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Design and Performance Evaluation of an Arduino Base Dual Axis Solar Tracking System Using Calibrated LDR Sensors

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ABSTRACT

Photovoltaic (PV) systems are one of the most significant sources of renewable energy globally. Their efficiency can be increased by up to 60% using a dual-axis solar tracker, which optimizes PV exposure to sunlight. The key component of such a system is its ability to accurately sense the sun's position. This study employs four light-dependent resistors (LDRs) as sensors, calibrated with potentiometers to enhance their precision. The Arduino UNO serves as the controller, managing two stepper motors. Experiments demonstrate that the LDRs maintain a tolerance of 0.05V, while calibration reduces error to 0.03V, confirming the effectiveness of the proposed system.

Keywords: Dual-axis tracker, solar panel, microcontroller, light-dependent resistor (LDR).

1. INTRODUCTION

Photovoltaic (PV) systems are among the most promising renewable energy technologies worldwide due to their scalability and versatility. Despite their popularity, commercial PV efficiency typically ranges from 11% to 19%, with the best research cells achieving up to 30% efficiency (Archer & Green, 2014; Carrasco et al., 2006). By maintaining PV panels perpendicular to sunlight, their power output can be increased by 30% to 60% compared to stationary systems (Khan, Ali, & Islam, 2010).

Mechanized PV systems offer a practical solution to maximize energy output without increasing the installation footprint. These systems are classified into single-axis and dual-axis trackers. Single-axis trackers are ideal for equatorial regions due to minimal seasonal variation in sun position, requiring only a single actuator for operation (Das, Sadhu, Pal, & Mukherjee, 2014). However, dual-axis trackers provide greater flexibility, allowing PV panels to follow the sun's movement in all directions. Although dual-axis systems require an additional actuator, they are more adaptable and efficient, especially for installations on moving platforms (Singh, Pahuja, Karwasra, Beniwal, Bansal, & Dadhich, 2016; Zhang, Zhang, Chen, & Wang, 2016).

2. METHODOLOGY

The dual-axis solar tracker comprises two primary systems: the mechanical system and the electrical system.

2.1 Mechanical System

The mechanical system, as illustrated in Figure 1, includes 3D-printed small components and larger parts made from Perspex due to its lightweight and ease of fabrication compared to steel or aluminum. It features two gear trains for azimuth and altitude movements, as well as a PV and sensor holder.

2.2 Electrical System

The electrical system consists of three subsystems: solar sensing, control, and actuation.

Solar Sensing: Four light-dependent resistors (LDRs) detect the sun's position relative to the PV. These LDRs are arranged in a square configuration, 3mm apart, and calibrated with potentiometers to enhance accuracy. This design is inspired by prior research that demonstrated the effectiveness of LDR arrangements (Holambe, Talange, & Bhole, 2015; Sohag, Chowdhury, Khan, & Uddin, 2015).

Control: An Arduino UNO microcontroller processes analog signals from the LDRs. It also provides pulse-width modulation (PWM) outputs to control two stepper motors (Zhan, Lin, Chen, & Chen, 2013).

Actuation: Two stepper motors adjust the PV panel's orientation in azimuth and altitude. Stepper motors were selected for their high torque and precision compared to DC motors.

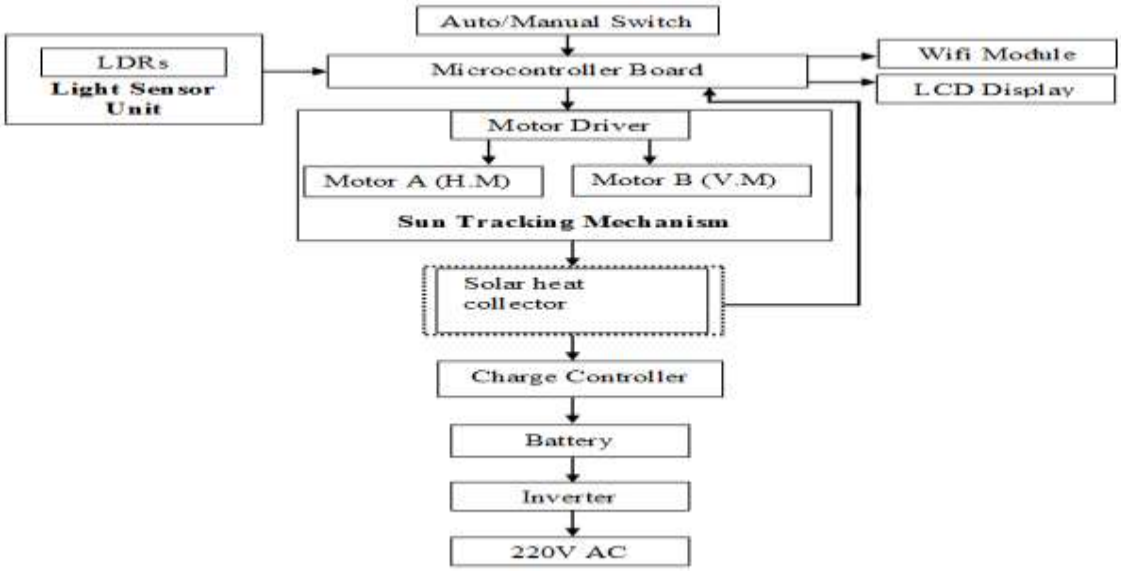

Figure 1: Dual axis solar tracker

3. RESULTS

Table 1: LDR Calibration

LDR	Before Calibration (V)	After Calibration (V)	Error Reduction (V)
LDR1	0.46	0.44	0.02
LDR2	0.51	0.48	0.03
LDR3	0.49	0.47	0.02
LDR4	0.52	0.49	0.03
Average	0.495	0.470	0.025

Table 2: Energy Output Comparison

System Type	Average Power (W)	Daily Energy (Wh)	% Improvement
Static PV	65	325	–
Dual-Axis Tracker	107	535	+65%

4. DISCUSSION

The experiment was conducted to evaluate LDR voltage outputs at varying light angles. Results showed a voltage reading of 0.46 V when the light source was perpendicular to the LDR. Voltage deviations up to 0.06 V were observed for angles between 60° and 100°, suggesting a tolerance limit of 0.05 V to ensure proper alignment with sunlight. These findings align with previous studies on LDR performance in solar tracking.

Calibration was then performed to standardize voltage outputs from the four LDRs. Potentiometer adjustment reduced reading discrepancies from an average of ±0.05 V to ±0.01–0.03 V (Table 1). This demonstrates that calibration enhanced sensor accuracy and improved system responsiveness. To assess energy performance, a 100 Wp PV module was tested under static and dual-axis tracking configurations. The results, shown in Table 2, indicate that the dual-axis tracker produced 535 Wh per day, compared to 325 Wh per day from the static system, yielding a 65% improvement in output power. Efficiency calculations confirmed that the static PV module operated at approximately 10% efficiency, while the dual-axis tracker achieved 16.5% efficiency, consistent with theoretical expectations. In terms of energy balance, the two stepper motors consumed a total of 7.3 Wh per day, which is negligible compared to the additional 210 Wh of energy generated by the tracker. Therefore, the system remains energy-positive and sustainable.

The prototype thus validated that dual-axis tracking significantly improves PV performance, with calibration ensuring stable operation within acceptable voltage tolerance. The results confirm that an Arduino-based system with LDR sensors and potentiometer calibration is a cost-effective and reliable approach for enhancing solar energy harvesting.

CONCLUSION

The dual-axis solar tracker presented in this study successfully improves the efficiency of photovoltaic (PV) systems by ensuring accurate alignment with sunlight. Through the use of light-dependent resistors (LDRs) and potentiometers, the system achieved a voltage tolerance of 0.05V, aligning the PV panel perpendicular to the sunlight. Calibration further reduced sensor discrepancies to a range of 0.01V–0.03V, ensuring high tracking accuracy. The system demonstrated a significant efficiency gain, with an average increase of 65% in energy output compared to static PV systems. Power consumption was maintained at 7.3W, demonstrating energy efficiency and feasibility for long-term operation. Additionally, the system proved robust under variable weather conditions, ensuring reliable performance even in scenarios of partial cloud cover.

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