International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 10 | Oct - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

Dual Axis Solar Power Tracking System

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Abstract - The Dual Axis Solar Power Tracking System is an advanced renewable energy solution designed to improve the efficiency of solar photovoltaic (PV) panels by automatically adjusting their orientation according to the Sun's position. Unlike fixed solar panels, this system tracks sunlight in two directions: horizontal (azimuth) and vertical (elevation). The proposed system uses an Arduino Uno microcontroller, four Light Dependent Resistors (LDRs), and two servo motors to achieve automatic solar tracking. The LDR sensors detect variations in sunlight intensity and send corresponding signals to the Arduino Uno. The microcontroller processes these signals and controls the servo motors to rotate and tilt the solar panel toward the direction of maximum illumination. This continuous adjustment helps the panel receive sunlight more directly throughout the day. The system is designed to be cost-effective, energy-efficient, and suitable for educational and small-scale applications. Its performance can be evaluated by measuring the voltage, current, and electrical energy generated and comparing the results with those of a fixed solar panel under similar environmental conditions. The proposed system provides practical knowledge of embedded systems, sensor interfacing, motor control, and renewable energy technology. It can be further enhanced with IoT-based monitoring and data logging for improved performance analysis.

Key Words: Dual-Axis Solar Tracking, Arduino Uno, LDR Sensors, Solar Photovoltaic System, Servo Motor, Renewable Energy.

1. INTRODUCTION

Solar energy is one of the most promising renewable energy sources because it is clean, abundant, and environmentally friendly. With the increasing demand for electricity and the depletion of conventional energy resources, solar photovoltaic (PV) systems have gained significant importance in residential, industrial, agricultural, and commercial applications. Solar panels convert sunlight directly into electrical energy without producing harmful emissions during operation. However, the electrical energy generated by a solar panel depends on several factors, including solar radiation intensity, temperature, weather conditions, and the angle at which sunlight strikes the panel. Therefore, improving the orientation of solar panels toward the Sun is an important approach to enhancing their energy-generation performance.

Conventional solar panels are generally installed at a fixed angle and direction. Although fixed solar systems are simple, economical, and require less maintenance, they cannot continuously maintain the optimum orientation toward the Sun throughout the day. The apparent position of the Sun changes from morning to evening and varies with the seasons. As a result, the amount of sunlight received by a fixed solar panel may decrease when sunlight falls at an angle rather than directly onto its surface. Solar tracking technology addresses this limitation by automatically adjusting the position of the solar panel according to the direction of maximum sunlight.

A **Dual Axis Solar Power Tracking System** is an advanced solar tracking arrangement that moves a solar panel along two independent axes: horizontal and vertical. These movements allow the panel to follow changes in both the Sun's azimuth and elevation angles. Compared with a fixed panel or a single-axis tracking system, dual-axis tracking can maintain a more favourable orientation toward the Sun under suitable operating conditions. However, the actual improvement in energy generation depends on geographical location, weather conditions, tracking accuracy, and the energy consumed by the tracking mechanism.

In a typical low-cost dual-axis solar tracking system, an Arduino Uno microcontroller acts as the main control unit. Four Light Dependent Resistors (LDRs) are arranged in pairs to detect differences in sunlight intensity from different directions. The sensor arrangement may use a small separator to create measurable differences between the light falling on the sensors. The Arduino Uno processes the sensor readings and determines the direction in which the panel should move. Two servo motors or suitable geared motors are used to provide horizontal and vertical movement. The controller continuously compares the sensor readings and adjusts the panel position until the light intensity becomes approximately balanced.

The proposed system integrates sensor technology, embedded programming, motor control, and solar photovoltaic technology into a practical engineering application. Its performance can be evaluated by measuring the voltage, current, and energy generated by the tracking panel and comparing these results with those of a fixed solar panel under similar environmental conditions. Such measurements help determine whether the additional energy generated justifies the cost and power consumption of the tracking mechanism.

This review paper examines the working principle, major components, control techniques, advantages, limitations, and potential applications of dual-axis solar tracking systems. It also considers opportunities for improvement through efficient mechanical design, low-power control circuits, Internet of Things (IoT)-based monitoring, and data logging. The study aims to provide an understanding of how dual-axis tracking can contribute to improved solar energy utilization and support the development of affordable renewable energy solutions for educational and small-scale applications.

2. Body of Paper

2.1 Overview of Solar Tracking Systems

Solar tracking systems are designed to adjust the orientation of solar photovoltaic (PV) panels according to the apparent movement of the Sun. The primary objective is to increase the amount of solar radiation received by the panel throughout the day. Solar tracking systems are generally classified into fixed solar systems, single-axis tracking systems, and dual-axis tracking systems.

Fixed solar systems maintain a constant orientation and have a simple construction with low maintenance requirements. Single-axis tracking systems rotate the panel along one axis, typically following the Sun's east-to-west movement. Dual-axis tracking systems provide movement along both horizontal and vertical axes, enabling the panel to adjust to changes in the Sun's azimuth and elevation angles. Although dual-axis systems involve additional mechanical components and control requirements, they can improve solar energy collection under suitable environmental conditions.

2.2 Working Principle of Dual Axis Solar Tracking System

The dual-axis solar tracking system operates by detecting variations in sunlight intensity and adjusting the position of the solar panel accordingly. Four Light Dependent Resistors (LDRs) are arranged in different directions to detect the relative intensity of incident light. The sensors are connected to the analog input pins of the Arduino Uno through suitable voltage-divider circuits.

The Arduino Uno continuously reads the sensor values and compares the readings of the left and right sensors and the upper and lower sensors. If a significant difference is detected between a pair of sensors, the controller determines the direction in which the panel should move. Two motors are used to control the horizontal and vertical movements of the panel. The movement continues until the difference between the corresponding sensor readings falls within a predefined tolerance range.

This process allows the solar panel to maintain an orientation closer to the direction of maximum illumination. A tolerance range is important because it reduces unnecessary motor movement caused by minor fluctuations in light intensity. The system can also include limit switches and mechanical stops to prevent excessive rotation.

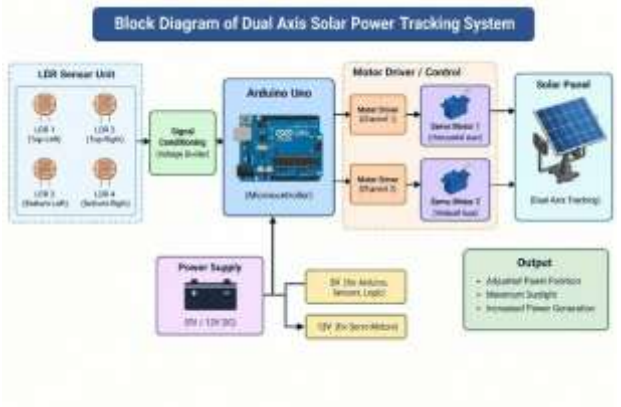


Fig: Block Diagram

2.3 Major Components of the System

2.3.1 Arduino Uno

The Arduino Uno is the main control unit of the system. It is based on the ATmega328P microcontroller and provides analog input pins for reading LDR sensor signals. The controller processes the sensor readings according to the programmed algorithm and generates control signals for the motors. Its simple programming environment, low cost, and availability make it suitable for educational and prototype applications.



Fig: Arduino Uno

2.3.2 Light Dependent Resistors (LDRs)

An LDR is a light-sensitive component whose resistance changes according to the intensity of incident light. Its resistance generally decreases as the light intensity increases. Four LDRs are used to estimate the direction of stronger illumination. A suitable arrangement of sensors and a small separator can help create a detectable difference between the readings when sunlight falls from different directions.

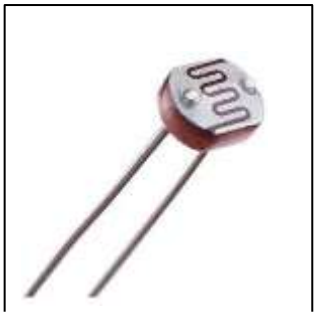


Fig: LDR

2.3.3 Servo Motors

Servo motors provide controlled angular movement of the solar panel. One motor controls horizontal rotation, while the second controls vertical tilt. Small servo motors can be used for lightweight demonstration models, whereas larger panels may require geared DC motors, stepper motors, or other actuators with suitable torque and a compatible motor driver.



Fig: Servo Motor

2.3.4 Solar Photovoltaic Panel

The solar PV panel converts incident solar radiation into direct-current electrical energy. The generated voltage and current depend on panel specifications, sunlight intensity, temperature, and electrical loading. The panel is mounted on a mechanical frame that allows movement along both tracking axes.



Fig: Solar Photovoltaic Panel

2.3.5 Power Supply

A regulated power supply provides the required voltage to the controller and sensors. Motors may require a separate power supply capable of delivering sufficient current. The mechanical structure supports the panel and motors while maintaining stability during movement. Proper wiring, secure mounting, and protection against environmental conditions are necessary for reliable operation.



Fig: Power Supply

2.4 System Architecture and Control Algorithm

The system consists of an LDR sensor unit, Arduino Uno, motor-control arrangement, dual-axis mechanical assembly, and solar PV panel. The LDR sensors provide light-intensity information to the controller. Based on the difference between sensor readings, the Arduino generates commands for the horizontal and vertical actuators.

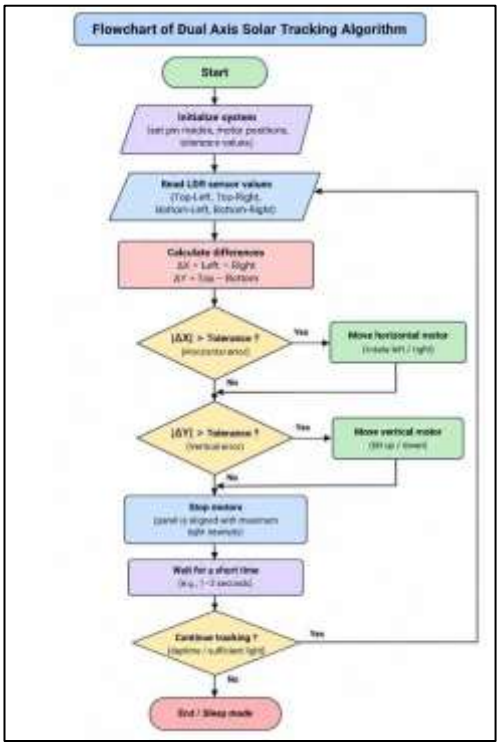


Fig: Flowchart

The basic control algorithm follows these steps:

1. Initialize the sensor inputs and motor positions.
2. Read the analog values from all four LDR sensors.
3. Calculate the differences between the left-right and upper-lower sensor pairs.
4. Compare the differences with predefined tolerance values.
5. Adjust the horizontal motor when the left-right difference exceeds the tolerance.
6. Adjust the vertical motor when the upper-lower difference exceeds the tolerance.
7. Repeat the process continuously while ensuring that the motors remain within their permitted movement limits.

This feedback-based method enables the system to respond to changes in sunlight direction. However, sensor calibration, suitable tolerance settings, motor response time, and mechanical accuracy influence the overall tracking performance.

2.5 Performance Evaluation

The performance of a dual-axis solar tracking system can be evaluated by comparing it with a fixed solar panel under similar operating conditions. Important parameters include output voltage, output current, electrical power, total energy generated, tracking accuracy, response time, and motor energy consumption.

The instantaneous electrical power can be calculated using:

$P = V \times I$

Where:

P = Electrical power in watts (W)

V = Output voltage in volts (V)

I = Output current in amperes (A)

The electrical energy generated over a period can be estimated by integrating or summing power measurements over time. For practical testing, both panels should have comparable ratings and should be measured under the same sunlight and loading conditions. Measurements should preferably be repeated on multiple days to account for variations in weather and solar radiation.

The percentage improvement in energy generation can be calculated as:

$$\text{Percentage Improvement} = [(E_t - E_f) / E_f] \times 100$$

Where E_t is the energy generated by the tracking system and E_f is the energy generated by the fixed system over the same measurement period. The net benefit should also account for the electrical energy consumed by the motors and controller.

2.6 Advantages and Limitations

The major advantage of a dual-axis tracking system is its ability to adjust the solar panel in two directions, potentially increasing the collection of solar radiation compared with a fixed installation. It also provides practical experience in embedded systems, sensor interfacing, motor control, and renewable energy technologies. Such systems can be useful for educational demonstrations, small solar installations, and experimental research.

However, dual-axis tracking systems have certain limitations. They require additional mechanical components, control circuitry, and maintenance. Motor operation consumes electrical energy, and moving structures may require protection against wind, rain, dust, and corrosion. LDR-based systems can also be affected by cloud cover, reflections, and rapidly changing light conditions. Therefore, suitable mechanical design, sensor

filtering, motor control, and weather protection are important for reliable operation.

Parameter	Fixed Solar Panel	Single-Axis Tracking	Dual-Axis Tracking
Movement	No movement	One rotational axis	Two rotational axes
Sun tracking	No automatic tracking	Tracks the Sun along one axis	Tracks changes in azimuth and elevation
System complexity	Low	Moderate	High
Initial cost	Low	Moderate	Relatively high
Control system	Usually not required	Simple or moderate	More complex
Mechanical components	Few	Moderate	More
Maintenance	Low	Moderate	Relatively high
Energy collection	Depends on fixed orientation	Can improve collection compared with fixed panels	Can improve collection under suitable conditions
Power consumption	No tracking-motor consumption	Requires actuator power	Requires actuator power for two axes
Typical applications	Rooftops and small solar installations	Solar farms and medium-scale systems	Research systems and selected solar installations

Table 1. Comparison of Fixed, Single-Axis, and Dual-Axis Solar Tracking Systems

Parameter	LDR-Based Tracking	Time-Based Tracking	Astronomical Tracking
Working principle	Detects relative light intensity using sensors	Moves panel according to a predefined schedule	Calculates the Sun's position using time, date, and location
Main components	LDRs, controller, motors	Clock/timer, controller, motors	Controller, real-time clock or accurate time source, location data, motors
Feedback	Closed-loop	Usually open-loop	Usually open-loop
Tracking accuracy	Depends on sensor arrangement	Depends on schedule and	Depends on solar-position calculations
	and calibration	mechanical accuracy	and positioning accuracy
Cloudy weather	May respond to changing or diffuse light	Continues scheduled movement	Continues calculated movement even when the Sun is obscured
Environmental sensitivity	Sensitive to shadows, reflections, and sensor contamination	Less dependent on instantaneous light intensity	Less dependent on optical sensors
Programming complexity	Low to moderate	Low to moderate	Moderate to high
Initial cost	Low	Low to moderate	Moderate
Main limitation	Sensor readings can be affected by weather and surrounding objects	Errors may accumulate if the schedule is inaccurate	Requires accurate time, coordinates, and calibration
Suitability	Low-cost educational prototypes	Simple scheduled tracking systems	Applications requiring predictable solar-position control

Table 2. Comparison of LDR-Based, Time-Based, and Astronomical Solar Tracking Methods

2.7 Applications and Future Scope

Dual-axis solar tracking systems can be used in educational laboratories, small photovoltaic installations, solar research platforms, and selected agricultural or remote-power applications. The system can be further improved by incorporating IoT-based monitoring, wireless data transmission, automated energy logging, and remote performance analysis. Additional improvements may include low-power actuators, more accurate position sensors, maximum power point tracking (MPPT), and hybrid control techniques that combine light sensors with astronomical solar-position calculations.

Future developments should focus on balancing tracking accuracy, energy gain, operating cost, and mechanical reliability. This balance is essential for making dual-axis solar tracking a practical and economically suitable solution for different photovoltaic applications.

3. CONCLUSIONS

Dual-axis solar tracking is a promising technique for improving the orientation of photovoltaic panels toward the Sun. An Arduino Uno-based system using LDR sensors and suitable motors offers an affordable platform for demonstrating automatic solar tracking. Its performance must be verified through controlled measurements of energy generation and tracking-system consumption. Further improvements in control

algorithms, mechanical design, and monitoring technology can enhance its reliability and practical usefulness.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to our **SPI Coordinator, Mr. V. B. Takale**, for his valuable guidance, encouragement, and support throughout the preparation of this review paper on *"DUAL AXIS SOLAR POWER TRACKING SYSTEM"*

We would also like to express our sincere gratitude to our **Project Coordinator, Mr. M. N. Waghmode**, for his valuable guidance, continuous encouragement, and technical support throughout the preparation of this review paper.

We are also thankful to **Mr. N. E. Bhutekar, Head of the Electronics and Telecommunication (E&TC) Department**, for his valuable suggestions, academic guidance, and support.

We extend our sincere thanks to our respected Principal, **Dr. P. T. Kale**, Vice Principal, **Dr. M. S. Yadav**, and Academic Dean, **Dr. V. S. Dabhade**, for their encouragement and academic support.

We are grateful to all faculty members of the E&TC Department for their cooperation, technical assistance, and constructive suggestions. Finally, we thank **JSPM Bhivrabai Sawant Polytechnic, Wagholi, Pune**, for providing the necessary facilities and a supportive learning environment to complete this review paper successfully.

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