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Solar Tracker Panels with Dual Axes Using Auto and Manual Modes

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Abstract

The growing demand for renewable energy sources has resulted in notable progress in solar panel technology, specifically in optimizing energy absorption. Solar Tracker Panels with Dual Axes (STPDAs) are a significant advancement in this area, providing improved energy efficiency through automated and manual tracking modes. The growing global energy demand has heightened the need for alternative energy sources to reduce reliance on fossil fuels. Solar energy, being a significant renewable source, offers a potential solution to this problem. This research explores the performance of various solar tracking systems, specifically manual, single-axis, and auto-tracking systems, to improve solar energy capture. Through experimental analysis, the study highlights that dual-axis auto-tracking systems outperform manual and single-axis systems in aligning with the sun's movement, thus optimizing energy conversion. Data collected over different time intervals demonstrate that the auto-tracking system increases efficiency by 38.87% compared to the manual system and 8.96% over the single-axis system. The results indicate that implementing auto-tracking technology in solar panels can significantly enhance the efficiency of solar energy utilization, contributing to more sustainable energy solutions for smart homes.

Keywords: Solar Tracker Panels, Dual-Axis Tracking, Renewable Energy

1. Introduction

Dual-axis solar tracker panels utilizing both auto and manual modes represent a significant advancement in optimizing solar energy capture. These systems enhance efficiency by continuously aligning solar panels with the sun's trajectory, thus maximizing energy output. Auto solar trackers employ sensors, such as Light Dependent Resistors (LDRs), to detect sunlight and adjust the panel's position accordingly. This method has been shown to significantly improve power generation efficiency [1]. Advanced systems incorporate microcontrollers, GPS, and orientation sensors, allowing for precise tracking with minimal power consumption [2]. Manual modes allow users to adjust the panel's orientation based on specific needs or environmental conditions, providing a balance between automated efficiency and user control [3]. Studies indicate that dual-axis systems can increase energy output by up to 16.03% compared to fixed installations, demonstrating the effectiveness of both tracking modes [4]. Dual-axis solar trackers can enhance energy yield by up to 45% compared to fixed-tilt panels [5]. A dual-axis system with Fresnel lenses achieved a maximum power output increase of 16.03%. The integration of advanced tracking mechanisms allows for continuous optimization of solar panel orientation, maximizing energy capture throughout the day [2]. Although dual-axis systems may have higher initial costs due to complex components, their increased energy output can lead to lower long-term costs per kilowatt-hour produced. The operational efficiency of dual-axis systems, despite a slight reduction in numerical calculation efficiency, supports their viability as a sustainable energy solution [6]. Implementing dual-axis solar tracker panels in commercial and residential settings involves several key design considerations to optimize energy efficiency and system reliability. These considerations include control algorithms, integration with smart systems, and environmental adaptability. This method enhances energy production by up to 27.75% compared to fixed systems, utilizing a proportional-integral scheme with anti-wind-up configurations [7]. MPC has shown a 20.2% increase in energy generation efficiency, outperforming traditional control methods [8].

Implementing smart battery management enhances battery life by monitoring voltage, current, and temperature [9]. Integrating IoT allows for remote monitoring and control, improving decision-making based on real-time data

[8]. Systems that incorporate weather sensors can dynamically adjust panel orientation based on environmental conditions, further optimizing energy production [3].
However, a comprehensive understanding of the solar tracker panels with dual axes using auto and manual modes remains incomplete. Therefore, this study aims to experimentally analyze the solar tracker panels with dual axes using auto and manual modes.

2. Methodology

This research employed an experimental design using Light Dependent Resistors (LDRs) for solar tracking. The methodology is divided into key stages: the experimental setup, site selection, hardware and software components, and system integration.

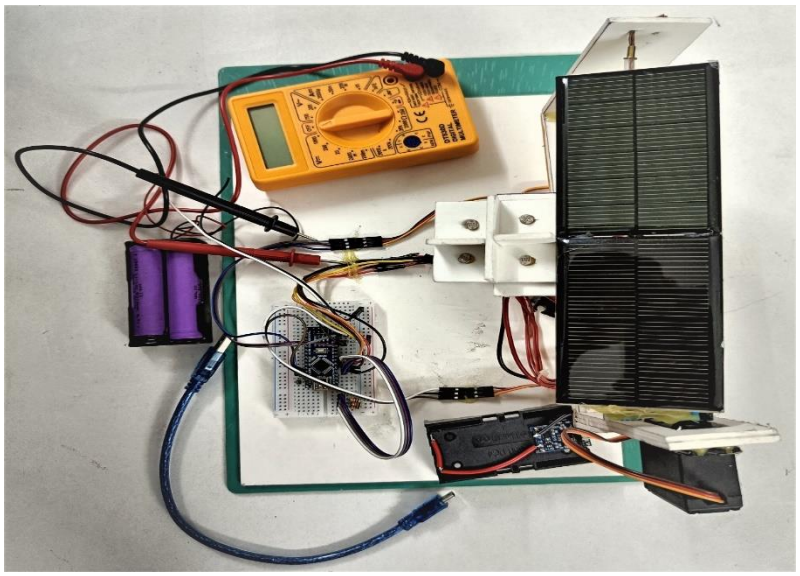


Fig. 1. Final project setup.

3.1 Experimental Setup and Working Principle: The dual-axis and single-axis solar tracking systems were constructed using LDRs connected to an Arduino microcontroller. Four LDRs were used for the dual-axis system, while two LDRs were utilized for the single-axis system. The LDRs detected the light intensity from the sun, and their resistance changed accordingly. The Arduino converted the analogue values from the LDRs into digital signals, which were used to control a DC motor. When one LDR received more light than the other, the Arduino activated the motor to reposition the solar panel, ensuring optimal alignment with the sun. This continuous adjustment increased the system's capacity to capture solar energy efficiently.
3.2 Site Selection: The experiment was conducted in Dhaka, Bangladesh, on the rooftop of a building. The data collection occurred on June 23, 2023, a sunny day, from 7:00 a.m. to 5:00 p.m. This location and time ensured optimal solar exposure for testing the tracking systems.
3.3 Hardware and Software Components: The hardware components included:

- Solar Panel: A polycrystalline mini solar panel (6V, 1W) was selected for its balance of efficiency and cost.
- LDRs (Light Dependent Resistors): Four LDRs were used to detect sunlight intensity, directing the solar panels to the area with maximum sunlight.
- Resistors: 1kΩ resistors were utilized to regulate voltage within the system.
- Arduino Uno: The Arduino served as the central microcontroller, interpreting signals from the LDRs and controlling the motors that adjusted the solar panel’s position.
- Servo Motors (Mini Servo SG90): Two servo motors were employed for horizontal and vertical axis movement.
- 12V Lead-Acid Battery: This powered the system and ensured consistent performance throughout the experiment.
- Multimeter: Used for measuring voltage, current, and resistance during testing.

The software component involved programming the Arduino in the Arduino Integrated Development Environment (IDE), using a C++-based language. The code controlled the movement of the solar panels based on input from the LDR sensors, ensuring real-time adjustment.

3.4 System Integration: All hardware components were integrated into the final project setup, which allowed the solar panels to track the sun across both axes efficiently. The system was designed to maximize solar energy absorption by continuously adjusting the panel's orientation based on real-time light intensity data from the LDR sensors. This setup significantly improved solar energy capture compared to stationary systems.

This methodology ensured that the dual-axis solar tracker operated with higher efficiency than conventional systems, maximizing energy conversion throughout the day.

3. Results and Discussion

The experimental results from the study reveal a clear performance advantage of the dual-axis auto solar tracking system over the manual and single-axis systems. Data was collected for each tracking method across various times of the day, highlighting the power output in watts. The auto solar tracking system consistently captured higher power, with a total energy output of 109 W, compared to 95.07 W from the single-axis system and 66.63 W from the manual system. Table 1 presents difference among generated current, voltage and power in different solar tracking systems.

Table 1: Difference among generated current, voltage and power in different solar tracking systems.

Solar Tracking System / Time	Manual Solar Tracking System			Single Axis Solar Tracking System			Auto Solar Tracking System		
	Current (A)	Voltage (V)	Power (W)	Current (A)	Voltage (V)	Power (W)	Current (A)	Voltage (V)	Power (W)
7:00	0.04	2.10	0.084	0.07	3.31	0.231	0.08	3.41	0.27
8:00	0.08	3.24	0.259	0.41	7.29	2.988	0.49	7.67	3.75
9:00	0.39	7.12	2.77	0.46	8.79	4.04	0.73	8.99	6.56
10:00	0.44	9.18	4.39	0.72	10.11	7.27	0.87	10.21	8.88
11:00	0.61	11.21	6.83	0.81	11.57	9.37	0.97	11.91	11.55
12:00	0.73	11.89	8.68	0.97	11.97	11.61	1.01	12.06	12.19
13:00	0.79	12.06	9.52	1.01	12.11	12.23	1.09	12.11	13.20
14:00	1.01	12.10	12.22	1.09	12.16	13.25	1.17	12.18	14.25
15:00	0.89	11.21	9.97	1.06	11.96	12.67	1.14	12.16	13.86
16:00	0.77	9.02	6.94	1.03	11.31	11.64	1.04	12.02	12.50
17:00	0.69	7.21	4.97	0.99	9.87	9.77	1.00	11.89	11.89

The auto tracking system's ability to perfectly align with the sun throughout the day resulted in a 38.87% improvement in efficiency compared to the manual system, and an 8.96% increase over the single-axis system. This superior performance can be attributed to the auto tracker’s ability to adjust to the sun's position with greater precision, maximizing the amount of solar irradiance converted into electrical energy.

The auto tracker shows a consistent alignment with the sun's path throughout the day, leading to optimal energy conversion. Specifically, the auto tracking system captures the highest power output at each time interval, with a maximum power of 14.25 W at 14:00. This is in contrast to the single-axis tracker, which peaks at 13.25 W, and the manual system, which maxes out at 12.22 W. This improved performance is due to the ability of the auto tracking system to continuously adjust both horizontally and vertically to the sun’s movement, ensuring maximum exposure.

The auto tracking system's efficiency improvement over the manual system was calculated at 38.87%, while the efficiency improvement over the single-axis system was 8.96%. These efficiency gains are critical for optimizing solar panel usage in real-world applications. The dual-axis auto tracker not only maximizes solar energy capture but also contributes to more efficient energy systems for smart homes.

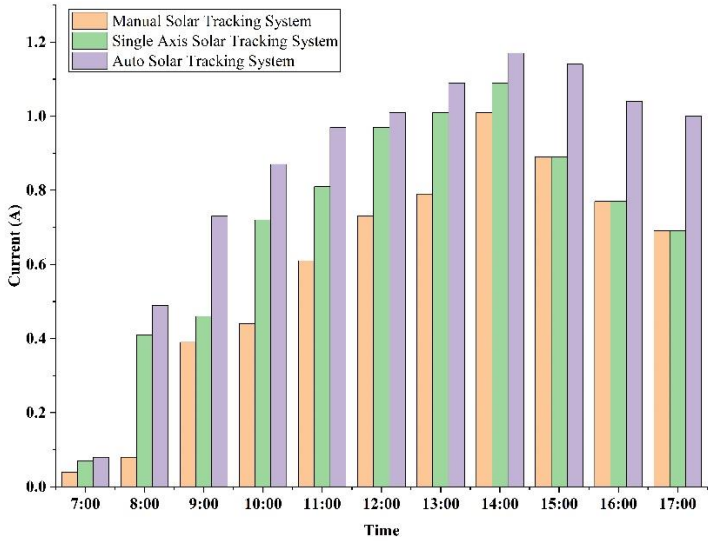


Fig. 2. Comparison of obtained current in different solar tracking system.

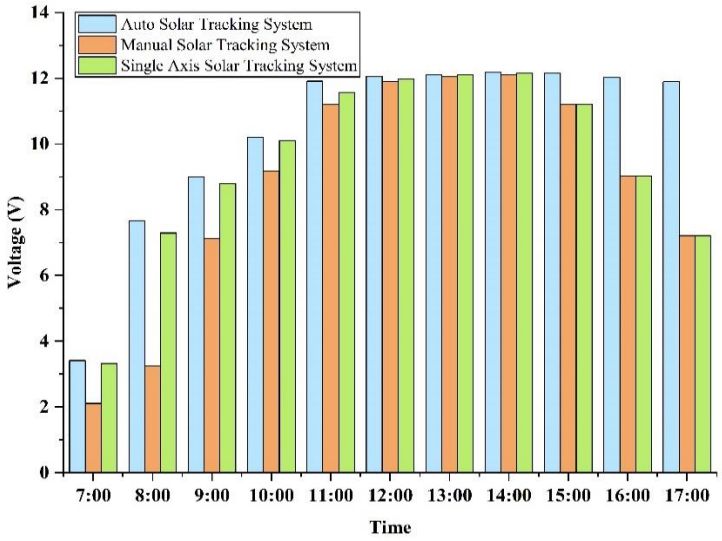


Fig. 3. Comparison of obtained voltage in different solar tracking system.

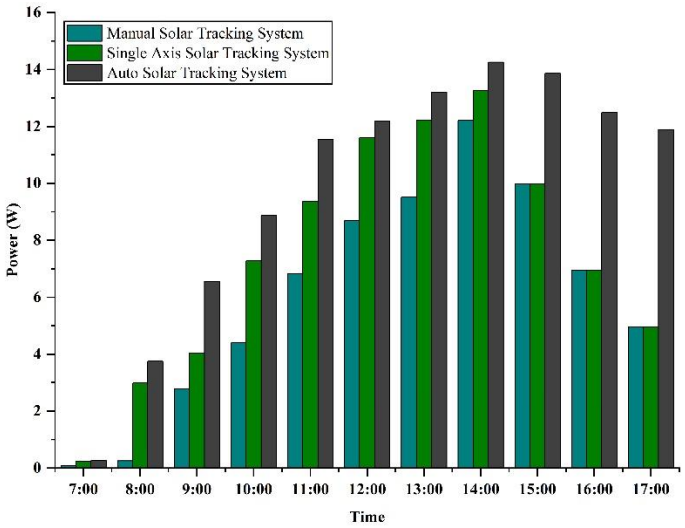


Fig. 4. Comparison of obtained power in different solar tracking system.

This enhanced performance is evident in the bar chart comparisons (Fig. 2. to Fig. 4.), which clearly show the superior power output of the auto tracking system. Thus, the dual-axis auto solar tracker presents a compelling solution for improving solar energy conversion and utilization.

4.4 Efficiency of Solar Track System

The efficiency of solar tracking systems is assessed by comparing the power output of tracked versus stationary solar panels. Efficiency is defined as the percentage ratio of output power to input power. In this study, the power generated by the tracking system serves as the reference for measuring efficiency.

To illustrate, we compare the power output of a single-axis tracking system and an automatic tracking system against a manual axis solar system. The efficiency is calculated as follows:

1. Efficiency of the Single-Axis Tracking System Compared to the Manual Axis Solar System

The efficiency is computed using the formula:

It is mathematical expressed as:

$$\text{Efficiency} = \frac{(\mathbf{P}tracked - \boldsymbol{P}stationary)}{\mathbf{P}tracked} \times 100\,\% \quad (1)$$

2. Efficiency of the Automatic Solar Tracking System Compared to the Manual Axis Solar System

The efficiency is calculated as:

$$\text{Efficiency} = \frac{(\mathbf{P}tracked - \boldsymbol{P}stationary)}{\mathbf{P}tracked} \times 100$$

Where,

Power generated by the single-axis tracking system = 95.070 W

Power generated by the manual axis solar system = 66.63 W

$$\text{Efficiency} = \frac{(95.070 - 66.63)}{95.070} \times 100$$

Efficiency = 29.91 %

Efficiency of Auto solar tracking system to the manual solar system pointing to the Figure. 4.2:

$$\text{Efficiency} = \frac{(\mathbf{P}tracked - \boldsymbol{P}stationary)}{\mathbf{P}tracked} \times 100$$

Where,

Power generated by the automatic solar tracking system = 109 W

Power generated by the manual axis solar system = 66.63 W

$$\text{Efficiency} = \frac{(109 - 66.63)}{109} \times 100$$

Efficiency = 38.87%

3. Improvement in Efficiency of the Automatic Tracking System Compared to the Single-Axis Tracking System

The improvement in efficiency is given by:

$$\text{Improvement} = \text{Efficiency}_{\text{auto-tracking}} - \text{Efficiency}_{\text{single-axis}} \quad (2)$$

Where:

- Efficiency of the automatic tracking system = 38.87%
- Efficiency of the single-axis tracking system = 29.91%

So,

$$\text{Improvement} = 38.87\% - 29.91\% = 8.96\%$$

This calculation demonstrates that the automatic solar tracking system offers an 8.96% improvement in efficiency over the single-axis tracking system. Fig. 5. shows the efficiency difference in different tracking system.

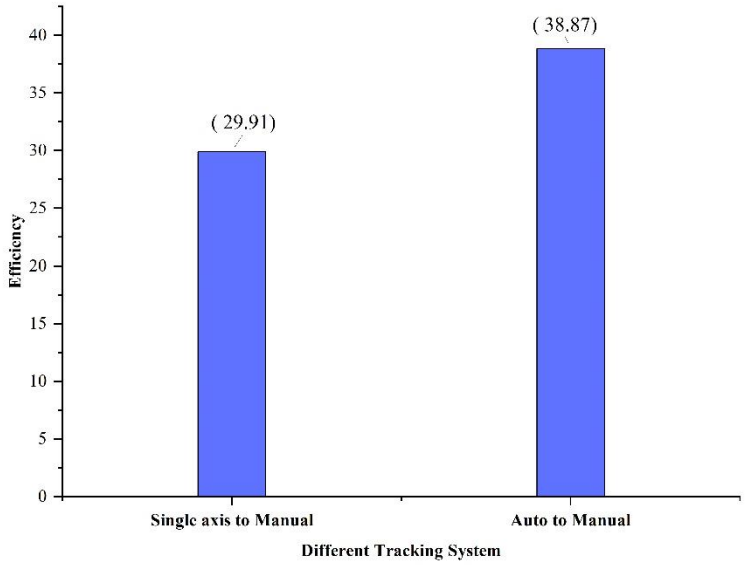


Fig. 5. Efficiency difference in different tracking system.

Conclusion

This research demonstrates that solar tracking systems, particularly dual-axis auto trackers, significantly improve the efficiency of solar energy conversion compared to manual and single-axis systems. The data collected during the experiments highlight a clear advantage of the auto-tracking system in aligning with the sun's path, resulting in higher energy output throughout the day. The efficiency of the auto-tracker was shown to be 38.87% greater than the manual tracking system and 8.96% higher than the single-axis tracker. These findings underline the importance of advanced tracking mechanisms in maximizing solar energy utilization, making them crucial for future energy solutions. The results of this study suggest that the implementation of dual-axis auto-tracking technology can provide a practical and efficient method for enhancing the performance of solar panels, contributing to the development of smart energy systems and a reduction in reliance on fossil fuels.

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