

Automatic Solar Tracker Robot Using ESP32

Adarsh, Chanaksha Samrat, Ganesh, Ullas

Department of Electrical and Electronics
Engineering, Dr. Ambedkar Institute of Technology,
Bengaluru

Under the Guidance of: **Mr. Madhusudhan M**, Assistant Professor, Department of EEE

Abstract—This project presents the design and implementation of an Automatic Solar Tracker Robot (ASTR) controlled by an ESP32 microcontroller. The system integrates dual-axis solar tracking with robotic mobility to maximize energy harvesting compared to conventional fixed panels. Sunlight intensity is detected using Light Dependent Resistors (LDRs), and DC motors adjust the panel's orientation in real time. Voltage and current sensors continuously monitor electrical output, which is displayed on a 2×16 LCD, while a 12V lead-acid battery stores the generated energy. Wireless manual control is enabled through an HC-05 Bluetooth module. The firmware, developed in Embedded C using the Arduino IDE, incorporates closed-loop algorithms for tracking, calibrated measurement routines, and Bluetooth command parsing. The experimental evaluation confirms that the prototype improves energy utilization and offers a portable renewable energy solution suitable for field applications.

Index Terms—Autonomous Robot, Dual-Axis Tracking, ESP32, LDR Sensors, Renewable Energy, Solar Tracking

I. INTRODUCTION

Solar energy is one of the most promising renewable sources, but its efficiency depends heavily on how effectively sunlight is captured. Conventional fixed photovoltaic panels often operate below their potential because the Sun's position changes throughout the day, altering the angle of incidence. To address this limitation, solar tracking systems are employed, which dynamically adjust the orientation of panels to maintain maximum exposure.

The Automatic Solar Tracker Robot (ASTR) is designed to enhance energy absorption by combining dual-axis tracking with robotic mobility. Light Dependent Resistors (LDRs) are used to sense variations in sunlight intensity, while the ESP32 microcontroller processes these inputs and generates control signals for DC motors to reposition the panel. With its ability to move toward regions of stronger irradiance, the robot improves overall energy yield in outdoor environments. The system also integrates wireless control and real-time monitoring, making it suitable for portable renewable energy applications such as agriculture, mobile energy platforms, and emergency power supply.

II. MOTIVATION AND SCOPE

Conventional fixed photovoltaic panels often experience reduced efficiency as the sun changes position throughout the day. Although single-axis trackers provide some improvement by adjusting the orientation along one axis, they remain inadequate in dynamic outdoor conditions. The Automatic Solar Tracker Robot (ASTR) addresses these shortcomings

by integrating dual-axis tracking with mobility. This combination allows the system to continuously align with maximum sunlight while relocating to areas of higher irradiance. As a result, the ASTR offers a portable and efficient energy solution suitable for applications such as agriculture, remote monitoring, and emergency power supply.

III. SYSTEM DESIGN AND METHODOLOGY

The Automatic Solar Tracker Robot (ASTR) brings together sensing, control, actuation, power management, and communication within a compact design. Light Dependent Resistors (LDRs) are used to detect directional sunlight intensity, while the ESP32 microcontroller runs the tracking logic and issues control signals. The DC motors adjust the tilt and rotation of the panel to maintain optimal alignment. Voltage and current sensors provide real-time measurements, which are shown on a 2×16 LCD display. The energy harvested from the solar panel is stored in a 12V lead-acid battery and an HC-05 Bluetooth module enables wireless manual control when required.

A. Key Hardware Components

ESP32 Microcontroller: The ESP32 functions as the primary control unit of the system. It collects analog inputs from the LDR sensors, processes the data, and generates PWM signals to drive the DC motors for solar panel orientation. In addition, it manages Bluetooth communication for wireless control. The microcontroller is equipped with a dual-core processor, integrated Wi-Fi and Bluetooth modules, and is designed for low power consumption, making it well-suited for portable and energy-efficient applications.

LDR Sensors: Light Dependent Resistors (LDRs) are positioned at different angles to sense the intensity of sunlight. Their resistance decreases as the light level increases, and this variation is used by the control system to determine the direction of maximum illumination. Based on these readings, the solar panel is aligned toward the brightest source, ensuring optimal energy capture.

DC Motors: The system employs two motors to adjust the solar panel's tilt and rotation, ensuring proper alignment with sunlight. Another pair of motors is dedicated to driving the robot base, enabling mobility and repositioning. All motors are operated through the L298N motor driver, which receives control signals from the ESP32 microcontroller for precise and coordinated movement.

Motor Driver (L298N): The L298N module serves as the interface between the ESP32 microcontroller and the DC

motors. It boosts the low-power control signals from the ESP32 to supply sufficient current for motor operation at 12V.



Fig. 1. Block diagram of the Automatic Solar Tracker Robot (ASTR)

The driver supports bidirectional rotation and provides dual-channel functionality, allowing simultaneous control of both tracking and mobility motors.

HC-05 Bluetooth Module: The HC-05 module provides wireless connectivity, allowing the robot to be controlled through a smartphone. Establishes communication with the ESP32 microcontroller using the UART interface (TX/RX pins). With a typical operating range of up to 10 meters, it enables convenient remote operation and enhances the system's portability.

Voltage and Current Sensors: These sensors continuously monitor the electrical output from the solar panel in real time. The ESP32 microcontroller receives the analog signals, calculates the corresponding power values, and presents the results on the LCD display. This setup ensures accurate performance tracking and helps evaluate the efficiency of the solar tracker system.

LCD Display (2x16): The LCD module provides a realtime interface for the user by displaying measured voltage, current, and calculated power values along with system status indicators. This enhances monitoring capability and improves user interaction by making the performance of the solar tracker easily observable.

Solar Panel: The solar panel serves as the primary energy source of the system. It transforms incoming sunlight into electrical power, which is used to operate the robot and simultaneously charge the battery. The panel is installed on a movable frame, allowing it to be repositioned for optimal exposure to sunlight.

12V Lead-Acid Battery: The battery functions as an energy storage unit, ensuring continuous operation when sunlight is insufficient. It supplies stable power to the ESP32 microcontroller and the DC motors during cloudy weather or low-light periods, thereby maintaining reliable system performance.

Chassis and Frame: The chassis serves as the structural foundation of the robot, offering both mechanical support and mobility. It securely accommodates all electronic and mechanical components, ensuring stability while allowing smooth movement in outdoor environments.

B. Subsystems

Sensing: LDRs measure differential light intensity. **Control:** ESP32 processes signals, generates PWM, and manages

Bluetooth. **Actuation:** DC motors adjust panel orientation and drive the robot base. **Power:** Solar modules charge a 12V battery; sensors compute readings using:

$$P = V \cdot I$$

Communication: HC-05 provides wireless override and mobility commands.

C. System Flow

- 1) The LDR sensors capture variations in sunlight intensity and transmit the readings to the ESP32 microcontroller.
- 2) The ESP32 analyzes the input data and generates PWM signals that are sent to the motor driver.
- 3) Based on these signals, the DC motors adjust the solar panel's orientation and reposition the robot whenever necessary.
- 4) Voltage and current sensors continuously monitor the electrical output; the ESP32 computes the power values and displays them on the LCD.
- 5) The HC-05 Bluetooth module enables wireless manual control, allowing the user to override mobility and tracking functions when required.

IV. IMPLEMENTATION

The hardware setup consisted of the ESP32 microcontroller, LDR sensors, motor driver circuits, DC motors, an LCD module, Bluetooth interface, solar panels, and a 12V lead-acid battery. The firmware was programmed in Embedded C using the Arduino IDE, incorporating threshold-based tracking to minimize oscillations, calibrated routines for voltage and current measurement, and command parsing for Bluetooth communication. System integration tests were carried out to ensure proper coordination among the sensing, control, actuation, and communication subsystems.

V. RESULTS AND DISCUSSION

Field experiments conducted under direct sunlight demonstrated that the tracker reliably oriented the solar panel toward the point of maximum irradiance, achieving a response time of less than two seconds. Comparative measurements confirmed that the system delivered higher voltage and current outputs than a stationary panel. The Bluetooth-enabled mobility feature also showed stable performance, maintaining consistent responsiveness within a range of approximately 10 meters. However, certain limitations were observed, including reduced efficiency during cloudy weather and minor mechanical misalignments that slightly affected tracking accuracy.

TABLE I
PERFORMANCE COMPARISON: STATIC VS. TRACKED PANEL

Parameter	Static Panel	ASTR (Tracked)
Voltage (V)	10.2	13.4
Current (A)	0.8	1.1

Overall, the Automatic Solar Tracker Robot (ASTR) presents a practical and economical approach that combines

solar energy optimization with robotic mobility. Its compact design and dual-axis tracking capability make it a portable solution for enhancing renewable energy utilization in diverse applications.



Fig. 2. Experimental results of the Automatic Solar Tracker Robot (ASTR)

ACKNOWLEDGEMENT

We sincerely thank our project guide Mr. Madhusudhan M, Assistant Professor, Department of Electrical and Electronics Engineering, Dr. Ambedkar Institute of Technology, Bengaluru, for his valuable guidance, encouragement, and support throughout the course of this project. We also extend our gratitude to the faculty and staff of the Department of EEE for providing the necessary facilities and assistance.

VI. CONCLUSION

The Automatic Solar Tracker Robot (ASTR) demonstrates effective integration of hardware and software to deliver a portable, intelligent, and energy-efficient solution. Its continuous tracking capability improves solar energy utilization, while wireless control and real-time monitoring expand its usefulness in field applications. The system shows strong potential for deployment in off-grid agricultural areas, mobile energy platforms, and disaster recovery operations. Future enhancements may focus on improving dual-axis tracking accuracy, incorporating IoT-based monitoring for remote supervision, and upgrading battery capacity to ensure longer operational endurance.

REFERENCES

- [1] M. A. Al-Sheikh, "IoT-Enabled Dual-Axis Solar Tracking System Using ESP32 and Blynk for Real-Time Monitoring and Energy Optimization," *Jupiter Journal of Electrical & Informatics Engineering*, vol. 3, no. 1, 2025. e-ISSN: 3031-349X.
- [2] A. D. Morales et al., "Maximum Solar Energy Tracking Leverage: High-DoF Robotics System with Deep Reinforcement Learning," *arXiv Preprint*, vol. 13, 2025. Electronic ISSN: 2169-3536.
- [3] A. Jiang et al., "V-Model Based Integration of Mechatronics and Power Electronics in Solar Tracking Systems," *IEEE Xplore*, 2024. arXiv:2411.14568.
- [4] Z. K. Aciroz, M. Sameer, M. Shahid, and A. Mohd, "Design and Development of Solar Powered Automated Grass Cutting Machine," *International Journal for Research in Applied Science and Engineering Technology (IJRASET)*, 2023.
- [5] IJERT, "LDR-Based Sun Tracking," *International Journal of Engineering Research & Technology (IJERT)*, vol. 11, no. 4, pp. 215–219, 2022.
- [6] A. Abdelaziz et al., "Simultaneous Placement of Multiple Rooftop Solar PV Integrated Electric Vehicle Charging Stations for Reliability Benefits," *Energy Reports*, 2022.
- [7] R. K. Gaur and A. Goel, "Dual Axis Solar Tracker and Battery Management System," *International Journal of Thoughts (IJCRT)*, 2021.
- [8] Y. M. Chen, C. C. Lin, Y. C. Chang, and H. C. Wu, "Energy Recovery and Harvesting in Electric and Fuel Cell Vehicles: A Review of Recent Advances," *Renewable and Sustainable Energy Reviews*, vol. 117, pp. 109–124, 2020.
- [9] R. Haripriesth, S. S. Kumar, and M. R. Prakash, "Solar Tracking of EV Charging System Using IoT," *International Research Journal of Engineering and Technology (IRJET)*, vol. 7, no. 5, pp. 245–250, 2020.
- [10] M. Kuss and A. Pratt, "Vehicle-Solar Grid Integration in a Commercial School Bus Operation," *IEEE Transactions on Transportation Electrification*, vol. 5, no. 3, pp. 456–464, 2019.