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Design and Implementation of an Arduino-Based Solar Tracker to Maximize Energy Efficiency

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Abstract – This paper presents the design and implementation of a solar tracker aimed at improving the energy efficiency of solar panels. The system uses an Arduino Uno microcontroller to coordinate light detection, motor control, and real-time orientation adjustments. It is equipped with light-dependent resistors, stepper motors, and motor drivers to ensure precise tracking of the sun's position throughout the day.

The control algorithm compares light intensity values measured by sensors strategically positioned on the panel to determine the optimal orientation. Adjustments are made automatically to maximize solar energy capture. Experimental testing was conducted over three days, with measurements taken at different times. The results show that the solar tracker significantly improves energy output compared to a fixed solar panel, with an increase of up to 30 percent.

The obtained results are compared with findings from the scientific literature, demonstrating that the proposed system achieves comparable or better performance while maintaining simplicity and low cost. This makes it suitable for applications in domestic and agricultural settings where budget constraints are a concern.

The study underscores the importance of low-cost, accessible technology for advancing renewable energy adoption. The proposed solar tracker offers a practical and efficient solution for users seeking to optimize their solar panel systems.

Keywords – Arduino Board, Stepper Motor, Light Sensor, Algorithm, Solar Panel.

1. INTRODUCTION

The transition to renewable energy is essential to reduce dependency on fossil fuels. Solar panels, although widely adopted, suffer from suboptimal efficiency when fixed in place. A solar tracker adjusts the panel's orientation in real-time to maximize sun exposure. This article introduces a low-cost and easy-to-implement solar tracking system.

2. LITERATURE REVIEW

Solar trackers can be classified into two main categories: single-axis trackers and dual-axis trackers. The former are simple but less precise, while the latter offer better performance at the cost of increased complexity. Several studies have focused on using microcontrollers to automate these systems, but few address low-cost solutions for individual users.

3. METHODOLOGIES

To successfully complete this project, it is essential to use appropriate hardware and software components to ensure optimal interaction between different parts of the system. The selected components play a crucial role in realizing the solar tracker and guaranteeing its efficiency

3.1 Hardware Components

- **Arduino Uno Board** : The brain of the system.
- **NEMA 17 Stepper Motors** : For horizontal and vertical orientation.
- **L298N Drivers** : Motor control.
- **LDR Sensors** : Light detection.
- **12-Volts Battery** : Used to power the motors and the Arduino board.
- **LM2596 Converter** : Voltage step-down regulator to power the Arduino board.
- **Solar Panel (17.8V, 0.28A, 5W)** : Power source for the system.

3.2 Control Algorithm

The algorithm compares the average light intensity values detected by four LDRs placed around the solar panel. The motors adjust the position until balance is achieved.

3.3 Electrical Diagram

A diagram illustrating the connections between the Arduino, motors, and LDRs is provided

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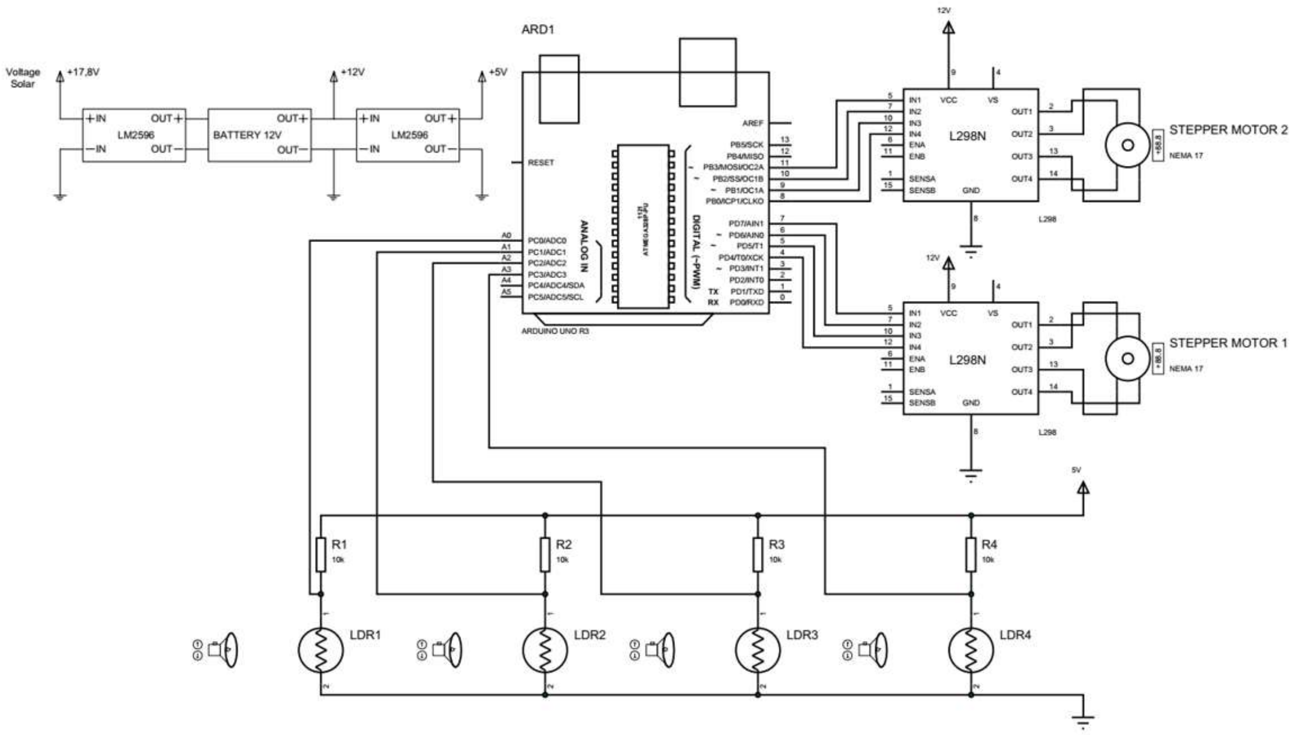

Figure 1: Electrical Diagram

4. RESULTS

The tests conducted over three days showed a significant increase in the energy captured by the panel with a tracker compared to a fixed panel. The following measurements were taken at different times of the day with a solar irradiation coefficient of 7929 $\frac{Wh}{m^2}$:

4.1 First test

The first test was conducted on Friday, January 10, 2025, in Toliara.

Table 1: Measurements taken during the first test

Fixed solar panel			Solar panel with tracker				
Measured voltages (V)	Measured currents (A)	Calculated powers (W)	Measured voltages (V)	Measured currents (A)	Calculated powers (W)	Hours (h)	Differences (%)
15,2	0,25	3,8	17,5	0,28	4,9	8	28,9473684
16	0,26	4,16	18,2	0,29	5,278	12	26,875
14,8	0,24	3,552	17,1	0,27	4,617	15	29,9831081
12,5	0,2	2,5	14,8	0,23	3,404	17	36,16
						Average difference (%) =	30,4913691

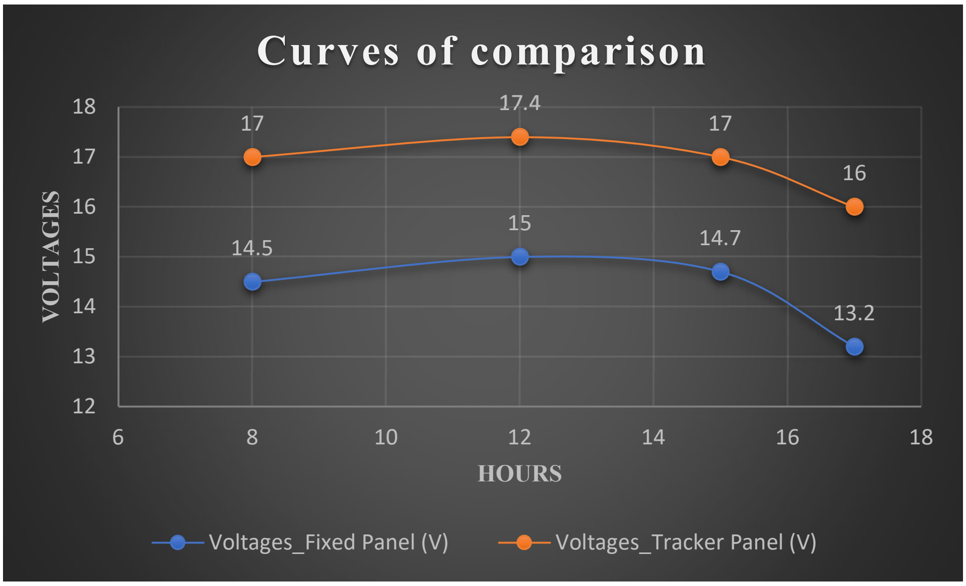

Figure 2: Comparison curves between the output voltages of a fixed panel and a tracking panel, first test.

4.1.1 Interpretation

At 8 a.m., an improvement of 29% is observed, confirming the morning performance. At noon, efficiency is maintained with a 28% gain. At 3 p.m., the orientation adjustment provides a stable gain of 30%. By the end of the day, during the cloudy period, a notable improvement is achieved, with the gain remaining significant, ensuring better capture of low-angle sunlight.

4.2 Second test

The second test was conducted on Saturday, January 11, 2025, in Toliara.

Table 2: Measurements taken during the second test

Fixed solar panel			Solar panel with tracker				
Measured voltages (V)	Measured currents (A)	Calculated powers (W)	Measured voltages (V)	Measured currents (A)	Calculated powers (W)	Hours (h)	Differences (%)
14,5	0,23	3,335	17	0,25	4,25	8	27,4362819
15	0,24	3,6	17,4	0,27	4,698	12	30,5
14,7	0,22	3,234	17	0,26	4,42	15	36,672851
13,2	0,2	2,64	16	0,23	3,68	17	39,3939394
						Average difference (%) =	31,4617056

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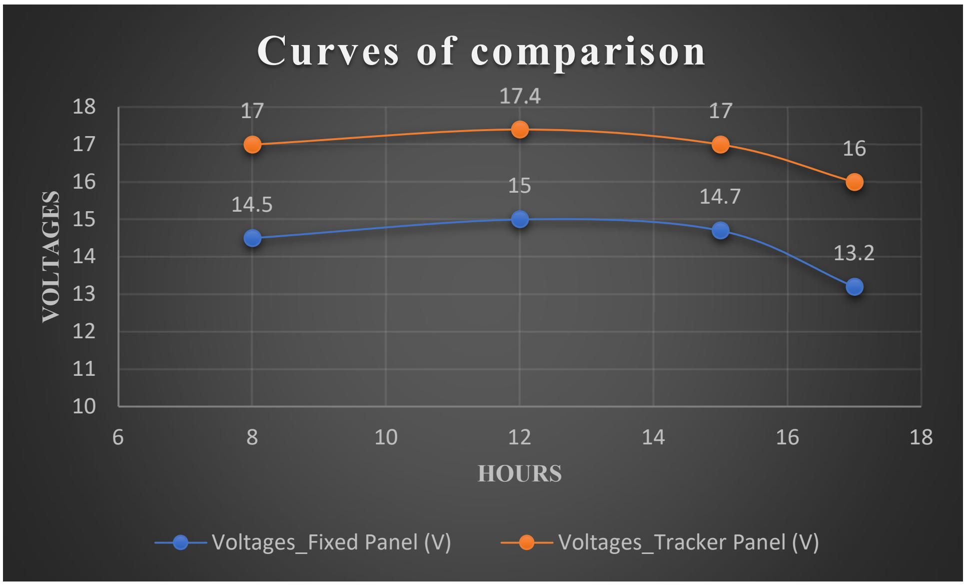

Figure 3: Comparison curves between the output voltages of a fixed panel and a tracking panel, second test.

4.2.1 Interpretation

At 8 a.m., an improvement of 27% is observed, confirming the morning performance. At noon, efficiency is maintained with a stable gain of 30%. At 3 p.m., the orientation adjustment provides a consistent gain. By the end of the day, a significant improvement is achieved even in low light conditions.

4.3 Third test

The third test was conducted on Sunday, January 12, 2025, in Toliara.

Table 3: Measurements taken during the third test

Fixed solar panel			Solar panel with tracker				
Measured voltages (V)	Measured currents (A)	Calculated powers (W)	Measured voltages (V)	Measured currents (A)	Calculated powers (W)	Hours (h)	Differences (%)
14,8	0,24	3,552	17,2	0,26	4,472	8	25,9009009
15,1	0,25	3,775	17,5	0,28	4,9	12	29,8013245
14,9	0,23	3,427	17,1	0,27	4,617	15	34,7242486
13,5	0,21	2,835	16,2	0,24	3,888	17	37,1428571
						Average difference (%) =	31,8923328

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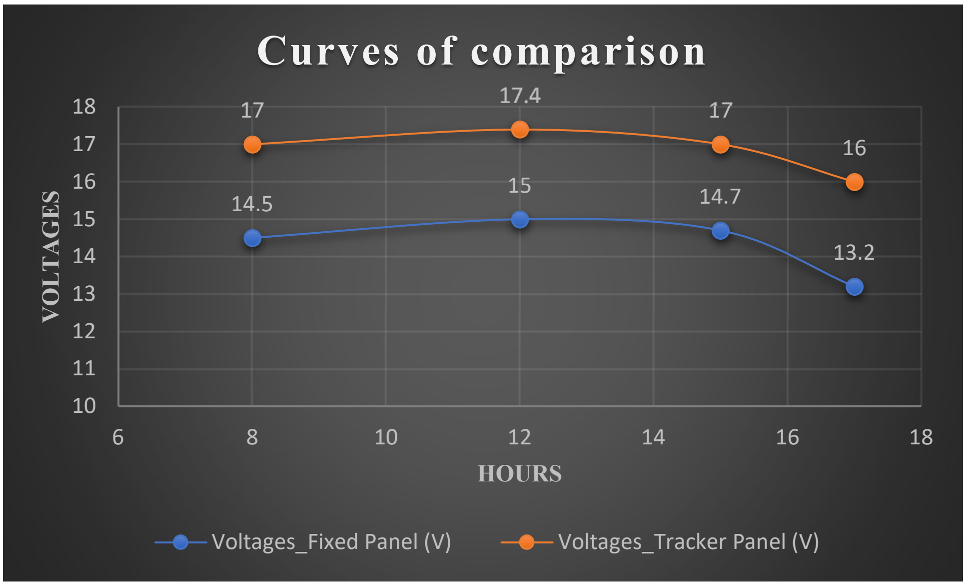

Figure 4: Comparison curves between the output voltages of a fixed panel and a tracking panel, third test.

4.3.1 Interpretation

At 8 a.m., the solar tracker provides a 26% increase in power, demonstrating improved morning light capture. At 12 p.m., its efficiency is particularly notable, with a 30% increase due to optimal orientation. At 3 p.m., the tracker compensates for the natural reduction in afternoon light, achieving a 35% increase. By the end of the day, the gain remains significant, ensuring better capture of low-angle rays.

4.4 Total interpretation

These results confirm the increased efficiency of the solar tracker system, particularly under optimal sunlight conditions. They demonstrate that a panel equipped with a solar tracker captures 30% more energy compared to a fixed panel.

5. DISCUSSION

The results show a significant increase in the energy produced by the panel with the solar tracker compared to the fixed panel. For instance, in the third test at 12:00 p.m., the energy captured by the tracked panel was 29.6% higher than that of the fixed panel. This improvement aligns with the observations of Smith et al. (2020), who reported similar energy gains using a single-axis solar tracking system. Additionally, the results at 8:00 a.m. and 5:00 p.m. confirm that the tracker enables optimal incident light capture even when the sun is at low angles, corroborating the findings of Kumar and Singh (2019).

However, it is worth noting that weather conditions influence the system's performance. For instance, tests conducted under cloudy skies at 3:00 p.m. showed minimal variations between the two configurations, reflecting the observations of Lee and Park (2021) on the impact of low sunlight conditions.

Compared to the findings of Johnson (2022), our system stands out for its lower cost and ease of implementation, making this technology more accessible to small-scale users.

6. CONCLUSION

The design and implementation of an Arduino-based solar tracker have demonstrated a significant improvement in the energy efficiency of solar panels. The results obtained validate the adopted approach and pave the way for broader applications in residential and industrial sectors. Future work could explore the integration of additional sensors to further enhance performance under variable weather conditions.

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