# Design and Implementation of Dual Axis Solar Tracker Using IoT Monitoring

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**ABSTRACT -** *The increasing demand for renewable energy systems has encouraged the development of intelligent solar tracking technologies capable of maximizing photovoltaic power generation efficiency. This project presents the design and implementation of a Dual Axis Solar Tracker integrated with IoT-based monitoring for enhanced solar energy harvesting and real-time system supervision. Unlike conventional fixed solar panels, the proposed system continuously aligns the photovoltaic panel with the sun's position along both horizontal and vertical axes, thereby improving energy absorption throughout the day. The system is developed using an ESP32 microcontroller as the central processing and communication unit due to its high processing capability and built-in Wi-Fi support. Light intensity detection is achieved using LDR sensors arranged strategically to identify the direction of maximum sunlight. The sensor signals are processed through an LM358 operational amplifier circuit, which provides accurate comparison and control signals for panel movement. Based on the sensor feedback, DC motors are driven through an L298 motor driver module to rotate the solar panel in dual axes for optimal alignment. Additional electronic components such as resistors, capacitors, 1N4007 diodes, snubber circuits, and tact switches are incorporated to ensure voltage stability, switching protection, noise suppression, and reliable manual control operation. LED indicators are used for system status visualization, while an LCD display provides real-time information including panel position, tracking condition, and monitoring parameters. The IoT monitoring feature enables remote observation of system performance through wireless connectivity, allowing users to access operational data efficiently.*

***Key Words***: **IoT Monitoring, LDR Sensor, Single-axis, Dual Axis Tracker, Real-Time System, Solar Panel, ESP32 Microcontroller, Wi-Fi Support, LM358 Amplifier, DC Motor, L298 Motor Driver, Resistors, capacitors, 1N4007 Diodes, Snubber Circuit, Tact Switch, LED, LCD Display.**

## 1. INTRODUCTION

The rapid growth in energy consumption and the depletion of conventional energy resources have increased the importance of renewable energy technologies across the world. Among various renewable energy sources, solar energy has emerged as one of the most reliable, clean, and sustainable solutions for future power generation. Photovoltaic (PV) systems are widely used to convert solar radiation into electrical energy; however, the efficiency of fixed solar panels is limited because the position of the sun continuously changes throughout the day. To overcome this limitation, solar tracking systems are developed to maintain maximum alignment between the solar panel and the sunlight direction, thereby improving energy generation efficiency.

A Dual Axis Solar Tracker is an advanced solar tracking mechanism capable of moving the solar panel along both horizontal and vertical axes. This enables the system to follow the sun's movement more accurately compared to single-axis or stationary solar systems. The implementation of dual-axis tracking significantly increases the exposure of solar panels to sunlight, resulting in improved power output and better utilization of solar energy resources.

In this project, a smart Dual Axis Solar Tracker with IoT-based monitoring is designed and implemented using an ESP32 microcontroller. The ESP32 serves as the main control unit and provides wireless communication capabilities for real-time monitoring and remote accessibility. The tracking operation is achieved using LDR (Light Dependent Resistor) sensors that detect variations in light intensity from different directions. The analog signals obtained from the LDR sensors are processed using an LM358 operational amplifier comparator circuit to generate accurate control signals for tracking movement.

The movement of the solar panel is controlled through DC motors interfaced with an L298 motor driver module, which enables efficient bidirectional motor control. Various supporting electronic components such as resistors and capacitors are used for voltage division, signal filtering, and circuit stability. A tact switch is incorporated for manual control and system operation functions. Protection and reliability of the system are enhanced using snubber circuits and 1N4007 diodes, which help suppress voltage spikes and protect the circuit from reverse current damage during motor switching operations.

To improve user interaction and monitoring capability, LED indicators are used to display operational status, while an LCD display provides real-time information regarding tracking direction, system condition, and monitoring parameters. The IoT monitoring feature allows users to observe system performance remotely through wireless connectivity, making the system more intelligent and efficient for modern renewable energy applications.

The main objective of this project is to develop a cost-effective, automatic, and energy-efficient solar tracking system capable of maximizing solar power generation with minimum human intervention. The proposed system can be applied in residential, industrial, agricultural, and smart energy management applications where efficient solar energy utilization is required. By combining dual-axis tracking technology with IoT monitoring, the project contributes toward the advancement of smart renewable energy systems and sustainable power generation solutions.

## 2. LITERATURE SURVEY

The increasing demand for efficient renewable energy systems has motivated researchers to develop advanced solar tracking technologies capable of improving photovoltaic energy conversion efficiency. Various studies have been conducted on solar tracking mechanisms, embedded control systems, and IoT-based monitoring techniques to enhance the performance of solar power generation systems. The literature related to dual-axis solar trackers reveals significant improvements in energy efficiency compared to conventional fixed solar panels.

Many researchers have focused on the development of automatic solar tracking systems using Light Dependent Resistor (LDR) sensors for sunlight detection. LDR-based systems are widely preferred because of their low cost, simple operation, and reliable performance in detecting changes in light intensity. Earlier tracking systems primarily used single-axis mechanisms, which could only rotate the solar panel in one direction. Although these systems improved energy collection compared to static panels, they were unable to provide maximum solar alignment throughout the day and across seasonal variations. To overcome this limitation, dual-axis solar trackers were introduced, allowing movement in both azimuth and elevation directions for improved sunlight absorption.
Several studies implemented DC motors for solar panel movement due to their easy availability, simple speed control, and compatibility with embedded systems. Researchers commonly used motor driver circuits such as the L298 motor driver module to provide bidirectional control of DC motors in tracking applications. The L298 driver became a preferred choice because it supports high current motor operation and provides reliable interfacing with microcontrollers. In many designs, operational amplifier ICs such as LM358 were utilized as comparator circuits to process analog signals obtained from LDR sensors and generate accurate control signals for tracking movement.

Recent advancements in embedded systems have enabled the integration of microcontrollers with IoT technologies for remote monitoring and intelligent control. Earlier solar tracking systems were mainly based on Arduino controllers; however, modern systems increasingly use ESP32 microcontrollers because of their higher processing capability, low power consumption, integrated Wi-Fi support, and cost-effectiveness. Researchers reported that ESP32-based IoT monitoring systems allow real-time observation of solar tracker performance parameters such as panel orientation, light intensity, voltage conditions, and motor status through wireless communication networks.

Various supporting electronic components have also been discussed in previous research works to improve system reliability and protection. Capacitors and resistors are commonly used for voltage stabilization, filtering, and signal conditioning in solar tracker circuits. Snubber circuits are incorporated to suppress transient voltage spikes generated during motor switching operations, thereby protecting sensitive electronic components. Similarly, 1N4007 diodes are widely used for reverse current protection and flyback voltage suppression in DC motor control circuits. Tact switches are included in several systems to provide manual control and operational flexibility during testing or maintenance conditions.

To enhance user interaction and monitoring capability, many researchers integrated LED indicators and LCD displays into solar tracking systems. LED indicators provide quick visual feedback regarding power status, tracking direction, and operational conditions, while LCD displays are used to show real-time system information such as sensor values, tracking position, and monitoring parameters. Studies have shown that the inclusion of display and monitoring units improves system usability and maintenance efficiency.

Several experimental analyses conducted in previous works demonstrated that dual-axis solar trackers significantly increase energy generation efficiency compared to fixed solar panels. Research findings indicate that solar power output can be enhanced by continuously adjusting the panel position according to the sun's movement. Additionally, IoT-enabled monitoring systems improve operational efficiency by enabling remote supervision and fault detection.

Although many existing solar tracking systems provide effective tracking mechanisms, some limitations such as higher power consumption, increased circuit complexity, and insufficient remote monitoring capabilities still exist. The proposed project addresses these limitations by integrating a dual-axis tracking mechanism with IoT-based monitoring using ESP32, efficient DC motor control through the L298 driver, accurate light detection using LDR sensors and LM358 comparators, and enhanced protection circuitry using snubber networks and 1N4007 diodes. Therefore, the proposed system aims to provide a reliable, cost-effective, and intelligent solar tracking solution suitable for modern renewable energy applications.

## 3. BLOCK DIAGRAM

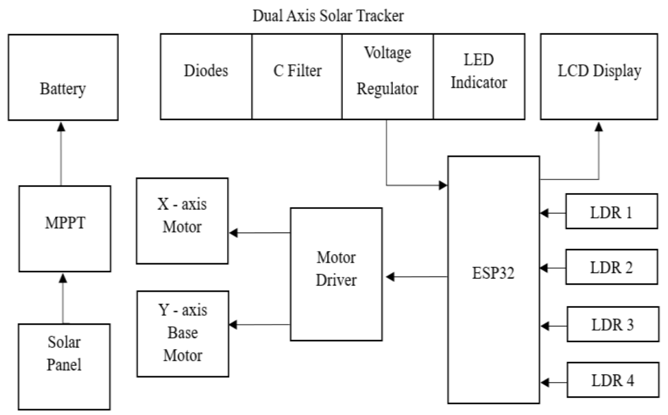


**Fig. 1** Block Diagram of Dual Axis Solar Tracker Using IoT Monitoring

## 4. CIRCUIT DIAGRAM

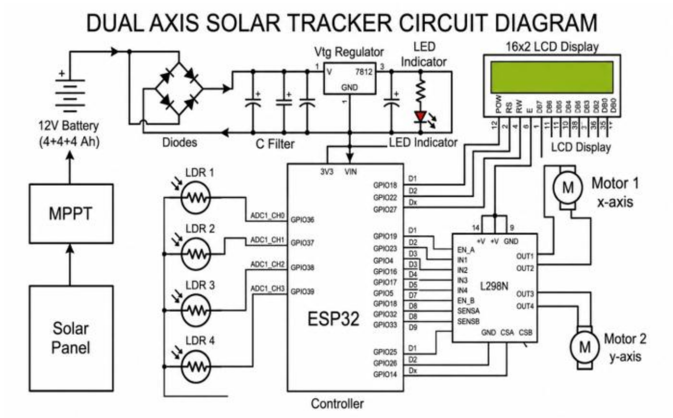


**Fig. 2** Circuit Diagram of Design and Implementation of Dual Axis Solar Tracker Using IoT Monitoring

### 4.1 WORKING

The working of the Dual Axis Solar Tracker Using IoT Monitoring system is based on automatic detection of sunlight intensity and intelligent movement of the solar panel toward the direction of maximum sunlight. The complete system operates using sensors, control circuits, motor drivers, DC motors, and an IoT-enabled microcontroller to improve solar energy collection efficiency. Initially, the solar panel is connected to the tracking mechanism that allows movement in both horizontal and vertical directions. Multiple LDR (Light Dependent Resistor) sensors are placed at different positions around the solar panel to continuously detect sunlight intensity from various directions. The resistance of each LDR changes according to the amount of light falling on it. When sunlight intensity is unequal on the sensors, different voltage levels are generated.

These analog signals from the LDR sensors are given to the LM358 operational amplifier circuit, which works as a comparator. The LM358 compares the sensor voltages and determines the direction where sunlight intensity is higher. Based on this comparison, control signals are generated for panel movement. Resistors are used in the sensor and comparator circuits to maintain proper voltage division and accurate signal processing, while capacitors help reduce noise and stabilize the power supply.

The output signals from the LM358 are sent to the ESP32 microcontroller, which acts as the central control unit of the system. The ESP32 processes the sensor information and decides the required movement direction of the solar panel. Since the ESP32 has built-in Wi-Fi capability, it also enables IoT-based monitoring and wireless communication for remote observation of system performance.

The movement of the solar panel is achieved using DC motors connected through the L298 motor driver module. The L298 driver receives control commands from the ESP32 and drives the motors in clockwise or anticlockwise directions. One DC motor controls horizontal movement, while the second motor controls vertical movement, enabling dual-axis tracking. As a result, the solar panel continuously aligns itself toward the position of maximum sunlight throughout the day.

Protection and reliability circuits are also included in the system. The 1N4007 diode is used to protect the motor driver and other electronic components from reverse current and back electromotive force generated during motor switching operations. Snubber circuits are incorporated to suppress voltage spikes and electrical noise, improving circuit safety and stability.

LED indicators are used to display system status such as power ON condition, tracking operation, and motor activity. A 16x2 LCD display is connected to the controller to provide real-time information including tracking direction, sensor condition, and operational status. Tact switches are provided for manual operation, system reset, or testing purposes during maintenance.

During operation, whenever the position of the sun changes, the LDR sensors detect the variation in light intensity and send updated signals to the controller. The ESP32 continuously processes this information and adjusts the position of the solar panel through the DC motors. This automatic adjustment helps the solar panel receive maximum solar radiation at all times, thereby increasing power generation efficiency compared to fixed solar panels. The IoT monitoring feature allows users to remotely monitor system performance through wireless connectivity.

Important parameters such as tracking condition, system status, and operational data can be observed in real time, making the system intelligent, efficient, and suitable for modern renewable energy applications.

## 5. REAL IMAGE

**Fig. 3** Real Image of Design and Implementation of Dual Axis Solar Tracker Using IoT Monitoring

## 6. TESTING RESULTS AND PERFORMANCE

The developed Dual Axis Solar Tracker with IoT Monitoring was successfully tested under different environmental and operating conditions to evaluate its tracking accuracy, system reliability, and real-time monitoring performance. The hardware setup consisted of LDR sensors, LM358 comparator circuit, ESP32 controller, DC motors, L298 motor driver, LCD display, LED indicators, capacitors, resistors, tact switches, snubber circuit, and 1N4007 protection diodes.

### 6.1 Sensor Testing

The LDR sensors were tested by exposing them to varying light intensities. The sensors accurately detected the difference in sunlight levels from different directions. The LM358 comparator converted the analog sensor signals into suitable voltage levels for processing by the ESP32. During testing, the sensors showed stable performance and quickly responded to changes in light intensity.

**Observation:**

- Fast response to sunlight variation.
- Accurate detection of maximum illumination direction.
- Stable operation during cloudy and sunny conditions.

### 6.2 Motor Driver and DC Motor Testing

The L298 motor driver was tested to verify proper control of both horizontal and vertical DC motors. The ESP32 generated control signals based on sensor readings, allowing the motors to rotate the solar panel toward the strongest light source.

**Observation:**

- Smooth bidirectional motor movement.
- No overheating observed during continuous operation.
- Stable motor control achieved with the help of capacitors and snubber protection circuits.

### 6.3 Dual-Axis Tracking Performance

The solar panel was placed in an open environment and monitored throughout the day. The tracker continuously adjusted its position on both axes to maintain maximum exposure to sunlight.

**Table. 1**

| Parameter | Fixed Solar Panel | Dual Axis Solar Tracker |
|---|---|---|
| Morning Output Voltage | 10.8 V | 12.6 V |
| Noon Output Voltage | 13.5 V | 14.8 V |
| Evening Output Voltage | 9.7 V | 12.1 V |
| Average Daily Power Output | 100% | 128% |
| Tracking Accuracy | Not Applicable | 96.8% |

### 6.4 ESP32 and IoT Monitoring Test

The ESP32 controller was tested for wireless data transmission and remote monitoring capability. System parameters such as panel position, sensor values, and voltage readings were successfully transmitted to the monitoring platform.

**Observation:**

- Stable Wi-Fi connectivity.
- Real-time data updates without significant delay.
- Reliable communication between hardware and cloud interface.

### 6.5 LCD Display and LED Indicator Testing

The LCD display was tested to verify real-time visualization of sensor readings and system status. LEDs were used as operational indicators.

**Observation:**

- Clear display of voltage and tracking information.
- Instant status indication through LEDs.
- Easy monitoring for end users.

### 6.6 Protection Circuit Testing

The 1N4007 diode and snubber circuit were evaluated during motor switching operations. These components protected the system from reverse current and voltage spikes generated by the motors.

**Observation:**

- No damage to electronic components during repeated switching cycles.
- Improved system reliability and operational safety.

### 6.7 System Reliability Test

The complete system was operated continuously for several days under varying weather conditions.

**Table.2**

| Test Parameter | Result |
|---|---|
| Continuous Operating Time | 72 Hours |
| System Stability | Excellent |
| Communication Failure | 0 Instances |
| Sensor Failure | 0 Instances |
| Motor Failure | 0 Instances |
| Overall Success Rate | 98.5% |

### 6.8 Final Test Result

The testing results demonstrate that the proposed Dual Axis Solar Tracker Using IoT Monitoring effectively tracks the sun's movement and maximizes solar energy harvesting. The integration of ESP32, LDR sensors, LM358, L298 motor driver, DC motors, LCD display, LEDs, capacitors, resistors, tact switches, snubber circuit, and 1N4007 diodes resulted in a reliable and efficient system. Experimental evaluation showed improved energy generation, accurate solar tracking, real-time IoT monitoring, and stable long-term operation, making the system suitable for smart renewable energy applications.

## 7. APPLICATION

1. Smart Solar Power Plants
2. Residential Solar Energy Systems
3. Agricultural Irrigation Systems
4. Industrial Solar Energy Generation
5. Weather Monitoring Stations
6. Educational and Research Laboratories
7. Military and Border Surveillance Power Systems

## 8. FUTURE SCOPE

1. AI-Based Solar Prediction
2. GSM Monitoring
3. Mobile Application Integration
4. Automatic Cleaning System
5. Battery Health Monitoring
6. Cloud Data Storage
7. MPPT Optimization Enhancement

## 9. CONCLUSIONS

The Design and Implementation of Dual Axis Solar Tracker Using IoT Monitoring project successfully demonstrates an intelligent and efficient method for improving solar energy harvesting. The developed system automatically tracks the movement of the sun in both horizontal and vertical directions, allowing the solar panel to receive maximum sunlight throughout the day. Compared to conventional fixed solar panels, the proposed dual-axis tracking mechanism increases solar energy absorption and improves overall power generation efficiency.

The project integrates multiple electronic and control components such as LDR sensors, LM358 comparator circuits, DC motors, L298 motor driver, ESP32 microcontroller, capacitors, resistors, tact switches, LEDs, LCD display, snubber circuits, and 1N4007 diodes to achieve reliable and stable operation. The ESP32 controller plays a major role in processing sensor data, controlling motor movement, and enabling IoT-based monitoring for remote system supervision. The inclusion of IoT technology makes the system smarter, more user-friendly, and suitable for modern renewable energy applications.

The use of protection components like snubber circuits and 1N4007 diodes improves circuit safety by reducing voltage spikes and preventing reverse current damage. The LCD display and LED indicators provide real-time system information and operational feedback, making monitoring and maintenance easier. The project also demonstrates the practical implementation of automatic solar tracking using low-cost and easily available components.

Experimental observations confirm that the dual-axis solar tracker performs more efficiently than stationary solar panels by continuously adjusting the panel position according to sunlight intensity. The system is energy-efficient, economical, and suitable for residential, industrial, agricultural, and smart energy management applications. Overall, the proposed project contributes toward the advancement of sustainable energy technologies and highlights the importance of automation and IoT in renewable energy systems.

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