

Arduino-based dual-axis solar tracking and panel positioning system using light dependent resistor sensors

Shravya , G Srikanth , Thodeti Bhargavi , Adepu Teja Pratap Sai Chandar 

Department of Electrical and Electronics Engineering, Geethanjali College of Engineering and Technology, Hyderabad, India

Article Info

Article history:

Received Mar 3, 2026

Revised Apr 27, 2026

Accepted May 12, 2026

Keywords:

Arduino-based control
DC motor drive
Dual-axis solar tracker
Light dependent resistor sensor
Photovoltaic system
Renewable energy

ABSTRACT

Solar energy is one of the most promising renewable energy sources; however, the power output of photovoltaic (PV) panels strongly depends on their orientation relative to the sun. Fixed solar panels cannot maintain optimal alignment throughout the day, resulting in reduced energy harvesting efficiency. This paper presents an Arduino-based dual-axis solar tracking and panel positioning system that automatically adjusts the panel in both azimuth and elevation directions to maximize solar exposure. The proposed system employs four light dependent resistor (LDR) sensors to detect variations in solar irradiance, while an Arduino Uno microcontroller processes the sensor signals and controls two DC motors through an L293D motor driver to adjust the panel orientation. A voltage sensing module and a DHT11 temperature sensor are integrated for real-time monitoring, with system parameters displayed on a 16×2 LCD. A hardware prototype was developed and tested under natural sunlight conditions. Experimental observations indicate that the PV output voltage varied approximately between 7 V and 11 V during daytime operation, demonstrating effective solar alignment and improved energy harvesting performance. The proposed system provides stable tracking with low power consumption and offers a simple and cost-effective solution for PV applications.

This is an open access article under the [CC BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license.



Corresponding Author:

Shravya

Department of Electrical and Electronics Engineering, Geethanjali College of Engineering and Technology
Hyderabad, Telangana, India

Email: 23r15a0225@gcet.edu.in

1. INTRODUCTION

Solar energy has emerged as one of the most promising renewable energy sources due to increasing global energy demand, depletion of fossil fuels, and growing environmental concerns. Photovoltaic (PV) systems convert sunlight directly into electrical energy; however, their output power strongly depends on the angle of incidence of solar radiation on the panel surface. Fixed solar panels cannot maintain optimal alignment with the sun throughout the day and across seasons, resulting in reduced energy conversion efficiency. To overcome this limitation, solar tracking systems have been developed to dynamically adjust panel orientation and maximize solar energy harvesting. Various solar tracking approaches have been reported in the literature. A satellite-compass-based dual-axis tracker integrating GPS and inclinometer sensors was proposed to achieve precise solar positioning without optical sensors, demonstrating improved power output compared to fixed systems [1]. Arduino-based discrete multi-position tracking strategies have also been evaluated for both single-axis and dual-axis configurations, showing enhanced annual energy generation while reducing continuous motor operation [2]. Experimental comparisons between tilted single-axis and azimuth-altitude dual-axis systems further confirm that dual-axis tracking provides superior performance by following both daily and seasonal solar movement [3].

Several studies have focused on improving tracking accuracy and system efficiency through advanced control strategies and hardware designs. Electromechanical dual-axis trackers driven by stepper motors have demonstrated energy improvements of approximately 25% compared to fixed panels while maintaining low tracking energy consumption [4]. Advanced control methods, including PI and optimized PID controllers, have also been applied to enhance tracking accuracy under varying solar conditions [5]–[7]. In addition, low-cost microcontroller-based implementations using LDR sensors have gained attention due to their simplicity and suitability for small-scale and residential PV applications [8]–[10]. Other studies have investigated structural optimization, mechanical robustness, and wind-load effects to improve system durability [11]–[13], while recent work has explored IoT-based monitoring platforms for real-time system performance evaluation [14], [15]. Further developments include self-powered tracking systems, timer-assisted tracking methods, hybrid energy-efficient tracking approaches, and experimental validation under real environmental conditions [16]–[25].

Despite these advancements, many existing dual-axis tracking systems rely on complex control algorithms, GPS-based positioning techniques, or high-precision sensors, which increase system cost and implementation complexity. Moreover, several studies emphasize simulation-based analysis rather than practical hardware implementation. Limited research also addresses the mechanical feasibility of small-scale tracking systems, particularly in terms of torque requirements and energy consumption of the tracking mechanism. Therefore, there is a need for a simple and cost-effective dual-axis solar tracking system that can be practically implemented while maintaining reliable tracking performance and minimal additional energy consumption. In this work, an Arduino-based dual-axis solar tracking and panel positioning system using LDR sensors is designed and experimentally validated. The system provides automatic panel alignment along both azimuth and elevation axes while maintaining low power consumption and simple hardware architecture. The main contributions of this work are summarized as follows:

- Design and implementation of a low-cost dual-axis solar tracking and panel positioning system using Arduino-based control architecture.
- Development of an LDR-based differential light sensing mechanism for real-time detection of solar irradiance variations and automatic panel alignment.
- Mechanical torque estimation and motor energy consumption analysis to evaluate the feasibility and operational efficiency of the tracking system.
- Experimental validation of the proposed prototype under natural sunlight conditions, demonstrating stable tracking operation and low additional energy consumption.

2. PROPOSED SYSTEM ARCHITECTURE

The proposed dual-axis solar tracking and panel positioning system is designed to maximize PV energy harvesting by maintaining the solar panel as perpendicular as possible to incident sunlight. The overall architecture consists of sensing, control, actuation, and power management units, as illustrated in Figure 1.

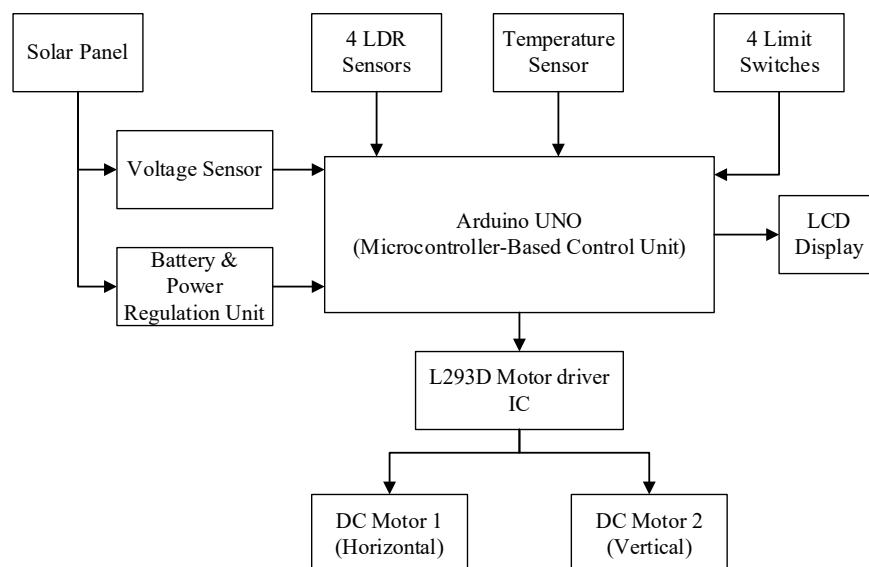


Figure 1. Block diagram of the proposed dual-axis solar tracking and panel positioning system

The block diagram illustrates the interaction between the sensing, control, and actuation units that enable automatic dual-axis solar tracking. A PV panel serves as the primary energy source, and its output voltage is monitored using a voltage sensor connected to the Arduino Uno microcontroller. The generated power is also supplied to a battery and power regulation unit to ensure stable operation of the control circuitry and motor driver.

To determine the direction of maximum solar irradiance, four light dependent resistor (LDR) sensors are arranged in a cross configuration to detect light intensity variations along the horizontal (east–west) and vertical (north–south) axes. The Arduino processes these signals and determines the required panel adjustment. A temperature sensor monitors environmental conditions, while limit switches prevent excessive mechanical rotation. The Arduino generates control signals for the L293D motor driver IC, which drives two DC motors responsible for azimuth and elevation movement of the panel. A 16×2 LCD displays real-time parameters such as panel voltage and temperature. This integrated architecture enables efficient solar tracking while maintaining low system complexity and cost.

3. WORKING PRINCIPLE OF THE DUAL-AXIS TRACKING SYSTEM

The proposed dual-axis solar tracking system operates based on differential light intensity sensing to maintain near-perpendicular alignment between the PV panel and incident sunlight. The system continuously detects the direction of maximum solar irradiance and adjusts the panel orientation along both azimuth (east–west) and elevation (north–south) axes.

Four LDR sensors are arranged in a cross configuration and separated by small barriers to create measurable differences in light intensity. When sunlight falls unevenly on the panel, the LDR sensors produce different resistance values proportional to the received irradiance. These signals are read by the Arduino Uno microcontroller, which compares the light intensity between opposite sensor pairs. If a difference is detected between the left and right LDRs, the azimuth DC motor is activated through the L293D motor driver to rotate the panel horizontally toward the brighter side. Similarly, a difference between the top and bottom LDRs triggers the elevation motor to adjust the panel vertically. When the sensor readings become approximately equal, the controller stops the motors, indicating that the panel is aligned with the direction of maximum sunlight.

The system also monitors PV performance and environmental conditions using a voltage sensing module and a DHT11 temperature sensor. The measured parameters are displayed on a 16×2 LCD for real-time observation. Additionally, four limit switches are incorporated to restrict excessive mechanical rotation and ensure safe operation of the tracking mechanism. Through continuous sensing and controlled motor actuation, the system maintains optimal solar orientation throughout the day, thereby increasing the effective solar irradiance on the panel surface compared to a fixed installation.

The control algorithm implemented in the Arduino microcontroller is illustrated in Figure 2 (in Appendix). The controller continuously reads the signals from the four LDR sensors and compares the intensity differences between opposite sensor pairs. When the difference exceeds a predefined threshold value, the corresponding DC motor is activated to rotate the panel toward the direction of higher irradiance. Once the sensor readings become approximately balanced, the controller stops the motor, indicating proper solar alignment.

To avoid unnecessary motor oscillations caused by minor fluctuations in light intensity, a threshold-based decision method is applied. The threshold value is selected experimentally to ensure stable operation while maintaining adequate tracking sensitivity. In addition, short delays in motor actuation and continuous sensor monitoring help reduce the influence of temporary light variations caused by clouds or shadows. Although the system does not use explicit angular position sensors, the LDR-based approach provides sufficiently accurate solar alignment for small-scale PV applications while maintaining low system complexity and cost.

4. MECHANICAL DESIGN AND PERFORMANCE CONSIDERATIONS

4.1. Mechanical structure design

The mechanical structure of the proposed dual-axis tracking system is designed to provide stable support and controlled rotation of the PV panel. The frame is fabricated using a rigid metallic structure to ensure adequate strength and durability. The system provides two degrees of freedom: azimuth (east–west) rotation and elevation (north–south) tilt adjustment. Two DC motors coupled with external gear reduction mechanisms are used to drive the panel. The gearbox reduces motor speed and increases torque, enabling smooth rotation under load conditions. The azimuth motor is positioned at the base to rotate the entire panel horizontally, while the elevation motor controls vertical tilt. Limit switches are integrated at extreme positions to prevent over-rotation and ensure mechanical safety.

4.2. Torque estimation

To validate motor selection, the torque required to rotate the PV panel is estimated using basic mechanical principles. The force due to the weight of the panel is calculated as (1):

$$F = mg \quad (1)$$

where m is the mass of the panel and $g = 9.81 \text{ m/s}^2$ is gravitational acceleration.

The mass of the 10 W PV panel used in the prototype is approximately 1.2 kg based on manufacturer specifications. Substituting:

$$F = 1.2 \times 9.81 = 11.77N$$

The required torque is given by (2):

$$T = Fr \quad (2)$$

where r is the distance from the pivot to the center of mass of the panel.

For the developed structure, this distance is approximately 0.125 m based on the panel dimensions.

$$T = 11.77 \times 0.125 = 1.47 \text{ Nm}$$

Therefore, the motor–gearbox assembly must provide torque greater than 1.47 Nm to ensure reliable panel rotation.

4.3. Motor energy consumption analysis

The electrical power consumed by the DC motor is determined using:

$$P = VI \quad (3)$$

where V is the motor supply voltage and I is the operating current.

For the proposed system:

$$\begin{aligned} V &= 12V \\ I &\approx 0.4A \end{aligned}$$

Substituting into (3):

$$P = 12 \times 0.4 = 4.8 \text{ W}$$

The daily energy consumption is calculated as (4):

$$E = Pt \quad (4)$$

where t is the operating time in hours.

The motor operates intermittently during tracking adjustments, with an approximate total runtime of 120 seconds per day.

$$t = \frac{120}{3600} = 0.0333 \text{ hours}$$

Substituting into (4):

$$E = 4.8 \times 0.0333 \approx 0.16 \text{ Wh}$$

The system is powered by three 18650 lithium-ion cells connected in series, providing approximately:

$$\begin{aligned} V_{\text{battery}} &= 11.1 \text{ V} \\ \text{Capacity} &= 2.5 \text{ Ah} \end{aligned}$$

The total stored energy is:

$$E_{\text{battery}} = 11.1 \times 2.5 = 27.75 \text{ Wh}$$

The percentage of battery energy consumed daily by the tracking mechanism is therefore:

$$\frac{0.16}{27.75} \times 100 \approx 0.57\%$$

This indicates that the motor energy consumption is negligible compared to the available battery capacity, confirming efficient, and sustainable operation of the tracking system.

5. RESULTS and DISCUSSION

5.1. Prototype implementation and experimental observation

The fabricated dual-axis solar tracking prototype is shown in Figure 3. The system includes a 10 W PV panel mounted on a metallic frame that allows rotation along the azimuth (east–west) and elevation (north–south) axes. Two DC motors with gear reduction mechanisms provide controlled bidirectional movement of the panel. The electronic control unit, consisting of the Arduino Uno microcontroller, L293D motor driver, LDR sensor array, voltage sensing module, DHT11 temperature sensor, LCD display, and a battery pack formed by three 18650 lithium-ion cells connected in series, is mounted on the base platform.



Figure 3. Fabricated prototype of the proposed dual-axis solar tracking system

Experimental testing was conducted under natural sunlight conditions on the rooftop of Geethanjali College of Engineering and Technology, Hyderabad, India. The LDR sensors detect variations in light intensity, and the Arduino controller processes these signals to determine the required panel adjustment. When unequal illumination is detected, the corresponding DC motor rotates the panel toward the direction of maximum irradiance. Once balanced illumination is achieved across the sensors, the motors automatically stop, indicating optimal solar alignment. Limit switches prevent excessive rotation and ensure safe mechanical operation.

During testing, the PV panel output voltage was monitored using the integrated voltage sensor connected to the Arduino microcontroller. The measured voltage values were displayed on the LCD and recorded through serial monitoring. The output voltage typically varied between 7 V and 11 V depending on solar irradiance conditions, confirming effective solar alignment during operation.

Figure 4 illustrates the variation of PV output voltage throughout the day. The voltage gradually increases during the morning as solar irradiance rises, reaches a peak near midday, and decreases in the afternoon as sunlight intensity reduces. This trend confirms that the tracking mechanism maintains appropriate panel orientation and allows effective exposure to solar radiation.

5.2. Comparative analysis

To evaluate the effectiveness of the proposed system, a qualitative comparison between fixed, single-axis, and dual-axis PV tracking configurations is presented in Table 1. According to previous studies, single-axis solar tracking systems typically increase PV energy generation by approximately 10–20%, while dual-axis tracking systems can improve energy output by about 25–35% compared to fixed PV installations.

The approximate prototype cost is estimated to be around 50–60 USD, indicating that the proposed system can be implemented as a low-cost solar tracking solution.

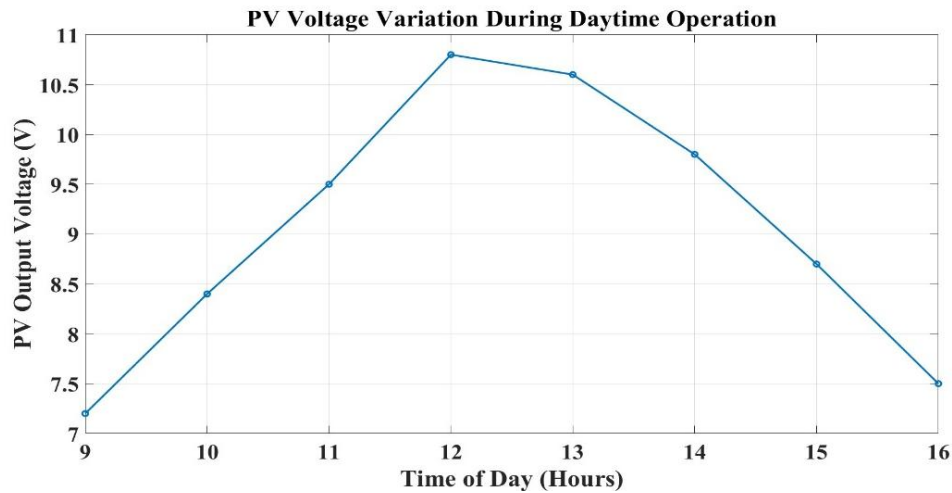


Figure 4. Typical variation of PV panel voltage during daytime operation of the dual-axis solar tracking system

Table 1. Comparison of fixed, single-axis, and dual-axis solar tracking systems

Parameter	Fixed system	Single-axis system	Dual-axis system (proposed)
Degrees of freedom	0	1	2
Tracking direction	No tracking	East-west only	East-west and north-south
Seasonal adjustment	Not available	Not available	Available
Solar incidence alignment	Limited	Moderate	High
Mechanical complexity	Low	Medium	High
Motor energy consumption	None	Low	Low (intermittent)
Implementation cost	Low	Moderate	Moderate
Typical energy gain	Baseline	10-20% increase	25-35% increase

6. CONCLUSION

This paper presented the design and experimental validation of an Arduino-based dual-axis solar tracking and panel positioning system. The proposed system utilizes four LDR sensors to detect variations in solar irradiance and automatically adjust the PV panel orientation along both azimuth and elevation axes. DC motors controlled through an L293D motor driver enable smooth panel movement, while limit switches prevent excessive rotation and ensure safe mechanical operation. The fabricated prototype demonstrated stable tracking performance under natural sunlight conditions.

Experimental observations indicated that the PV output voltage varied approximately between 7 V and 11 V during daytime operation, confirming effective solar alignment throughout the day. Mechanical torque analysis verified that the selected motor–gearbox assembly provides sufficient torque for reliable panel rotation. In addition, energy consumption analysis showed that the tracking mechanism operates intermittently and consumes only a small fraction of the available battery capacity. These results indicate that the additional energy required for tracking has negligible impact on overall system efficiency. Comparative analysis with fixed and single-axis systems further highlights the advantage of dual-axis tracking in improving solar alignment and energy harvesting potential.

The main contributions of this work include the development of a compact Arduino-based dual-axis solar tracking system, the implementation of an LDR-based differential sensing mechanism for automatic panel alignment, and the evaluation of mechanical torque and motor energy consumption to ensure reliable operation. However, the experimental validation was performed using a small-scale 10 W PV module under short-term testing conditions. Future work will focus on long-term performance evaluation under varying climatic conditions, integration of maximum power point tracking (MPPT) techniques to optimize power extraction, and incorporation of IoT-based monitoring for real-time system diagnostics. Additionally, scaling the system for larger PV panels will require higher torque motors and improved mechanical support structures.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CREDIT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Shravya	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓
G Srikanth		✓		✓		✓		✓	✓	✓	✓	✓	✓	
Thodeti Bhargavi	✓		✓	✓						✓	✓		✓	
Adepu Teja Pratap Sai Chandar			✓		✓		✓			✓		✓		✓

C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

- [1] C.-H. Wu, H.-C. Wang, and H.-Y. Chang, "Dual-axis solar tracker with satellite compass and inclinometer for automatic positioning and tracking," *Energy for Sustainable Development*, vol. 66, pp. 308–318, Feb. 2022, doi: 10.1016/j.esd.2021.12.013.
- [2] N. Thungsuk *et al.*, "Performance Analysis of Solar Tracking Systems by Five-Position Angles with a Single Axis and Dual Axis," *Energies*, vol. 16, no. 16, p. 5869, Aug. 2023, doi: 10.3390/en16165869.
- [3] S. Ray and A. K. Tripathi, "Design and development of Tilted Single Axis and Azimuth-Altitude Dual Axis Solar Tracking systems," in *2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, 2016, pp. 1–6, doi: 10.1109/icpeices.2016.7853190.
- [4] H. Shang and W. Shen, "Design and Implementation of a Dual-Axis Solar Tracking System," *Energies*, vol. 16, no. 17, p. 6330, Aug. 2023, doi: 10.3390/en16176330.
- [5] A. O. CA R. Algarin, AJ O. Castro, and J N Casas, "Dual-axis solar tracker for using in photovoltaic systems," *International Journal of Renewable Energy Research*, vol. 7 no. 1, 2017, doi: 10.20508/ijrer.v7i1.5147.g6973.
- [6] P. Singh, R. Pahuja, M. Karwasra, S. Beniwal, M. Bansal, and A. Dadhich, "Dual Axis Solar Tracking System for Solar Panel," *Bulletin of Electrical Engineering and Informatics*, vol. 5, no. 4, pp. 403–411, Dec. 2016, doi: 10.11591/eei.v5i4.565.
- [7] W. Lu and P. Ajay, "Solar PV tracking system using arithmetic optimization with dual axis and sensor," *Measurement: Sensors*, vol. 33, p. 101089, 2024, doi: 10.1016/j.measen.2024.101089.
- [8] C. Jamroen, P. Komkum, S. Kohsri, W. Himananto, S. Panupintu, and S. Unkat, "A low-cost dual-axis solar tracking system based on digital logic design: Design and implementation," *Sustainable Energy Technologies and Assessments*, vol. 37, p. 100618, Feb. 2020, doi: 10.1016/j.seta.2019.100618.
- [9] M. Alam, M. A. Dewan, S. S. Bashar, M. S. Miah, and A. Ghosh, "A Microcontroller Based Dual Axis Tracking System for Solar Panel," in *2019 3rd International Conference on Electrical, Computer & Telecommunication Engineering (ICECTE)*, Dec. 2019, pp. 25–28. doi: 10.1109/icecte48615.2019.9303534.
- [10] N. Othman, M. I. A. Manan, Z. Othman, and S. A. M. Al Junid, "Performance analysis of dual-axis solar tracking system," in *2013 IEEE International Conference on Control System, Computing and Engineering*, Nov. 2013, pp. 370–375, doi: 10.1109/iccscce.2013.6719992.
- [11] O. R. Alomar, O. M. Ali, B. M. Ali, V. S. Qader, and O. M. Ali, "Energy, exergy, economical and environmental analysis of photovoltaic solar panel for fixed, single and dual axis tracking systems: An experimental and theoretical study," *Case Studies in Thermal Engineering*, vol. 51, p. 103635, Nov. 2023, doi: 10.1016/j.csite.2023.103635.
- [12] M. A. M. S. Rahman, R. A. Ferdous, and M. A. Mannan, "Design & implementation of a dual axis solar tracking system," *American Academic & Scholarly Research Journal*, vol. 5, no. 1, pp. 47–54, 2013.
- [13] H.-S. Chen, X.-Q. Lin, C.-M. Hsu, and C.-F. Yang, "Fabrication of a Dual-axis Auto Solar Tracking System," *Sensors and Materials*, vol. 37, no. 6, p. 2421, 2025, doi: 10.18494/sam5671.
- [14] V. Mohanapriya, V. Manimegalai, V. Praveenkumar, and P. Sakthivel, "Implementation of Dual Axis Solar Tracking System," in *IOP Conference Series: Materials Science and Engineering*, vol. 1084, no. 1, p. 12073, Mar. 2021, doi: 10.1088/1757-899x/1084/1/012073.

- [15] S. A. Jumaat, M. N. A. M. Said, and C. R. A. Jawa, "Dual axis solar tracker with IoT monitoring system using arduino," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 1, p. 451, Mar. 2020, doi: 10.11591/ijpeds.v11.i1.pp451-458.
- [16] M. S. Rana, R. S. Prodhan, and M. N. Hasan, "Self Powered Automatic Dual Axis Tracking and Positioning System Design," in *2020 IEEE Region 10 Symposium (TENSYMP)*, 2020, pp. 166–169. doi: 10.1109/tensymp50017.2020.9230692.
- [17] D. Mereddy, V. R. R. V. and T. Sadula, "Smart Dual Axes Solar tracking," in *2015 International Conference on Energy Systems and Applications*, Oct. 2015, pp. 370–374, doi: 10.1109/icesa.2015.7503373.
- [18] Y. Yao, Y. Hu, S. Gao, G. Yang, and J. Du, "A multipurpose dual-axis solar tracker with two tracking strategies," *Renewable Energy*, vol. 72, pp. 88–98, Dec. 2014, doi: 10.1016/j.renene.2014.07.002.
- [19] G. Li, Y. Chen, Y. Yu, R. Tang, and A. Mawire, "Performance and design optimization of single-axis multi-position sun-tracking PV panels," *Journal of Renewable and Sustainable Energy*, vol. 11, no. 6, Nov. 2019, doi: 10.1063/1.5115976.
- [20] R. A. Ferdaus, M. A. Mohammed, S. Rahman, S. Salehin, and M. A. Mannan, "Energy Efficient Hybrid Dual Axis Solar Tracking System," *Journal of Renewable Energy*, vol. 2014, pp. 1–12, 2014, doi: 10.1155/2014/629717.
- [21] C. Alexandru and C. Pozna, "Simulation of a dual-axis solar tracker for improving the performance of a photovoltaic panel," in *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, vol. 224, no. 6, pp. 797–811, 2010, doi: 10.1243/09576509jpe871.
- [22] M. H. Kabir, M. H. Abu Jihad, and S. Chowdhury, "Analysis of Solar Panel Power Investigation using Fixed Axis, Single Axis and Dual Axis Solar Tracker," *Procedia Computer Science*, vol. 252, pp. 708–714, 2025, doi: 10.1016/j.procs.2025.01.031.
- [23] M. Hammas, H. Fituri, A. Shour, A. A. Khan, U. A. Khan, and S. Ahmed, "A Hybrid Dual-Axis Solar Tracking System: Combining Light-Sensing and Time-Based GPS for Optimal Energy Efficiency," *Energies*, vol. 18, no. 1, p. 217, Jan. 2025, doi: 10.3390/en18010217.
- [24] U. Mamodiya and N. Tiwari, "Dual-axis solar tracking system with different control strategies for improved energy efficiency," *Computers and Electrical Engineering*, vol. 111, p. 108920, Oct. 2023, doi: 10.1016/j.compeleceng.2023.108920.
- [25] V. Fedenko, B. Dzundza, M. Pavlyuk, and O. Poplavskiy, "Design of a complex dual-axis solar tracker with an integrated solar PV monitoring system," *Eastern-European Journal of Enterprise Technologies*, vol. 3, no. 8 (135), pp. 6–13, 2025, doi: 10.15587/1729-4061.2025.332548.

APPENDIX

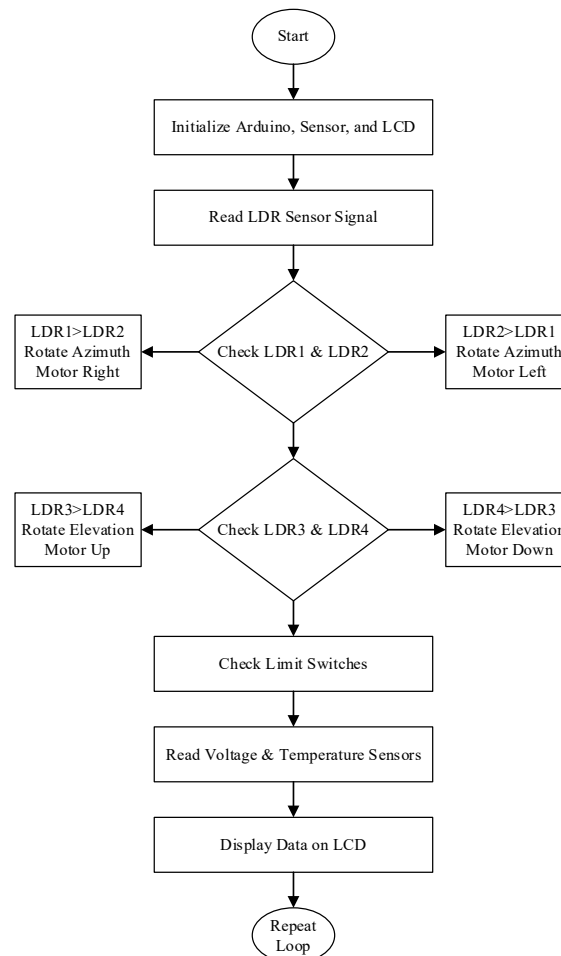


Figure 2. Flowchart of the Arduino-based control algorithm for the proposed dual-axis solar tracking system