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Light Intensity Optimization of a Microcontroller-Based Solar Tracking Panel

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Abstract

This paper is on the light intensity optimization of a microcontroller-based solar tracking panel system, addressing the limited efficiency of fixed solar panels in capturing solar energy. This project aims to improve fixed solar panels by using a tracking system that always follows the sun's direction using a microcontroller. An automated tracking system for solar panels usually has two types: single-axis and dual-axis. This project studies the light intensity gained from the solar panel based on the tilt angle of the solar panel according to the sun's movement. The gyroscope is used to gather data on the tilt angle to analyze and compare it to a fixed solar panel at an optimal angle. A DC multimeter measures the voltage and current obtained from the solar panel, and a DC motor moves the panel every 1 hour. At the end of this work, a complete automatic solar tracking system with high efficiency was successfully developed. There is an increase of 9.195% in the efficiency of the power gained by applying the solar tracker system. Therefore, a solar tracker can help improve the efficiency of collecting renewable energy of solar.

1. Introduction

In an era marked by increasing environmental concerns and the urgent need to address climate change, the exploration and utilization of renewable energy sources have gained paramount importance. Renewable energy, often called green or clean energy, is derived from sources naturally replenished over a relatively short period. Unlike finite fossil fuels, such as coal, oil, and natural gas, renewable energy sources offer a sustainable and environmentally friendly alternative to meet our energy demands. Renewable energy technologies harness the power of natural processes, such as sunlight, wind, water, and geothermal heat, to generate electricity and provide heat for various applications [1-3]. Renewable energy is crucial in mitigating climate change while promoting energy security and economic growth by significantly reducing greenhouse gas emissions and minimizing the detrimental effects of traditional energy sources on the planet.

Solar is one of the renewable energies which can be gathered from the sun and is unlimited. Solar panels or solar photovoltaics can be used to capture solar energy from the sun. Most solar panels used currently are fixed solar panels. Since energy is heavily required to power many modern devices, energy must be gathered as efficiently as possible. A fixed solar panel can collect the sun's intensity at its full potential once a day when the sun directly hits the solar panel[4]. This paper proposed an automated solar tracking system to overcome this problem.

Most past studies on a solar tracking system utilize a microcontroller as the system's primary controller. Microcontrollers are easy to use and program [5-7]. Current studies show solar tracking systems use a light-dependent resistor (LDR) to detect the current sun position and a motor to control the movement of the solar panel. An LDR is a resistor that decreases resistance when the input light intensity increases. With this, it can measure the sunlight's intensity by observing the output data, such as the voltage passing through it. The lower the voltage, the better for the solar tracking system [8 - 9]. This project aims to move the solar panel using optimum angles through calculation and by using a gyroscope to verify the tilt angle of the solar tracker and whether it follows the parameters set or not.

The solar tracking system's movement is controlled using a motor or more. Controlling the movement of the solar panel can be done by using two types of axis: single-axis and dual-axis. A single-axis solar panel tracking system moves on either the horizontal or vertical planes using a DC motor. Dual-axis usually uses a servo motor for better accuracy, moving the solar panel in all four directions: North, South, East, and West. Most studies choose to move the solar panel on the horizontal plane as it follows the earth's rotation around the sun [10-14]. Studies are also conducted by integrating the solar tracking system with the Internet of Things (IoT). The solar tracking system can be controlled through the Blynk application on a smartphone [15]. The application will display the current value of the output voltage produced by the two solar panels. The Blynk application can turn the solar panel on or off based on user's preferences.

Since energy is heavily required to power a lot of modern technology, energy must be gathered as efficiently as possible. A fixed solar panel can collect the sun's intensity at its full potential once a day when it directly hits the panel [16-18]. Therefore, a solar tracker should be considered to collect the solar output at its full capability every hour. The existing miniature solar tracking systems utilized microcontrollers like Arduino or NodeMCU as the primary controllers. This project aims to utilize a gyroscope with a microcontroller to determine the optimal angle for capturing light intensity, and to study the effect of weather variability on the solar tracker system.

This paper comprises an introductory section, background context, and an exposition of the research inquiry regarding light intensity optimization using a solar tracker panel. Following this is the methodology section, which elucidates the research techniques and data collection methods employed for fixed and tracked solar panel using microcontroller. Subsequently, the paper presents results and discussions that elucidate the study's discoveries pertaining to the power obtained from fixed and tracked solar panels in different weather condition. In conclusion, this paper offers a summary of the system's light intensity optimization in pinpointing tracked solar panel advantages.

2. Research Method

This section describes the methodology employed for the light optimization microcontroller-based solar tracker system. The process begins with designing a solar tracker panel that moves hourly based on sun location. Then, the solar tracker panel system is tested during sunny, cloudy and rainy conditions and compared to a standard fixed solar panel.

2.1 Solar Tracking Panel Altitude and Tilt Angle Calculations

There are two types of solar tracking systems: a single-axis and a dual-axis tracking system. For this work, the focus is on single-axis tracking with vertical axis movement. The vertical axis movement is better for collecting light intensity data as it follows the sun's movement throughout the day from the east to the west. Fig. 1 shows the types of solar tracking system.

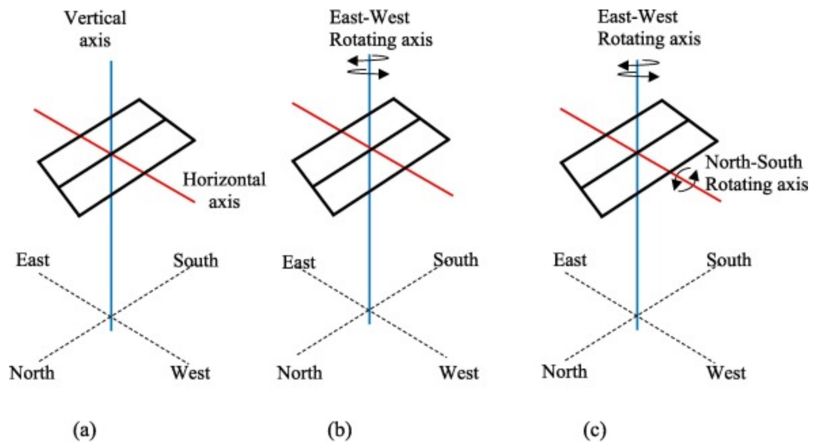

Fig. 1 *Type of solar tracking system: (a) Fixed solar panel; (b) Single-axis; (c) Dual-axis [19]*

Fig. 2 shows the solar elevation angles change from morning to noon to evening. Solar elevation refers to the angular separation between the imaginary horizontal plane of your location and the sun in the sky. Also referred to as the solar latitude angle, it is measured in degrees and essentially indicates how high the sun is positioned in the sky. During morning and evening hours, when the sun is near the horizon, the solar elevation is close to 0°. Conversely, at solar noon, when the sun is directly overhead, the solar elevation angle is at its peak.

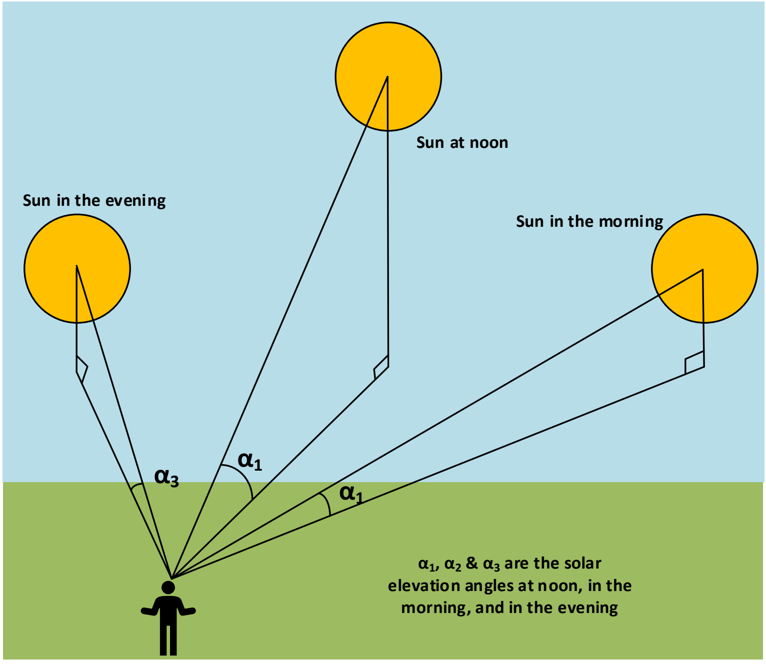

Fig. 2 *The solar elevation angles change from morning to evening [19]*

The placement of the solar panel is crucial to optimize solar tracking. So, the optimal tilt angle for the solar panel is calculated based on Selangor's latitude and longitude: 3.0738° North, 101.5183° East. The position of the solar altitude and the best tilt angle are calculated using formulas (1) and (2). β is the solar altitude angle, and α is the optimum tilt angle. For finding β , the angle is subtracted with the estimation of the earth's tilt angle, which is 23.45°. Since the experiment was conducted during the December solstice, formula 180° is the azimuth angle to obtain the best results [20-25].

$$\beta = 90° - latitute\ angle - 23.45° \quad (1)$$

$$\alpha = 180° - 90° - \beta \quad (2)$$

Table 1 shows the solar altitude obtained and the best optimum tilt angle based on Selangor location and December solstice.

Table 1 *Fixed-angle solar panel*

Solar altitude angle (β)	Optimum tilt angle (α)
63.47° looking South	26.53° facing South

From the best optimum tilt angle calculation, the solar tracker panel is set to move automatically by -1° or +1° hourly, starting from 0800 to 1700, with the best tilt angle assumed at noon. The summary of the solar panel movement can be seen in Table 2.

Table 2 *Solar tracker panel angle setting*

Time	Tilt angle (β)
0800	30.53°
0900	29.53°
1000	28.53°
1100	27.53°
1200	26.53°
1300	25.53°
1400	24.53°
1500	23.53°
1600	22.53°
1700	21.53°

2.2 Solar Tracking Panel System

In this work, a three-axis gyroscope (on the RFS module) is used to determine the tilt angle of the solar panel. The brain of the project is an Arduino UNO, connected to two outputs; the DC motor and the seven segments display. The DC motor controls the solar panel's movement, and the seven segments display the current tilt angle of the solar tracker to verify it is moving according to the parameter set. The solar tracker panel follows the azimuth angle of the fixed solar panel, but the optimum tilt angle is varied by ± 1°. Fig. 3 shows that the RFS board is placed directly beside the solar panel for accurate tilt angle measurements. The tilt angle values are shown on the seven-segment display attached to the solar panel.

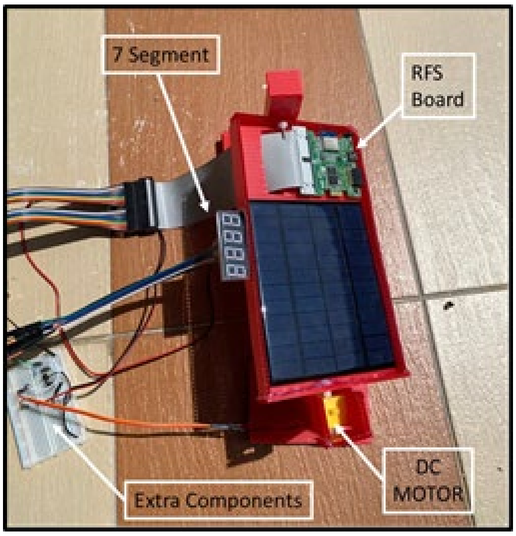

Fig. 3 *Solar tracker panel system prototype*

For this work, the solar panel used for the tracking system and fixed tilt is a mini polycrystalline solar panel—the solar panel parameters are shown in Table 3 below.

Table 3 *Solar panel specification*

Maximum output voltage	12V
Maximum output current	167mA
Dimensions	110mm x 136mm

3. Results and Discussion

The experiment occurred from November to December 2022 in the College of Engineering compound. Power measurement obtained from the solar panel system is taken daily from 0800 to 1700. The data is separated into sunny, cloudy, and rainy days. Data from fixed and tracked solar panels are taken to study the effects of the movement of tilt angle on light intensity optimization.

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3.1 Normal Sunny Conditions

Five power output reading sets are chosen for comparison in the experiment period (November – December 2022). The data taken are for both fixed solar panels and solar tracker panels. Fig. 4 shows he fixed solar panel output power on different sunny days (24 Nov, 4 Dec, 17 Dec, 28 Dec, and 29 Dec) at various times of the day, from 0800 to 1700 hours. The output power is measured in watts, and the trends show the typical solar power generation curve, peaking around midday and decreasing towards the morning and evening. On average, the power output for fixed solar panels on sunny days is 1.91 W. The average lowest reading is obtained at 1700 with 1.39 W, and the highest is at 1300 with 2.33 W. The performance of fixed solar panels, as seen here, typically follows a bell-shaped curve due to the movement of the sun. Studies like [1] and [3] emphasize the importance of optimizing energy harvesting systems by adjusting to environmental factors. In this context, the power outputs recorded across different days show the need for improvements, such as tracking systems that could optimize power generation as solar angles change. While Fig.4 doesn't directly show the temperature impact, days with lower performance could potentially benefit from such methods to prevent efficiency drops due to heat buildup or dust accumulation. [8] and [9] highlight improvements in photovoltaic efficiency using cooling techniques like nanofluid cooling or water cleaning and [20] discusses optimizing tilt angles based on weather conditions to maximize performance.

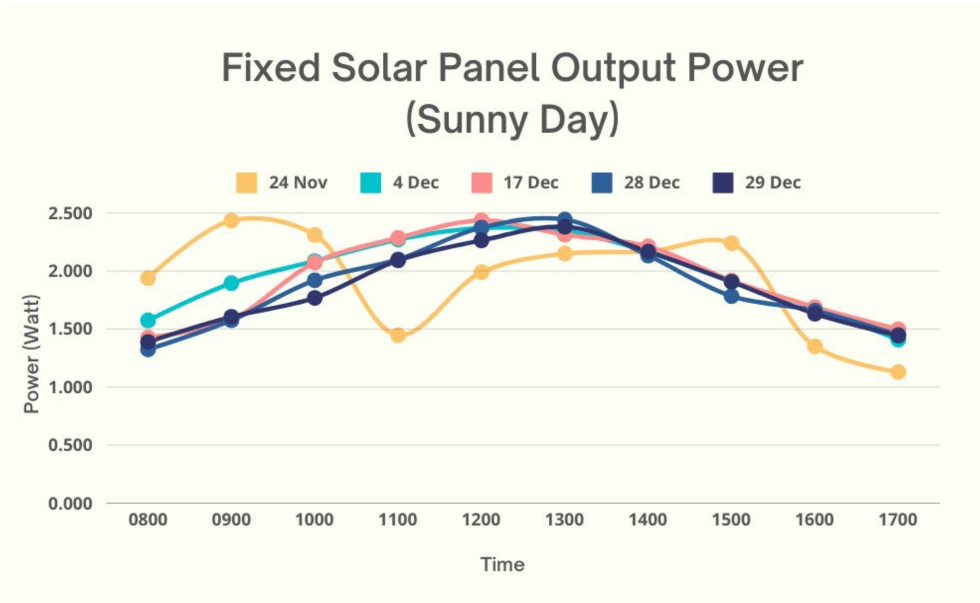

Fig. 4 *Fixed solar panel output on a sunny day*

Fig. 5 shows the output power on the solar tracker panel on the same date as in the fixed solar panel experiment. On average, the lowest power produced by the solar tracker panel is at 1700 with 1.68 W. The highest value was obtained at 1300 with 2.39 W. For the five-day data collection, the average power output for sunny conditions is 2.09 W. Data in Fig.5 aligns with the findings from [5] and [6], where intelligent and optimized solar tracking systems are used to maximize solar power output. In these studies, the solar tracker system adapts to sunlight variations, increasing efficiency, especially around peak sunlight hours (between 10 AM and 2 PM). The relatively higher power output during this time range in your graph suggests the effectiveness of tracking systems in optimizing energy harvest by maintaining an optimal panel angle. The variations in output on different days could also be attributed to weather conditions, as discussed by [4], who used adaptive control systems to address the impact of environmental conditions like cloud cover on solar panel efficiency. Despite the system tracking the sun, the power output shows some dips around 11 AM on November 24, which could be due to intermittent shading or atmospheric disturbances.

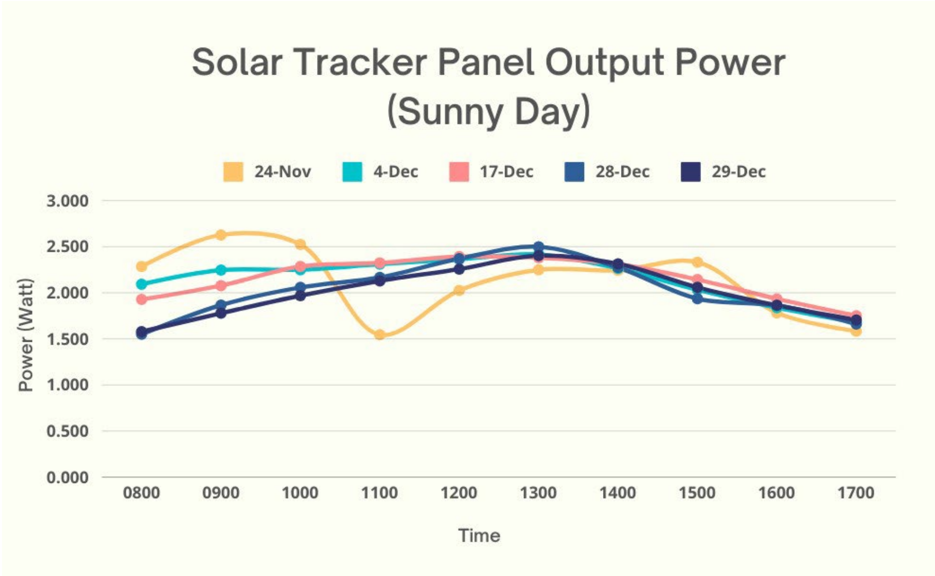

Fig. 5 *Tracked solar panel output on a sunny day*

Fig. 6 shows the average reading from 0800 to 1700 for both fixed and solar tracker panels throughout the experiment period with sunny day conditions. It can be seen in this Fig. 6 that solar tracker panels have improved power production compared to fixed-angle solar panels from 1100 to 1700. On average, the improvement is 9.195% on solar tracker panels compared to fixed solar panels, showcasing the improvement in energy capture when using solar tracking technology. [17] conducted a similar analysis, showing that single-axis solar trackers outperform fixed systems, especially during non-peak hours. This is evident from the figure where the solar tracker maintains relatively higher power output during the early morning and late afternoon when sunlight is less intense.

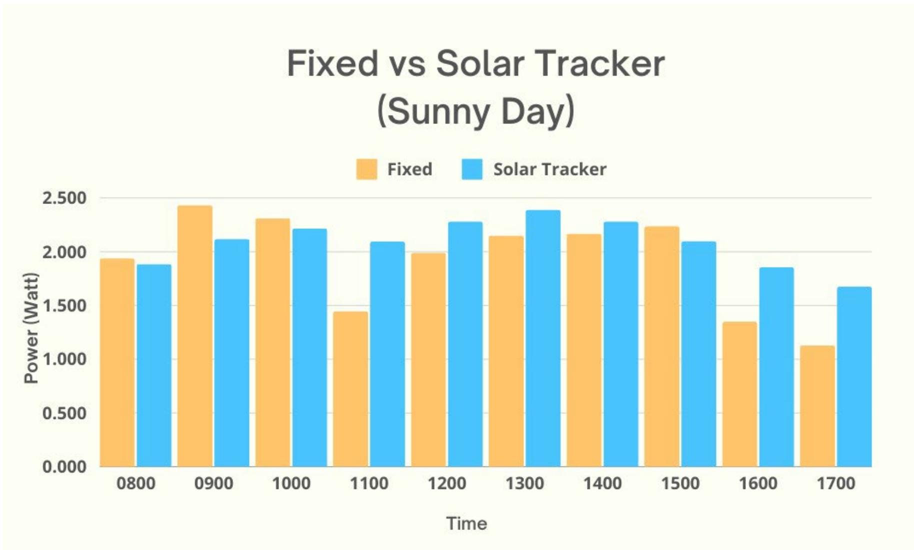

Fig. 6 *Average power output comparison for fixed and solar tracker panels on sunny day*

3.2 Other Conditions

Malaysia's weather is unpredictable; there are also cloudy and rainy days. The amount of solar energy that solar trackers and fixed solar panels can gather decreases in cloudy and rainy weather due to clouds obstructing some of the sun's light, which lowers the energy that reaches the panels. Based on this prediction, Fig.s 7 and 8 show the fixed and solar tracking panels during cloudy and rainy weather. Fig. 7 shows both types of panels will see a similar decrease in yield when the clouds are thick, and the clouds cover the sun. Cloudy days limit the total solar radiation reaching the panels, as described in studies like [2] and [3]. Despite reduced sunlight, solar tracking systems are still beneficial, as they maximize the capture of diffuse light that penetrates cloud cover. This correlates with the data in the figure, showing that even on a cloudy day, the tracker performs better than the fixed system. [18] confirm this in tropical climates, where trackers can significantly enhance photovoltaic energy generation by reducing losses due to suboptimal angles.

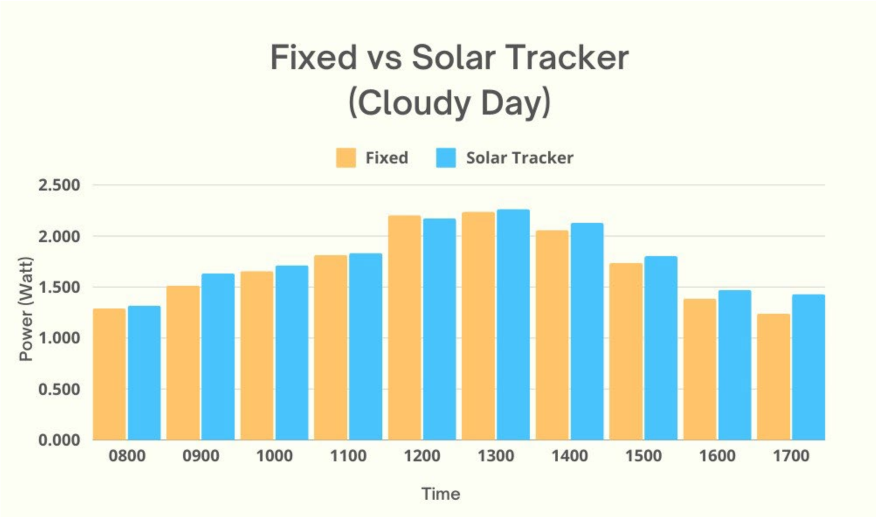

Fig. 7 *Average power output comparison for fixed and solar tracker panels on cloudy day*

Fig. 8 shows the fixed solar and solar tracking panels on a rainy day. When this data is taken, the dark cloud starts at 0800 and starts raining at 0900. The output power measure during this time is quite low; however, when the rain stops, the solar panel starts picking up the solar energy as intended. Solar tracker panels still perform much better compared to fixed solar panels. [8] and [4] explain that adverse weather conditions, like rainy days, not only reduce solar irradiance but can also lead to cooling of solar panels, which slightly improves their efficiency. However, this effect is not enough to offset the substantial reduction in solar radiation. The performance of the tracker is consistent with findings from [13] and [22], where the single-axis and dual-axis tracking systems can still capture more energy than fixed systems under various weather conditions. The studies confirm that although the total energy harvested is lower on rainy days, the trackers continue to outperform fixed systems in terms of energy yield.

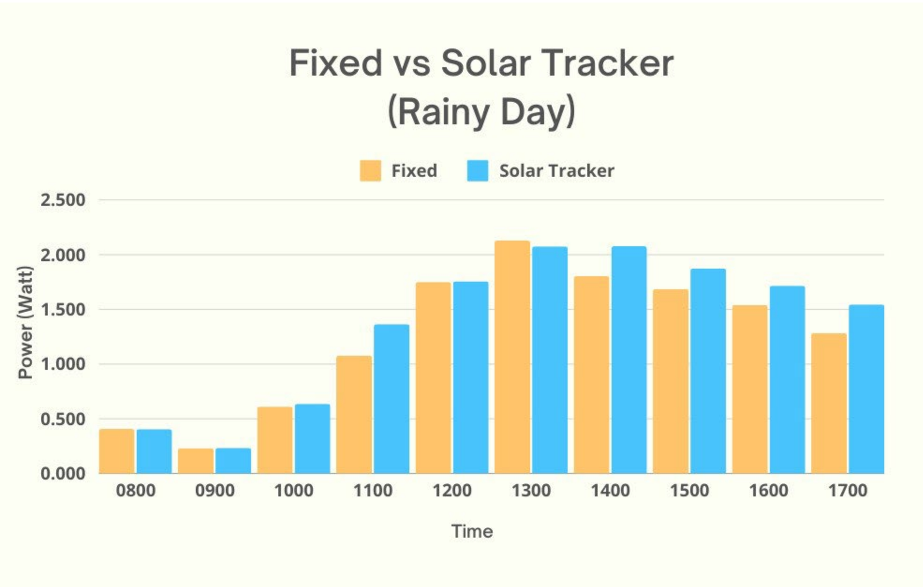

Fig. 8 *Average power output comparison for fixed and solar tracker panels on rainy day*

Table 4 shows the performance of fixed solar panels and solar trackers under different weather conditions (sunny, cloudy, and rainy). It provides the average power output in watts and the percentage increase in power from using a solar tracker. The table highlights the significant increase in power generation using solar trackers, especially under sunny conditions. [5], [6], and [12] explain how solar tracking systems improve the alignment of solar panels with the sun throughout the day, optimizing energy output. Table 4 also shows that the effectiveness of solar trackers diminishes under less ideal weather conditions (cloudy and rainy days), though they still offer an advantage over fixed systems.

Table 4 *Fixed solar panels and solar trackers performance under different weather conditions (sunny, cloudy, and rainy)*

	Sunny		Cloudy		Rainy	
	Fixed	Solar Tracker	Fixed	Solar Tracker	Fixed	Solar Tracker
Average power (Watt)	1.9155	2.0901	1.7142	1.7772	1.2521	1.3684
Power increase (%)		↑8.73%		↑3.15%		↑5.82%

4. Conclusion

In conclusion, this paper presents a comprehensive study on the optimization of light intensity in a microcontroller-based solar tracking system. With the increasing significance of solar energy as a renewable resource in Malaysia, the need to enhance the efficiency of solar panels becomes paramount. Traditional fixed solar panels are limited by their static orientation, which leads to suboptimal power generation as they fail to adapt to the sun's changing position throughout the day. The project focuses on developing an automated solar tracking system that aligns the solar panel with the sun's direction using a microcontroller to address this issue. The project assesses the advantages of a dynamic tracking approach by analyzing the light intensity gained by the solar panel at different tilt angles corresponding to the sun's movement. Leveraging data from a gyroscope to accurately determine the panel's tilt angle, and utilizing a DC multimeter to measure power output, the study quantitatively evaluates the performance of the solar tracking system. The developed automatic solar tracking system proves to be highly efficient through experimental validation. By continuously adjusting the solar panel's position to align with the sun's trajectory, a notable improvement of 9.195% in power generation efficiency is achieved compared to a fixed solar panel at an optimal angle. This result underscores the potential of solar tracking technology to enhance the collection of renewable solar energy significantly. The system can be enhanced for future recommendations by adding a dual-axis tracking system that moves in all directions for complete optimization.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Muhammad Hazim Hazrin, Siti Lailatul Mohd Hassan;* ***data collection:*** *Muhammad Hazim Hazrin;* ***analysis and interpretation of results:*** *Muhammad Hazim Hazrin, Siti Lailatul Mohd Hassan, Ili Shairah Abdul Halim;* ***draft manuscript preparation:*** *Muhammad Hazim Hazrin, Siti Lailatul Mohd Hassan, Nasri Sulaiman. All authors reviewed the results and approved the final version of the manuscript.*

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