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Development of A Dual-Axis Solar Tracker with Passive Cooling for Enhanced Performance

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Abstract: The dual-axis solar tracker system presented in this project utilizes light intensity measurements to optimize the alignment of solar panels with the sun's position. The system employs four Light Dependent Resistors (LDRs) to detect the intensity of sunlight in both the X-axis and Y-axis directions. Based on the readings from the LDRs, servo motors are controlled to adjust the position of the solar panel, enabling it to constantly face the sun for maximum energy absorption. In addition to the solar tracking functionality, the system incorporates a heat sink as a cooling mechanism. As solar panels tend to heat up during operation, the heat sink aids in dissipating excess heat, improving the overall efficiency and longevity of the solar panel. The heat sink is integrated into the system, ensuring effective cooling and thermal management. By combining solar tracking based on light intensity and the integration of a heat sink as a cooler, the proposed system enhances the performance and reliability of solar panels. The continuous alignment with the sun's position maximizes energy generation, while the heat sink mitigates the detrimental effects of overheating. This system serves as a practical solution for optimizing solar energy utilization in various applications, such as renewable energy systems, solar-powered devices, and off-grid installations.

Keywords: Dual Axis Solar Tracker, Passive Cooling System, Heat Sink

1. Introduction

Due to the global shortage of electricity, there has been a continuous search for readily available and environmentally friendly sources of electric power in the field of development [1]. The increasing use of fossil fuels, such as coal, and the associated challenges of global warming and severe weather conditions have prompted nations worldwide to explore alternative energy sources and reduce their reliance on fossil fuels. Malaysia, like many other countries, has implemented various measures in its 8th Malaysia Plan since 2001 to facilitate the rapid integration of renewable energy into its national grid [2]. Solar energy has emerged as one of the most promising renewable

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energy sources globally, contributing to the growing demand for electric power [3]. Malaysia's geographical location results in hot and humid weather conditions throughout the year, accompanied by abundant rainfall.

Consequently, Malaysia receives a substantial amount of solar radiation, with most areas experiencing a daily solar radiation average ranging from 4.7 to 6.5 kWh/m2 [4]. This highlights Malaysia's significant solar radiation potential for electricity generation. Moreover, solar energy is regarded as one of the best power sources due to its natural availability and lack of pollution. The process of converting sunlight into electricity, known as the photoelectric effect, has been widely adopted and continues to improve. Despite the infinite availability of solar energy, its efficient harvesting poses challenges due to panel inefficiencies.

Traditionally, solar panels were fixed in position and did not dynamically adjust their orientation towards the sun. However, given the sun's changing position throughout the day, a dynamic tracking system is necessary to maximize solar energy absorption. Additionally, high temperatures can negatively impact the voltage output of solar cells, resulting in reduced overall power output [4]. The objective of this project is to develop a dual-axis solar tracker that optimizes light absorption while employing a passive cooling system through the integration of a heat sink attached to the solar panel body.

2. Materials and Methods

This section specified the approach used to determine, designate, and analyze the workflow process and hardware implementation inquiries, which will systematize a work-specific in the development of a solar tracker.

2.1 Project Block Diagram

A block diagram is used to represent the layout and structure of the involved system. Each of these components serves a specific purpose. Figure 1 illustrates the block diagram for this project.

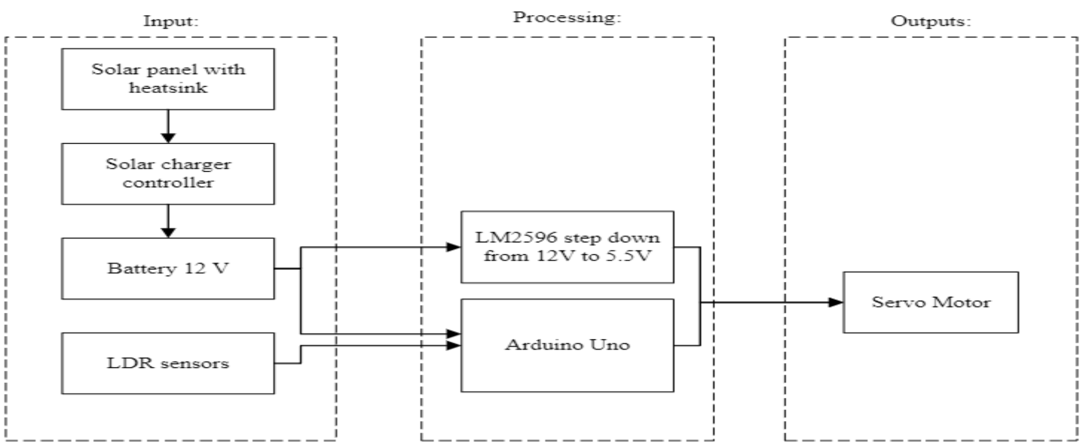

Figure 1: Block diagram system dual-axis solar tracker with heat sink.

The block diagram showcases the key components and their connections in the solar tracking system. At the input stage, there is a solar panel with a heatsink designed to capture solar energy efficiently. The heatsink aids in dissipating excess heat from the solar panel, ensuring optimal performance. The solar panel serves as the primary source of energy for the system. To monitor the intensity of light, four Light Dependent Resistors (LDRs) are strategically placed across the solar panel. These LDR sensors detect variations in light levels and provide input signals to the Arduino Uno, the central microcontroller of the system.

The Arduino Uno processes these signals and executes appropriate control actions. The 12V battery acts as a secondary power source, ensuring uninterrupted operation during low-light conditions or when solar energy is insufficient. A solar charge controller is incorporated into the system to regulate the charging of the battery from the solar panel. This controller safeguards against overcharging or deep discharging, thereby prolonging the battery's lifespan. To achieve precise solar panel positioning, three servo motors are employed. The Arduino Uno uses the input signals from the LDR sensors to control the servo motors, adjusting the position of the solar panel based on the detected light intensity. This dynamic tracking mechanism maximizes the absorption of solar energy.

Lastly, an LM2596 step-down voltage regulator is implemented to convert the battery's 12V voltage to 5.5V. This regulated voltage is specifically directed to power the servo motors, ensuring their optimal functioning and longevity.

2.2 Simulation Circuit Diagram

The design was performed by using Proteus software. Figure 2 shows the simulation design of the full circuit of the system.

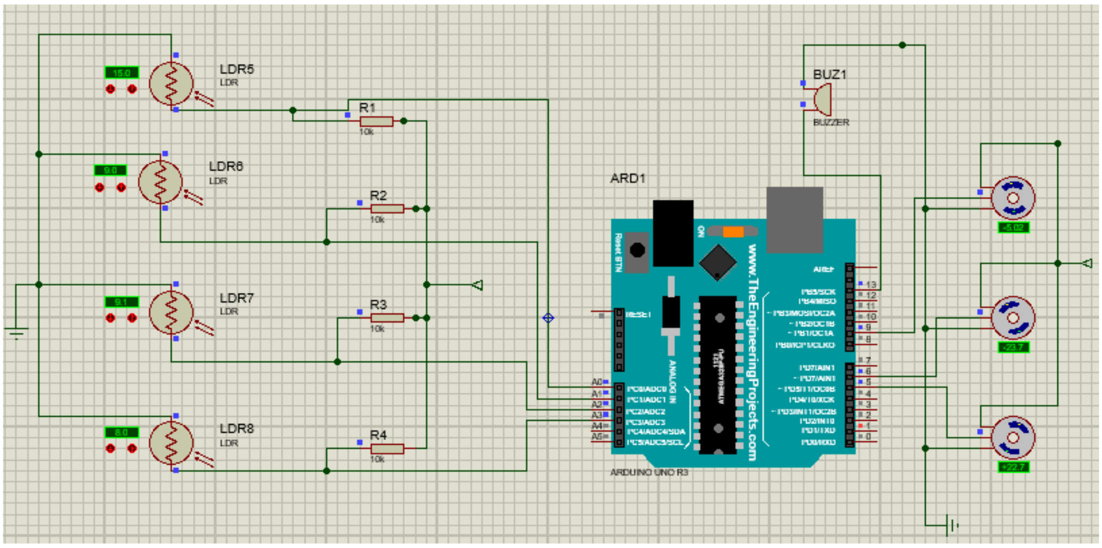

Figure 2: Simulation full circuit of the system

For the circuit design in the solar tracker dual-axis system, there are four Light Dependent Resistors (LDRs) utilized as light sensors, and their values will be compared to determine which one is more sensitive to the light source. This information will be transmitted to the Arduino as an analog value. If the solar panel isn't exactly perpendicular to the sun, the LDR sensor will be split by a divider, casting a shadow on half of it. The Arduino Uno serves as the circuit's "brain," directing the actions of the servo motor. The microcontroller processes the information gathered from the sensors. The servo motor will be directed to turn at a precise angle by the microcontroller. This system also includes a program for a buzzer which is when the switch on will buzz for 0.2 seconds.

2.3 Flow Chart of The System

Figure 3 shows the flow chat for this system.

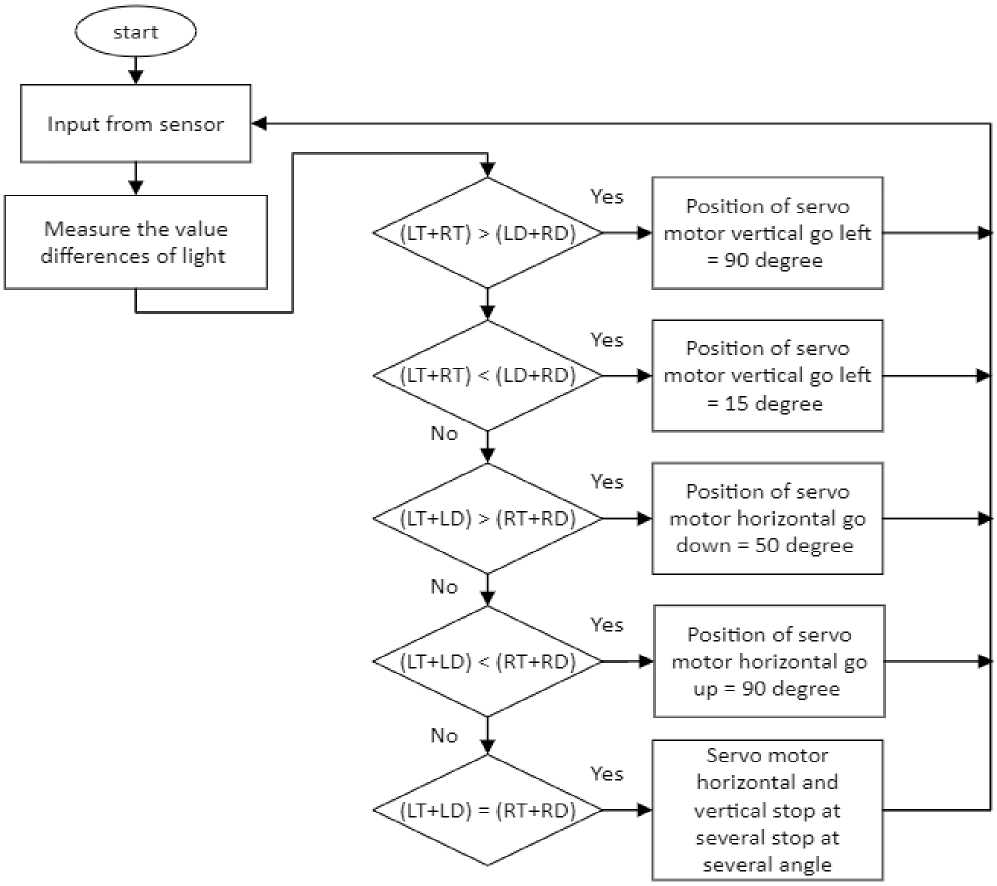

Figure 3: Flow chart of the system

The flowchart depicted in Figure 3 shows the working principle of the whole system for the solar tracker dual-axis system. Starting from four LDR sensors that detect and measure the value differences of light. The data that has been received from the sensor will be read in Arduino UNO to make a comparison for positioning the solar panel directly toward the sun ray. The system will analyze the data to determine the direction of the sun and make horizontal and vertical servo motors move accordingly to the commend that has been set in Arduino IDE.

For horizontal and vertical motion, this project employs two 180-degree servo motors. The servo motor will be operated according to the LDR sensor that has been detecting the light. The sensor has five conditions to make the servo motor rotate. First, when sensors LT and RT detect more light than LD and RD the vertical servo motor will go left side which is 90 degrees. Second, when LT and RT are less than LD and RD, the vertical servo motor will rotate from 0 degrees to a 15-degree angle.

Third, when sensor LT and LD are more than sensor RT and RD the horizontal servo motor will go down and rotate to a 50-degree angle. Fourth, when sensors LT and LD are less than sensors RT and RD, the horizontal servo motor is rotated up 90 degrees, and finally, when all of the sensors are equal, indicating that all of the sensors have detected sun rays, the motor is turned off. All this depends on the position of the sun and whether the sensor can detect the sun or not. The system will be looped to get the best position of the sun.

2.4 Experiment Procedure

The experiment was done in a room with a starting temperature of 32.2 ° C. The angle for the static solar panel was set at 60°. The voltage and temperature data were collected after 15 minutes for each angle of the light source. A 150W heat bulb was used as the source of light. Below are the steps for the experiment procedures: The experimental setup of the dual-axis solar tracker is shown in Figure 4.

Figure 4: Solar tracker setup

The experiment was conducted as follows:

i. White blank paper was marked with angles for the source of light (150W built) to be directed towards the solar panels of both solar tracker and fixed solar panel.
ii. The angle for source light was set to 0 º, followed by 60 º, 90º, 120 º, and 180º.
iii. The positive terminal of the solar panels was connected to the positive terminal of a multimeter while the negative terminal of the solar panel was connected to the negative terminal of the multimeter.
iv. The thermocouple used direct contact to measure the temperature of the surface.
v. The voltage and temperature data were collected after 15 minutes for each angle of the source light.
vi. Measured using the multimeter and recorded for further analysis.
vii. Steps 5 and Step 6 were repeated for the solar tracker solar panel and solar tracker with a heat sink.

By following this experimental procedure, data on voltage and temperature were obtained for different angles of the source light, providing valuable information for the analysis and evaluation of the solar panel's performance.

3. Results and Discussion

This chapter focuses on presenting the results and analysis of the project, with a specific emphasis on evaluating the performance of dual-axis solar trackers with cooling systems, dual-axis solar trackers, and fixed-angle solar panels. The first part of the analysis involves assessing the performance of dual-axis solar trackers with cooling systems. This includes examining the tracking accuracy, energy output, and the effectiveness of the cooling mechanisms in maintaining optimal panel temperature. By analyzing the collected data, the advantages of utilizing dual-axis tracking combined with cooling systems in maximizing solar exposure and minimizing efficiency losses due to heat can be elucidated.

3.1 Results

Table 1 presents the average results obtained from the experiment conducted on the fixed-angle solar panel, dual-axis solar tracker, and dual-axis solar tracker with a heat sink. The table provides a comprehensive comparison of various performance voltages, power, and temperature.

Table 1: Data analysis for three model solar panel

	Temperature (C °)	Voltage (V)	Power(W)
Fixed solar Panel	36.7	16.4	9.8
Solar tracker	39.7	17.3	10.4
Solar tracker with heatsink	38.1	17.4	10.4

The analysis of the experimental results reveals interesting insights into the performance of the different configurations. At a fixed angle, the solar panel achieved an average power output of 9.9 W, with an average temperature of 36.7°C. This indicates that the fixed-angle solar panel was able to generate a certain level of power under the given conditions. However, the average temperature suggests that the panel might have experienced a relatively higher temperature, which can negatively impact its efficiency and overall performance.

Comparatively, the dual-axis solar tracker demonstrated a slightly higher average power output of 10.4 W, with an average temperature of 39.7°C. The increase in power output suggests that the solar tracker's ability to orient itself towards the sun resulted in improved energy generation. However, the average temperature indicates that the solar tracker might have experienced a higher operating temperature compared to the fixed-angle panel, which could affect its long-term reliability and efficiency.

Interestingly, when a heat sink was incorporated into the dual-axis solar tracker, the power output remained at 10.4 W, while the average temperature dropped to 37.7°C. This indicates that the heat sink effectively managed the temperature of the solar panel, preventing excessive heat buildup and maintaining a more optimal operating temperature. The consistent power output suggests that the heat sink successfully dissipated excess heat, potentially enhancing the panel's overall performance and longevity.

Overall, the results demonstrate that both the dual-axis solar tracker and the dual-axis solar tracker with a heat sink outperformed the fixed-angle solar panel in terms of power generation. The addition of a heat sink further improved the temperature management of the solar panel, which can have long-term benefits for its efficiency and reliability. These findings highlight the significance of solar tracking and thermal management techniques in maximizing the performance and output of solar panels. Figure 5 and Figure 6 show a graph of voltage against the angle of the light source and a graph of temperature against the angle of the light source.

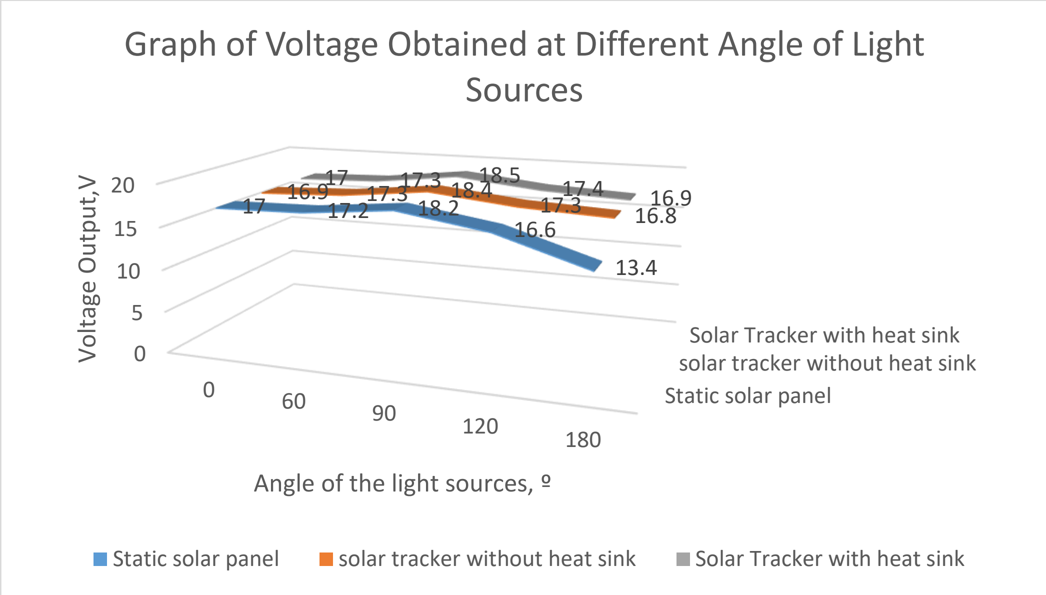

Figure 5: Graph of voltage against the angle of the light source

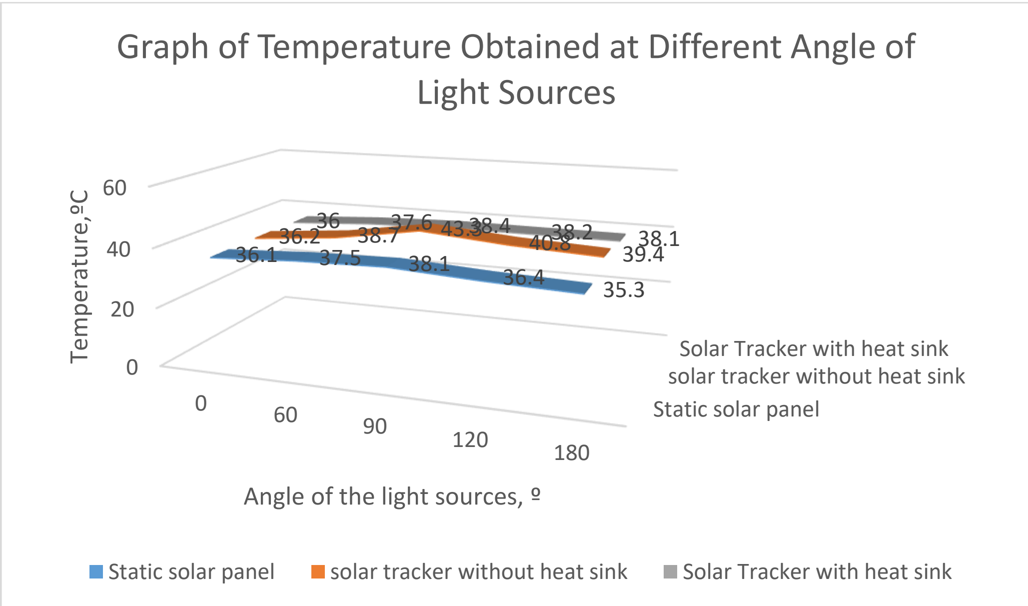

Figure 6: Graph of temperature against the angle of the light source

In the voltage-angle graph, it can be observed that at an angle of 0°, the static solar panel achieved a voltage of 17 volts, while both the solar tracker without a heat sink and the solar tracker with a heat sink had slightly lower voltages of 16.9 volts and 17 volts, respectively. As the angle of the light source increased to 60°, all three configurations showed an increase in voltage, with the static solar panel reaching 17.2 volts, the solar tracker without a heat sink reaching 17.3 volts, and the solar tracker with a heat sink also reaching 17.3 volts. At an angle of 90°, the voltages continued to rise, with the static solar panel reaching 18.2 volts, the solar tracker without a heat sink reaching 18.4 volts, and the solar tracker with a heat sink reaching 18.5 volts. The voltage values fluctuated slightly at angles of 120° and 180°, but the trend of higher voltage output for the solar trackers, especially with the heat sink, remained consistent.

In the temperature-angle graph, similar patterns can be observed. At an angle of 0°, the temperature readings for all three configurations were relatively close, with the static solar panel at 36.1°C, the solar tracker without a heat sink at 36.2°C, and the solar tracker with a heat sink at 36°C. As the angle increased to 60°, the temperatures also increased, with the static solar panel recording 37.5°C, the solar tracker without a heat sink at 38.7°C, and the solar tracker with a heat sink at 37.6°C. At 90°, the temperatures continued to rise significantly, with the static solar panel reaching 38.1°C, the solar tracker without a heat sink reaching 43.3°C, and the solar tracker with a heat sink remaining relatively lower at 38.2°C. At angles of 120° and 180°, the temperatures varied, but the overall trend of higher temperatures for the solar tracker without a heat sink compared to the other configurations was evident.

These graphs visually represent the variations in voltage and temperature as the angle of the light source changes, highlighting the performance differences between the fixed-angle solar panel and the solar trackers with and without a heat sink. The data indicates that the solar trackers, especially with the heat sink, achieve higher voltages and maintain lower temperatures compared to the fixed-angle solar panel, which demonstrates the advantages of implementing solar tracking and cooling mechanisms in improving solar panel performance.

4. Conclusion

In conclusion, by implementing a dual-axis solar tracker, the project ensured that the solar panels were optimally positioned to receive maximum sunlight throughout the day. The integration of a passive cooling system further enhanced the performance of the solar panels by effectively managing their temperature and preventing overheating. Through experimental data collection and analysis, it was determined that the solar tracker with the cooling system achieved higher average power output compared to the fixed solar configuration. This indicates that the combined benefits of solar tracking and cooling resulted in improved solar panel performance and increased energy generation. Overall, this project demonstrates the effectiveness of integrating solar tracking and passive cooling systems to enhance the efficiency and output of solar panels. By optimizing the alignment of the panels with the sun's position and effectively managing their temperature, the solar tracker with the cooling system showcased superior performance compared to the fixed solar configuration. These findings contribute to the advancement of solar energy systems and highlight the potential for maximizing energy generation through innovative technologies.

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