

AUTOMATIC SOLAR TRACKER TO MAXIMIZE ENERGY USING ARDUINO

T Aruna Jacintha¹, HP Rahul Gowda², Harsha R³, Ramalingegowda HV⁴, Yashwanth Kumar K⁵

¹Department of Electronic & Communication Engineering, R R Institute Of Technology,(VTU) Bangalore, Karnataka, India.

²Department of Electronic & Communication Engineering, R R Institute Of Technology,(VTU) Bangalore, Karnataka, India.

³Department of Electronic & Communication Engineering, R R Institute Of Technology,(VTU) Bangalore, Karnataka, India.

*Corresponding Author: yashwanthkumar33@gmail.com

Abstract (Size 9)

This paper presents a mini-project on an Automatic Solar Tracker using Arduino to improve the efficiency of solar energy harvesting by overcoming the limitation of fixed solar panels that cannot follow the sun's movement. The system uses LDR sensors to detect sunlight intensity from different directions and sends this data to an Arduino microcontroller, which processes the signals and controls a servo motor to adjust the position of the solar panel toward the maximum light source. This automatic tracking mechanism ensures continuous alignment with the sun throughout the day, thereby maximizing energy output without manual intervention. The prototype was developed and tested under various lighting conditions, showing improved performance compared to stationary panels. The system is cost-effective, reliable, and scalable, with future enhancements such as dual-axis tracking and IoT-based monitoring for better analysis and control.

Keywords- Arduino, LDR, Solar panel, Servo motor, Motor Driver (L298N)

1. Introduction

Solar energy is a widely used renewable source due to its sustainability and environmental benefits, but fixed solar panels cannot continuously capture maximum sunlight as the sun's position changes throughout the day and seasons, leading to reduced efficiency. To address this issue, this project presents an Automatic Solar Tracker using Arduino that optimizes energy output by maintaining proper alignment of the solar panel with the sun. The system uses LDR sensors to detect sunlight intensity and an Arduino microcontroller to process the signals and control a servo motor that adjusts the panel toward the brightest light source. This enables real-time, automatic tracking without human intervention and adapts to changing weather and lighting conditions. The prototype was tested under various conditions and showed improved energy generation compared to stationary panels. The system is cost-effective,

efficient, and suitable for small-scale applications, with future enhancements such as dual-axis tracking, battery integration, and IoT-based monitoring for better performance analysis.

2. Related Work

Several recent studies highlight trends and challenges in Automatic solar tracker using Arduino.

Kabilan et al. (2025) presented a comprehensive overview of an advanced automatic solar tracking system using an ESP8266 microcontroller, emphasizing low-cost implementation, wireless communication, and improved energy efficiency compared to fixed solar panels; their study demonstrated that real-time light sensing combined with microcontroller-based control can dynamically adjust panel orientation to maximize solar energy capture, although it lacked detailed long-term

performance analysis under varying environmental conditions.

Asri et al. (2024) further enhanced this concept by integrating Internet of Things (IoT) technology for remote monitoring, data acquisition, and system optimization, showing that cloud-based analytics and real-time performance tracking improve system reliability and enable adaptive control, despite added complexity related to network dependency and security concerns.

Husin et al. (2021) compared fixed and auto-tracking solar panels with IoT monitoring, showing that real-time data helps improve efficiency and optimize performance under varying sunlight conditions.

Lee et al. (2022), Hamidin and Sadun (2023) developed an IoT-based automatic solar tracking system designed for oriented solar cell applications. Their study demonstrated effective performance through continuous monitoring and intelligent control of the panel position.

Patel et al. (2017) developed an automatic solar tracking system using a microcontroller, showing that automated control of solar panel movement based on light detection greatly increases energy output when compared to stationary photovoltaic installations, making the system more efficient and practical for continuous energy generation.

Gupta et al. (2020) developed an Arduino-based dual-axis solar tracker, demonstrating that dual-axis movement significantly enhances solar energy harvesting through optimal panel orientation.

3. Materials and Methods

A. System Architecture

The proposed system is designed as an Arduino-based automatic solar tracking system that uses light-dependent resistor (LDR) sensors to detect sunlight intensity. The system integrates multiple LDR sensors to monitor the position of the sun and adjust the orientation of the solar panel for maximum energy absorption. Key parameters such as light intensity and panel alignment are continuously measured to ensure efficient power generation.

The Arduino microcontroller acts as the central processing unit, controlling the system based on

sensor inputs. The LDR sensors are interfaced with the Arduino through analog input pins, where they provide varying voltage levels depending on light intensity. Based on these inputs, the Arduino processes the data and determines the direction in which the solar panel should move.

The system uses servo or DC motors to automatically adjust the panel position in real time. This ensures that the solar panel remains aligned with the sun throughout the day. The overall design improves energy efficiency, provides continuous tracking, and offers a reliable and cost-effective solution for solar power optimization.

B. Workflow Description

The working of the system follows a structured sequence of operations. Initially, the Arduino microcontroller powers up and initializes all connected components, including the LDR sensors and motor driver. Once initialization is complete, the system begins monitoring the surrounding light conditions.

After startup, the Arduino continuously reads light intensity values from multiple LDR sensors through its analog input pins. These sensors are placed at different positions to detect the direction of maximum sunlight. The collected data is compared to determine the difference in light intensity on each side of the solar panel.

Based on this comparison, the Arduino processes the signals and decides the direction in which the panel should move. If an imbalance in light intensity is detected, control signals are sent to the servo or DC motor to adjust the panel position toward the higher light source.

The system continuously updates the panel orientation in real time to maintain optimal alignment with the sun. Basic filtering or threshold conditions are applied to avoid unnecessary movements due to minor fluctuations or noise. This ensures stable operation, improved efficiency, and reliable solar energy tracking throughout the day.

The system also includes a feedback mechanism to ensure accurate positioning of the solar panel. The LDR sensors continuously monitor light intensity even after each movement, allowing the Arduino to verify whether the panel is correctly aligned with the

sun. If any deviation is detected, corrective adjustments are made automatically to maintain optimal positioning.

C. System Design

The system design of the Automatic Solar Tracker Using Arduino is based on the integration of sensing, processing, and actuation units to maintain continuous alignment of the solar panel with the sun. LDR sensors detect variations in sunlight intensity and convert them into electrical signals, which are sent to the Arduino microcontroller. The Arduino compares these values to identify the direction of maximum light and generates control signals to drive a servo motor that adjusts the panel position accordingly. The system is powered by a regulated supply for stable operation and remains stationary when light intensity is balanced. When changes in sunlight are detected, the controller makes precise adjustments to reorient the panel. Overall, the design is simple, reliable, and energy-efficient, ensuring improved solar tracking performance with minimal power consumption.

3.1 Hardware Components

A. Arduino Microcontroller

Arduino Microcontroller: The Arduino acts as the main controller of the solar tracking system. It processes inputs from LDR sensors, identifies the direction of maximum sunlight, and generates control signals to adjust the solar panel. It operates at 5V, is programmed using the Arduino IDE, and is preferred for its simplicity, flexibility, and low power consumption in real-time applications. The Arduino microcontroller is programmed using the Arduino IDE in embedded C and serves as the core controller of the automatic solar tracking system. It is responsible for initializing all connected components, continuously reading analog inputs from LDR sensors, and comparing light intensity values to determine the direction of maximum sunlight. Based on these comparisons, it makes real-time decisions and generates PWM control signals to drive servo or DC motors for adjusting the solar panel position. To improve stability and accuracy, basic thresholding and filtering techniques are used to avoid unnecessary movements caused by minor fluctuations in light readings. The system also handles simple fault conditions by maintaining the last stable position when sensor data is unreliable.

Overall, the Arduino ensures smooth coordination between sensing and actuation for efficient solar tracking.

B. LDR Sensor

The LDR (Light Dependent Resistor) sensors are simple and cost-effective light sensing components used in the automatic solar tracking system. They operate based on the principle that their resistance changes according to the intensity of incident light, allowing the system to detect variations in sunlight from different directions.

These sensors are arranged in multiple positions around the solar panel to compare light intensity levels. The Arduino reads the analog output from the LDR sensors and uses this data to determine the direction of maximum sunlight. This makes them highly suitable for real-time sun tracking applications due to their simplicity, reliability, and low cost.

C. Servo Motor Sensor

Servo or DC motors are used to rotate the solar panel and enable it to follow the movement of the sun. A servo motor is typically preferred for precise angle control in single-axis or dual-axis tracking systems, while DC motors with gear mechanisms are used when higher torque is required. The Arduino generates PWM (Pulse Width Modulation) signals to control the speed and direction of the motors. A proper mechanical structure is used to ensure smooth movement and accurate solar tracking throughout the day.

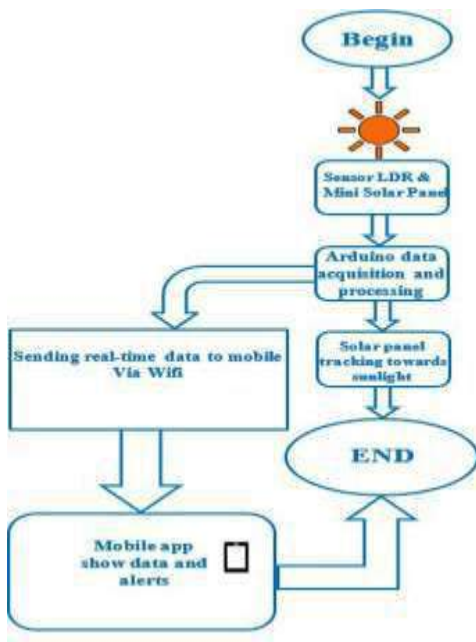


Fig. 1. Block Diagram of the Automatic Solar Panel

D. Software And Firmware

The firmware for the automatic solar tracking system is developed using Arduino IDE in embedded C for the Arduino microcontroller. It handles sensor initialization, continuous LDR reading, light intensity comparison, decision-making, and motor control. At startup, all components are initialized, and the system continuously reads analog sensor values to determine the direction of maximum sunlight. To improve stability, thresholding and simple filtering are used to reduce unnecessary motor movements caused by minor light fluctuations. Based on these readings, PWM signals are generated to control servo or DC motors for adjusting the solar panel position. The system also manages basic faults by holding the last stable position when readings are unstable. Its modular code structure allows easy modification and future upgrades.

4. Results and Discussion

The automatic solar tracking system showed reliable performance in aligning the solar panel with maximum sunlight. LDR sensors accurately detected changes in light intensity, allowing the system to adjust the panel position effectively with good response time and smooth operation. The Arduino processed sensor data and controlled the motor to orient the panel toward the brighter light source, ensuring improved energy absorption. The system remained stable during testing, with reduced

unnecessary motor movements, which helped lower power consumption and mechanical wear. Overall, the results confirm that the Arduino-based solar tracker is an efficient, cost-effective, and practical solution for enhancing solar energy utilization in small-scale applications.

A. Solar panel is in 0-degree position

The performance of the automatic solar tracking system is evaluated based on the position of the solar panel under controlled conditions. The results indicate that the solar panel initially remains at a 0-degree position, representing the default or reference alignment of the system.



Fig. 2. Automatic Solar Tracker Output Position in 0-Degrees

The observation shows that the system is able to maintain a stable initial position before tracking begins. Minor variations in movement may occur due to sensor sensitivity and environmental factors such as light intensity fluctuations.

Overall, the system demonstrates proper initialization and stable positioning at 0 degrees, forming a reliable starting point for accurate solar tracking and efficient energy capture.

B. Solar panel is in 90-degree position

The performance of the automatic solar tracking system is evaluated based on the panel position under controlled conditions. The results show that

the solar panel adjusts to a 90-degree position when maximum sunlight is detected from that direction.

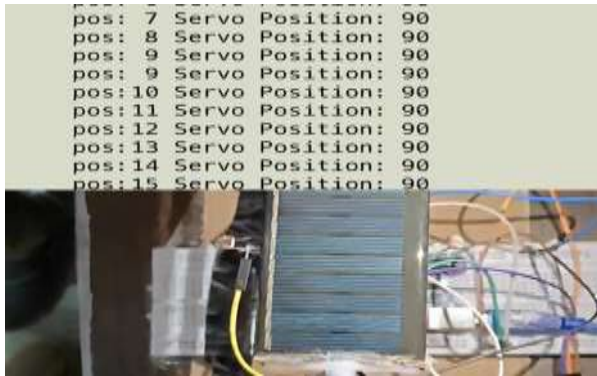


Fig. 3. Automatic Solar Tracker Output Position in 90-Degrees

The observation indicates that the system successfully rotates the panel from its initial position to align with the direction of highest light intensity. Minor variations in positioning may occur due to sensor sensitivity and environmental changes.

Overall, the system demonstrates effective tracking capability at 90 degrees, ensuring better alignment with sunlight and improved energy capture efficiency.

C. Solar panel is in 180-degree position

The performance of the automatic solar tracking system is evaluated based on the panel position under controlled conditions. The results show that the solar panel rotates to a 180-degree position when sunlight is detected from the opposite direction.

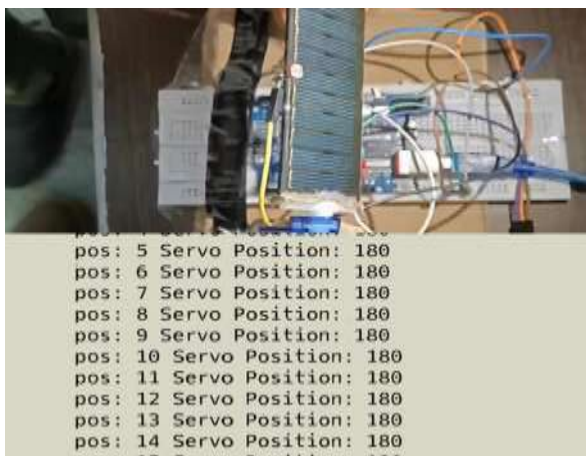


Fig. 4. Automatic Solar Tracker Output Position in 180-Degrees

The observation indicates that the system successfully tracks the change in light direction and adjusts the panel accordingly to maintain optimal alignment. Minor variations in positioning may occur due to sensor sensitivity and environmental conditions.

Overall, the system demonstrates reliable operation at 180 degrees, ensuring continuous tracking and improved solar energy capture throughout the day.

D. Performance Evaluation

The system demonstrated stable performance with smooth and timely adjustment of the solar panel position. The sensor readings remained consistent during operation, and the control mechanism ensured continuous alignment with the sun. The integration of LDR sensors with the Arduino proved effective for real-time light detection and automatic tracking.

E. Discussion

The proposed Arduino-based automatic solar tracking system uses LDR sensors and motor mechanisms to track sunlight in real time and adjust the solar panel position for improved energy capture.

Its main advantage is automatic alignment with the sun throughout the day, which significantly increases efficiency compared to fixed solar panels. The system is also simple, low-cost, and suitable for small-scale and educational applications.

However, certain limitations exist. The accuracy of the system can be affected by sensor sensitivity and environmental factors such as clouds, shadows, or uneven light distribution. LDR sensors may also respond slowly or give less precise readings under low light conditions.

Power consumption and mechanical wear are additional considerations, as continuous motor movement may reduce system efficiency over time. Proper calibration and optimized control logic are required to minimize unnecessary movements.

Despite these challenges, the system provides a strong foundation for further improvements. The integration of IoT features or advanced sensors can enhance monitoring and control, while more precise tracking algorithms can improve overall performance.

Overall, the system demonstrates a reliable, cost-effective, and scalable solution for improving solar energy utilization through automatic tracking.

5. Conclusion

The project "Automatic Solar Tracker Using Arduino" demonstrates a reliable and cost-effective approach to improving solar energy efficiency in small-scale applications by using LDR sensors, a motor driver, and an Arduino microcontroller to continuously monitor sunlight and adjust the solar panel for optimal alignment with the sun. This automatic tracking system ensures maximum energy absorption compared to fixed panels, as it responds quickly and accurately to changes in light direction while operating without manual intervention. It provides stable and consistent performance throughout the day, improving overall energy utilization in a simple and practical manner. The design is affordable and easy to implement, making it suitable for residential and educational use, and it also offers scope for future enhancements such as dual-axis tracking, IoT-based monitoring, and advanced control techniques for improved precision and efficiency.

The project "Automatic Solar Tracker Using Arduino" successfully demonstrates a cost-effective and reliable method to improve solar energy efficiency in small-scale applications. Using LDR sensors, a motor driver, and an Arduino microcontroller, the system automatically tracks sunlight and adjusts the solar panel to maintain optimal alignment with the sun. This ensures better energy absorption compared to fixed panels and provides stable, autonomous operation with quick response to changing light conditions. Overall, it offers a simple and practical solution for enhancing solar power efficiency and can be further improved with dual-axis tracking, IoT integration, and advanced control techniques for higher performance.

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