trackers, defined by their rotation axis.

The paper also explores the Earth's phenomena causing day and night and the role of seasonal changes in determining the amount of intercepted sunlight. Key angles such as the Zenith angle and Azimuth are considered in positioning the sun correctly. The Zenith angle, equivalent to the elevation angle, and the Azimuth angle, the angle between the south and the horizon point when the sun is directly below, are illustrated in Fig. 3 [5].

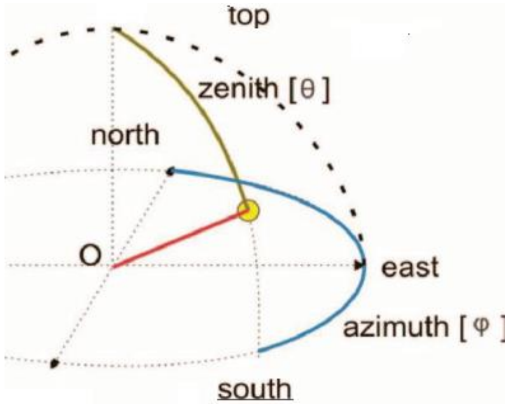


Figure. 3 Zenith and Azimuth Angle

Implementation of Dual Axis Solar Tracking System

An automatic solar detection system utilizing an Arduino prototype was developed, featuring an Arduino Microcontroller, four LDRs, and three stepper motors. The system operates through a combination of hardware and programmed firmware. The four LDRs are employed to detect light intensity, thereby optimizing the hardware's efficiency. These LDRs and stepper motors adjust in multiple directions to track sunlight effectively. The microcontroller governs the vertical tilt and horizontal rotation of the solar panel. With appropriately configured circuits, the solar panel will follow the sun's path, both vertically and horizontally. This setup ensures the system captures maximum sunlight, reducing energy generation costs and minimizing the number of solar panels needed. Figure 4 illustrates the enhanced power output of the solar tracker compared to traditional fixed PV systems, as well as the overall improvement of performance.

Typically, maximum solar energy cannot be captured using fixed solar panels alone, necessitating additional axis movement to harness more sunlight. The system's performance indicates that solar tracking can increase energy capture by 30-40%, compared to the 6-7% efficiency of fixed solar panels. Beyond using Arduino, integrating the Internet of Things (IoT) allows for data storage in the cloud, providing up-to-date information and precise sun position tracking [6].

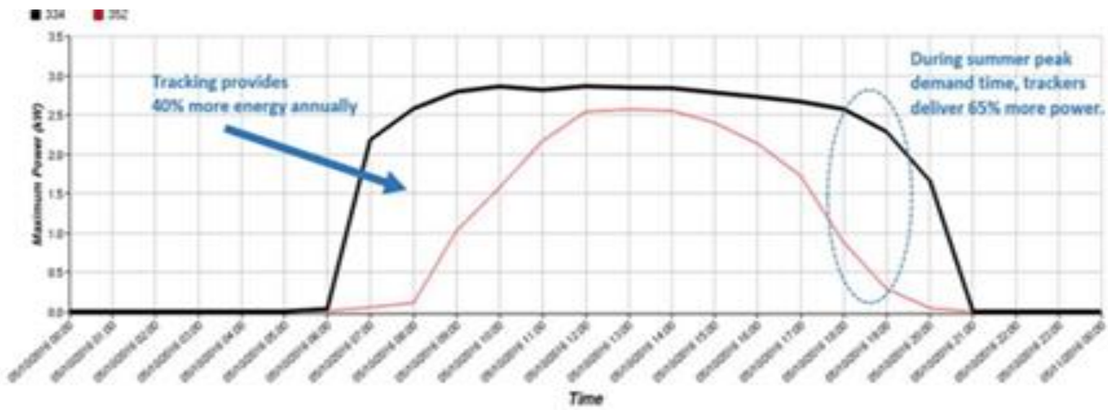
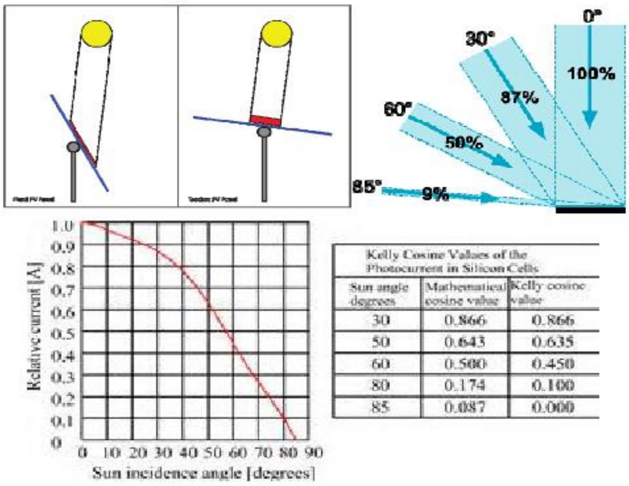


Figure. 4 The Performance Graph System

Simple Design and Implementation of Solar Tracking System Two Axis with Four Sensors for Bagdad City

This paper explores the design and implementation of a solar detection system that operates on two axes: the azimuth angle and the elevation angle, utilizing LDRs tailored to the actual dimensions of the project. The system's performance was compared to that of a fixed solar panel, and results showed that the solar tracker generated more power output. The study is organized into two main sections: hardware and electronics. The hardware section comprises a solar panel, two DC motors with a gearbox, and an LDR sensor module, while the electronics section addresses the circuitry.

The implementation process is divided into two stages. The first stage involves direct sensing using a set of LDR sensors to fine-tune the azimuth and elevation angles. The second stage focuses on monitoring the system's performance by measuring the voltage output under various weather conditions, such as cloudy, dusty, or rainy weather. During these conditions, the tracking system halts to maintain the solar panel's alignment with the sun, adhering to Kelly's Cosine theory of power. The energy extracted from the PV system is depicted in Fig. 5...



Kelly Cosine Values of the Photocurrent in Silicon Cells		
Sun angle degrees	Mathematical cosine value	Kelly cosine value
30	0.866	0.866
50	0.643	0.635
60	0.500	0.450
80	0.174	0.100
85	0.087	0.000

Figure. 5 Kelly Cosine Values Relationship

Furthermore, this paper provides an overview of the mechanism of solar tracking, highlighting its potential to increase solar energy acquisition, its operational costs, and its relatively low maintenance requirements. The design and implementation of solar detection using the described method prove highly effective in determining sunlight intensity. The results indicate that the solar tracking system is 35% more effective compared to fixed solar panels. Data analysis shows that the energy obtained from the solar tracker remains high throughout the day, from morning to evening, and is particularly elevated during peak sunlight hours. In contrast, fixed solar panels are only efficient during peak sun conditions [7].

Solar Tracking System

This paper explores the effects of global warming on the Earth and discusses the utilization of solar energy to power electrical devices. One effective approach is converting sunlight into electricity using solar panels. Typically, most installed solar panels face a single direction. Consequently, if a solar panel is positioned in the east while the sun is in the west, the panel cannot charge. Thus, alternative solutions are needed for efficient battery charging and continuous voltage generation. The proposed solution is a solar detection system that employs an AVR-Atmega16 microcontroller as the control unit, with LDRs detecting light intensity every 30 degrees per hour and rotating a full 180 degrees, as illustrated in Fig. 6. Unlike traditional fixed panels, this system allows rotation.

The LDR sends signals to the AVR-Atmega16 microcontroller, which then compares the data and adjusts the servo motor to the right, center, or left. The servo motor aligns the solar panel based on the highest light intensity and displays the output voltage on a Liquid Crystal Display (LCD). This system is particularly suitable for homes or small factories aiming to reduce long-term electricity bills.

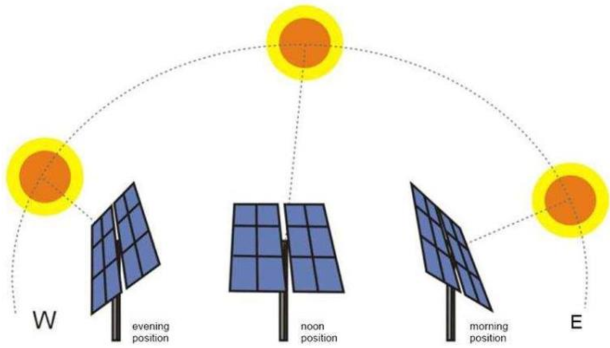


Figure. 6 Solar Tracking System

In general, this system uses the concept of solar tracking from sunrise to sunset. Therefore, the sun is always tracked and thus able to maintain the vertical flow of sunlight. Then increase the efficiency of solar panels to generate electricity [8],[9],[10]. A comparison between tracking and fixed solar panels is tabulated in Table 1.

Table I. Comparison of Solar Tracking System and Previous Type of Fixed Systems

Parameter	**Solar Tracking System**	**Previous Type of Solar System**
Type of circuit	Simple	Complex
Direction of sensor	30 degree from east to west (180 degree total)	45 degree from east or 45 degree from west
Output power	High	Low
Type of microcontroller	AVR (atmega16)	Intel8051

Besides that, this paper discusses the advantages and disadvantages of this system as tabulated in Table 2.

Table II. Advantages And Disadvantage of Solar Trackng System

Benefit	**Disadvantages**
The use of manpower is reduced	A little expensive
Save Power	Complex design
Easy installation	Depends on the climate
Improve system efficiency	
Low maintenance	

METHODOLOGY AND MATERIALS

This section explains the concepts of block diagrams, flowcharts, and circuits developed in this study.

Abbreviations and Acronyms

Figure 7 presents the block diagram of a dual-axis automatic solar tracker, which includes four LDR sensors, two servo motors, and an Arduino Uno serving as the microcontroller. The output from these four LDR sensors provides feedback to the microcontroller, which then adjusts the servo motors to orient the solar panel in the direction of the sun's movement, ensuring the maximum voltage output.

Flow Chart

Figure 8 shows the flow chart used to describe the work study. The main objective is to maximize the power output from the solar system with a dual-axis solar tracker. This system uses two servo motors. The first servo motor for 360 degrees i.e. horizontal direction. The second servo motor for 180 degrees which is the vertical direction that is parallel to the solar position.

The movement of the servo motor also depends on the value of the LDR resistance of the sensor and sunlight. The LDR sensor value depends on the sunlight based on four directions namely north, south, east, and west. If the LDR sensor reading is higher by any of the four positions, the sensor will send a signal to the Arduino Uno as a microcontroller. Next, the microcontroller will send a signal to the servo motor to move toward the position of the sun. The flow chart above can show the process from beginning to end for the solar tracking system.

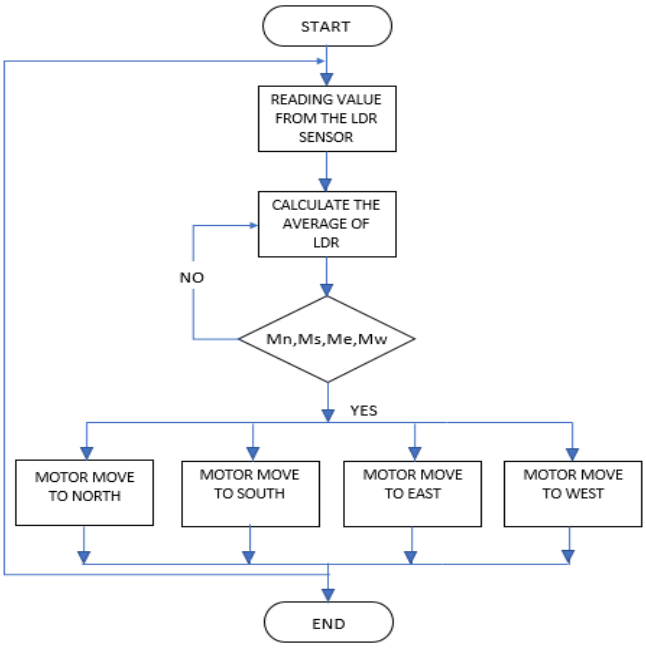


Figure. 7 Flow chart System

Circuit Diagram

Figure 9 shows a schematic diagram as well as significant circuit components, parts, and connections. Schematic diagrams are also used to calculate the costs involved in the project development. It is found that the cost to develop this project is small.

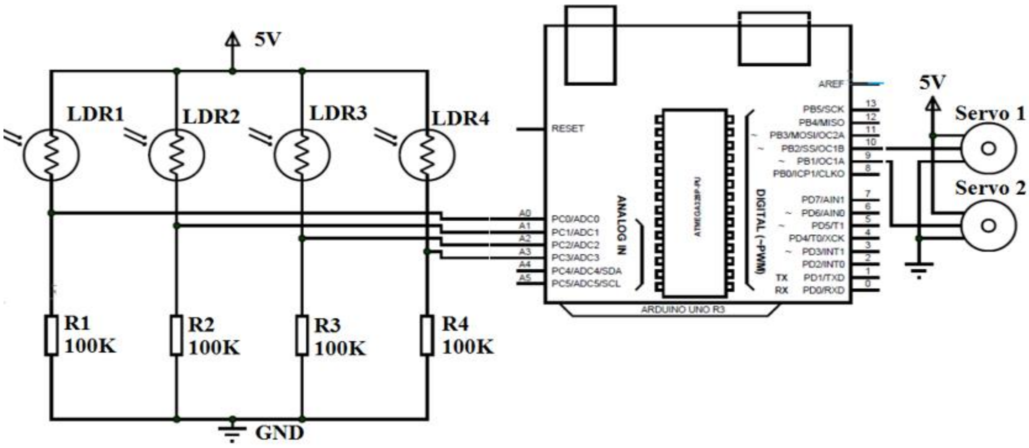


Figure. 8 Schematic Diagram System

Hardware Implementation

The Arduino Uno, depicted in Fig. 10, is a microcontroller board based on the Atmega-328. In this project, the microcontroller functions as the system's brain, executing instructions according to the programmed code. The board features 20 digital I/O pins (6 of which support Pulse Width Modulation (PWM) output) and 6 analog I/O pins. It is programmable using the Arduino Integrated Development Environment (IDE) via a type B USB cable. The board can be powered either through the USB cable or a barrel connector that accommodates voltages ranging from 7 to 20 volts, such as a 12-volt rectangular battery.

Figure. 9 Arduino Uno

Figure 11 shows the LDR sensor is used as a solar detector during light and dark. For this solar detector, the operation of the LDR will detect the concentration of sunlight and then send a feedback signal to the analog port input of the microcontroller. Finally, this microcontroller produces a digital voltage output.

Figure. 10 LDR

Solar energy can be used using Solar PV technology that converts sunlight into electricity. Also, solar PV is made of semiconductors shown in Fig. 12. When the solar panel is exposed to sunlight, it will start to produce voltage and current in the form of Direct Current (DC). The output voltage from the solar will be connected to the Inverter to produce Alternating Current (AC) and then fed to the electronic equipment.

Figure. 11 Solar Photovoltaic

RESULTS AND DISCUSSION

This section shows the voltage and current results produced by the Solar Development System Detector that has been developed. The results produced by this system are controlled by using a servo motor mechanism. The first and second servo motors control the horizontal and vertical axes to obtain accurate sunlight observation assisted by the LDR microcontroller and Arduino UNO. Tables 3 and 4 show the reading results issued by the fixed panel and tracking.

The differences in results for solar and fixed tracking are shown in percentage values. This percentage value is relatively large in the morning because there is a significant adjustment of the solar detector panel automatically in determining the position of the solar detector in the right conditions to get a large amount of sunlight.

Table III. Comparison of Output Voltage Between Tracking Panel and Fixed Panel

Time of The Day	Voltage (V)		Difference (%)
	Fixed Panel	*Tracking Panel*	
8:00 am	1.15	2.09	44.98
9:00 am	1.89	2.82	32.98
10:00 am	2.17	3.48	37.64
11:00 am	3.52	4.76	26.05
12:00 pm	5.75	5.91	2.71
1:00 pm	6.68	7.48	10.70
2:00 pm	7.76	7.79	0.39
3:00 pm	7.56	7.67	1.43
4:00 pm	6.25	6.58	5.02
5:00 pm	4.49	4.69	4.26

Table IV Comparison of Output Current Between Tracking Panel and Fixed Panel

Time of The Day	Current (mA)		Difference (%)
	Fixed Panel	*Tracking Panel*	
8:00 am	11.1	13.2	15.91
9:00 am	13.7	15.1	9.27
10:00 am	21.7	26.7	18.73
11:00 am	32.4	38.7	16.28
12:00 pm	53.7	58.3	7.89
1:00 pm	65.3	69.2	5.64
2:00 pm	69.8	74.4	6.18
3:00 pm	59.3	62.7	5.42
4:00 pm	36.5	45.3	19.43
5:00 pm	21.3	27.8	23.38

Figure 13 shows that the output voltage will vary according to the intensity of sunlight from 8.00 AM to 1.00 PM and 3.00 PM to 5.00 PM. It was found that the maximum output voltage for solar panel tracking and fixed is 7.79V and 7.76V respectively which is at 2.00 PM which is peak time. While the minimum output voltage from fixed and tracking solar panels is 4.69V and 4.49V occurs at 5.00 PM.

At peak time, at 2.00 PM, the highest readings are 74.4mA and 69.8mA for solar tracking and fixed solar panels. This is because the tracking of the solar panel is almost parallel to the sun compared to fixed solar. After all, the sunlight falls directly on the panel.

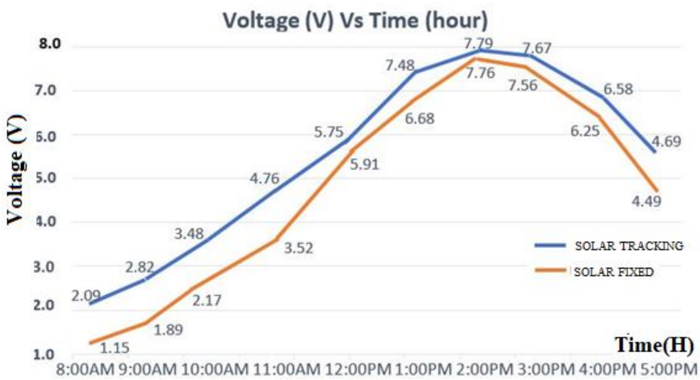


Figure. 12 Comparisons of Output Voltage for Dual Axis and Fixed Panel in Voltage

It was found that the output current increased from 11.00 pm to 2.00 pm and decreased in the afternoon. The lowest readings for fixed solar panels and detector solar panels were 21.3mA and 27.8mA occurred at 5.00 pm. The behavior for the rising and falling output current depending on the light intensity can be shown in Fig. 14.

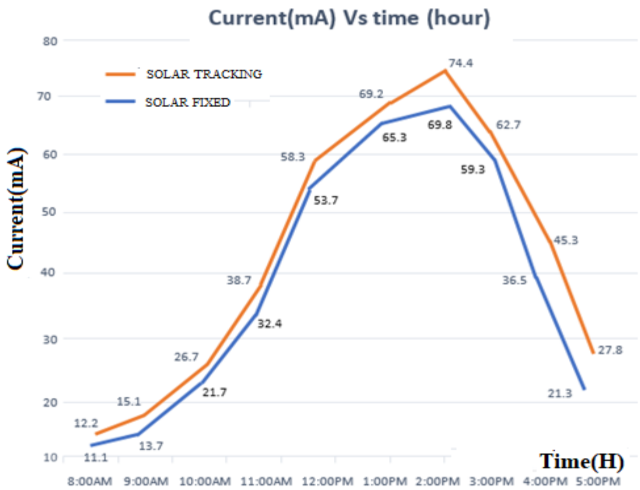


Figure. 13 Comparisons of Output Current Between Tracking Panel and Fixed Panel

Figure 15 represents the comparison of power yield between detector solar panels and fixed solar panels. A solar panel tracking system contributes more power than a fixed solar panel.

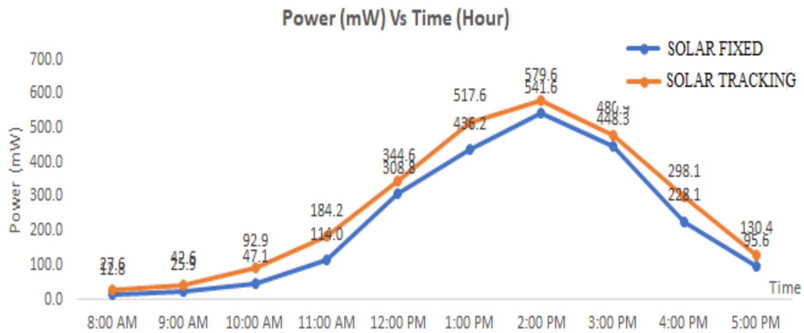
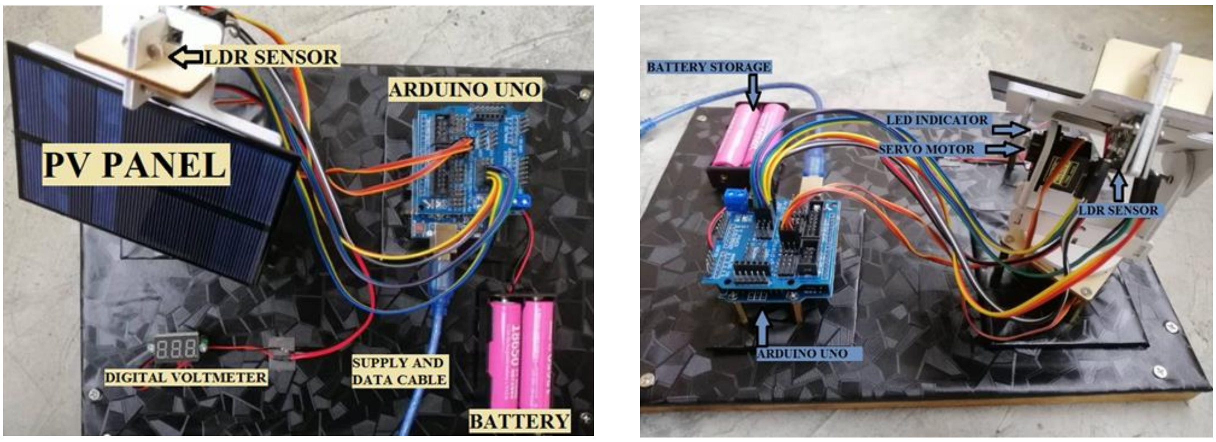


Figure. 14 Comparison Of Power Output Between Detector Solar Panels And Fixed Solar Panels

A simple and low-cost prototype is illustrated in Fig. 15. This system can be installed in difficult areas to get the correct position of the sun such as on a hillside or flat land.



(a) (b)

Figure. 15 Prototype Project View (a) Top (b) Back

CONCLUSION

The average performance of solar panel tracking in generating electricity is 45.1%. The study's findings indicate that solar panel tracking significantly increases electricity production in the morning and evening, while there is minimal difference at noon, demonstrating that fixed solar panels are only efficient during midday. This approach proves that solar panel tracking systems are more efficient than fixed solar panels and can be installed in various locations.

RECOMMENDATION

The developed system model can be further improved as follows:

a. Using a high-power servo motor to hold large-scale solar panels.
b. Build an automatic circuit to turn off and on the power supply system at sunset and sunrise to save electricity.
c. Using the Internet of Things (IoT) to monitor all the data from the solar panel to control the movement of the servo motor.
d. Using image processing to recognize light density more effectively.

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