Dual-Axis Solar Tracking System using Arduino

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Abstract — This paper presents the design and implementation of a dual-axis solar tracking system using an Arduino microcontroller. The system uses four light dependent resistors (LDRs) to sense the intensity of sunlight and two servo motors to orient the solar panel toward the direction of maximum illumination. The main objective of this project is to improve the efficiency of solar energy collection by continuously aligning the panel perpendicular to the sun's rays throughout the day. The system operates automatically using a 9 V power supply and does not require manual intervention. The proposed model is simple, low cost, and suitable for small-scale renewable energy applications where improved solar panel output is required.

Keywords: Arduino, Solar Tracker, Light Dependent Resistor (LDR), Servo Motor, Renewable Energy, Dual-Axis Tracking

I. INTRODUCTION

Solar energy is one of the most abundant, clean, and important sources of renewable energy available in nature. With the increasing demand for electricity and the depletion of conventional energy resources such as coal and petroleum, the use of renewable energy sources has become highly essential. Among all renewable energy sources, solar energy is widely preferred because it is freely available, environmentally friendly, and sustainable. Solar panels are commonly used to convert solar energy into electrical energy through the photovoltaic effect. However, the efficiency of a solar panel mainly depends on the angle at which sunlight falls on its surface. In conventional fixed solar panel systems, the panel remains stationary and receives maximum sunlight only for a limited period of the day when the sun is directly overhead. During the remaining hours, the intensity of sunlight falling on the panel decreases due to the changing position of the sun, resulting in lower energy generation and reduced efficiency.

To overcome this limitation, solar tracking systems are used to continuously orient the solar panel toward the direction of maximum sunlight. A solar tracker automatically adjusts the position of the panel according to the movement of the sun from east to west throughout the day. Solar tracking systems help in maximizing the exposure of solar panels to sunlight, thereby increasing the efficiency of power generation. Solar tracking systems are mainly classified into single-axis and dual-axis tracking systems. A single-axis tracker rotates the panel in one direction, whereas a dual-axis tracker provides movement in both horizontal and vertical directions. Dual-axis tracking systems are more efficient because they can track the sun more accurately and maintain the optimal angle of the solar panel at all times. This paper presents the design and implementation of a dual-axis solar tracking system using an Arduino UNO microcontroller. The proposed system uses four Light Dependent Resistors (LDRs) to detect the direction and intensity of sunlight. Based on the sensor values, the Arduino UNO processes the data and controls two servo motors to rotate the solar panel along both horizontal and vertical axes. The developed system is simple, reliable, and cost-effective. It automatically tracks the movement of the sun and ensures maximum exposure of the solar panel to sunlight throughout the day. As a result, the efficiency of solar energy absorption and power generation is improved compared to conventional fixed solar panel systems.

II. LITERATURE REVIEW

Solar tracking systems have been widely studied to improve the efficiency of photovoltaic panels. Earlier methods involved manual adjustment of solar panels at fixed intervals, which was time-consuming and inaccurate. With the advancement of microcontrollers and sensors, automatic solar tracking systems have been developed to overcome these limitations.

Many researchers have used light dependent resistors (LDRs) as sensors to detect the intensity of sunlight because of their low cost and simple working principle. Microcontroller-based systems, especially using Arduino, have become popular due to their ease of programming and flexibility in control applications. Single-axis solar trackers were initially developed to rotate the panel from east to west following the sun's daily path. However, these systems could not adjust the tilt of the panel according to the sun's elevation. To solve this problem, dual-axis solar trackers were introduced, which can track the sun both horizontally and vertically, thereby improving the overall efficiency of the solar panel. The proposed system in this paper follows the same concept of dual-axis tracking using LDR sensors and servo motors controlled by an Arduino microcontroller to achieve maximum solar energy utilization.

III. PROPOSED METHODOLOGY

The proposed dual-axis solar tracking system is designed to automatically orient the solar panel toward the direction of maximum sunlight. The system consists of four LDR sensors placed at four sides of the solar panel, an Arduino microcontroller for processing the sensor data, and two servo motors for moving the panel in horizontal and vertical directions.

The LDR sensors continuously sense the intensity of sunlight falling on them and produce corresponding voltage signals. These signals are given as inputs to the Arduino. The Arduino compares the values received from all four sensors and determines the direction in which the light intensity is highest.

Based on this comparison, control signals are sent to the servo motors. One servo motor controls the horizontal movement (left and right) of the panel, while the other servo motor controls the vertical movement (up and down). This process continues throughout the day, allowing the panel to follow the sun's movement automatically.

IV. HARDWARE COMPONENTS USED

The following hardware components are used in the implementation of the dual-axis solar tracking system:

Arduino Uno – Acts as the main controller of the system. It reads sensor values and controls the movement of servo motors.

- LDR Sensor – Detects the intensity and direction of sunlight. The resistance changes according to light falling on it.
- Servo Motor – Rotates the solar panel in horizontal and vertical directions to track maximum sunlight.
- Solar Panel – Converts solar energy into electrical energy.
- Breadboard – Used for assembling and testing the circuit without soldering.
- Jumper Wires – Provide electrical connections between components.
- Resistors (10kΩ) – Used with LDR sensors to form voltage divider circuits for accurate sensor readings.
- 9v Battery – Supplies electrical power to the Arduino and other components.
- Mounting Frame – Supports and holds the solar panel and motors in position.

V. BLOCK DIAGRAM

A. Block Diagram

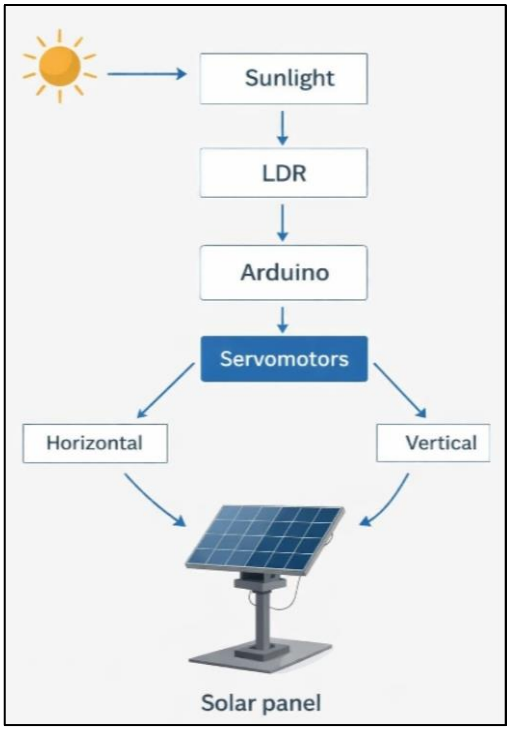


Fig. 1: Block Diagram of Dual Axis Solar Tracking System

The block diagram of the dual axis solar tracking system shows the flow of operation of the system. The sunlight is detected by the LDR sensors, which sense the intensity of light from different directions. The sensor data is sent to the Arduino UNO microcontroller for processing. Based on the received values, the Arduino controls the servo motors to rotate the solar panel in both horizontal and vertical directions. This automatic movement helps the solar panel to continuously face the direction of maximum sunlight, thereby improving the efficiency of power generation.

VI. CIRCUIT DIAGRAM

A. Circuit Diagram

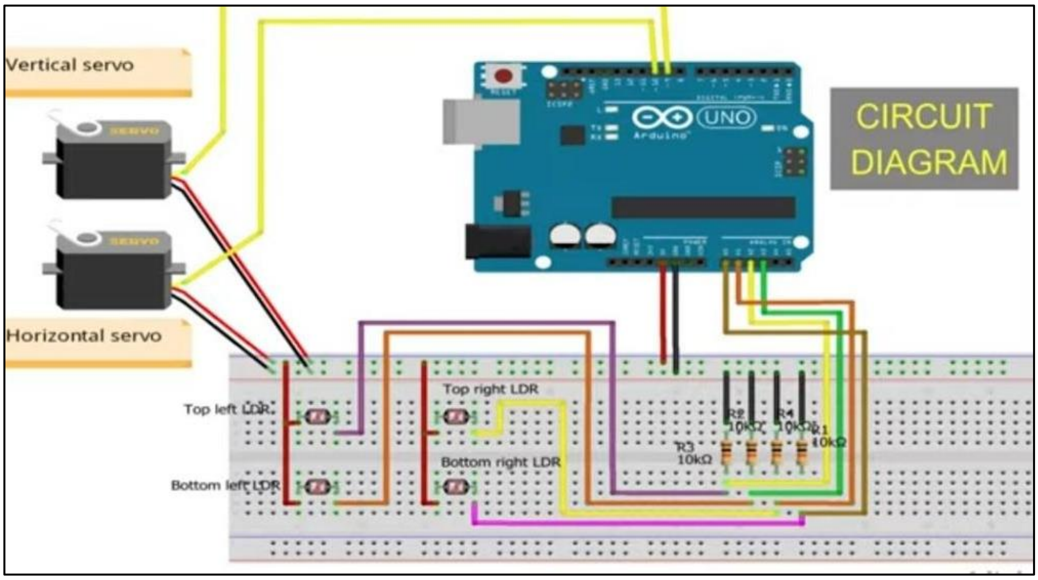


Fig. 2: Circuit Diagram of Dual Axis Solar Tracking System

The circuit diagram represents the electrical connections between the Arduino UNO, LDR sensors, servo motors, and solar panel. The LDR sensors are connected to the analog input pins of the Arduino to detect sunlight intensity. Based on the sensor values, the Arduino sends control signals to the servo motors, which rotate the solar panel in horizontal and vertical directions. The power supply provides the required operating voltage to the complete system.

VII. WORKING PRINCIPLE

The dual axis solar tracking system works on the principle of automatically orienting the solar panel toward the direction of maximum sunlight in order to achieve maximum solar energy absorption. The system continuously monitors the position of the sun and adjusts the orientation of the solar panel throughout the day using sensors, a microcontroller, and servo motors. The main components used in the system are LDR sensors, Arduino UNO microcontroller, servo motors, and a solar panel. The system uses four Light Dependent Resistor (LDR) sensors placed around the solar panel to detect the intensity of sunlight from different directions. The resistance of an LDR changes according to the amount of light falling on it. When sunlight falls equally on all the LDR sensors, the solar panel remains in its current position. However, when the intensity of sunlight becomes unequal due to the movement of the sun, the sensor receiving higher light intensity produces a different voltage value compared to the others. The output values from the LDR sensors are continuously sent to the Arduino UNO microcontroller. The Arduino acts as the central controlling unit of the system and compares the sensor values to determine the direction in which the solar panel should rotate. Depending on the difference in light intensity detected by the sensors, the Arduino generates suitable control signals for the servo motors. Two servo motors are used in the system to provide dual-axis movement to the solar panel. One servo motor controls the horizontal movement of the panel, while the second servo motor controls the vertical movement. Based on the control signals received from the Arduino, the servo motors rotate the solar panel toward the direction of maximum sunlight. This continuous adjustment enables the panel to follow the movement of the sun from east to west and maintain an optimal angle throughout the day.

The complete operation of the system is automatic and requires minimal human intervention. The hardware connections are implemented using a breadboard, jumper wires, and a power supply. The control program is developed using Arduino IDE and uploaded into the Arduino UNO using Embedded C programming language. By continuously tracking the position of the sun, the proposed dual axis solar tracking system increases the exposure of the solar panel to sunlight and improves the efficiency of power generation compared to conventional fixed solar panel systems. The developed system is simple, reliable, economical, and suitable for renewable energy applications.

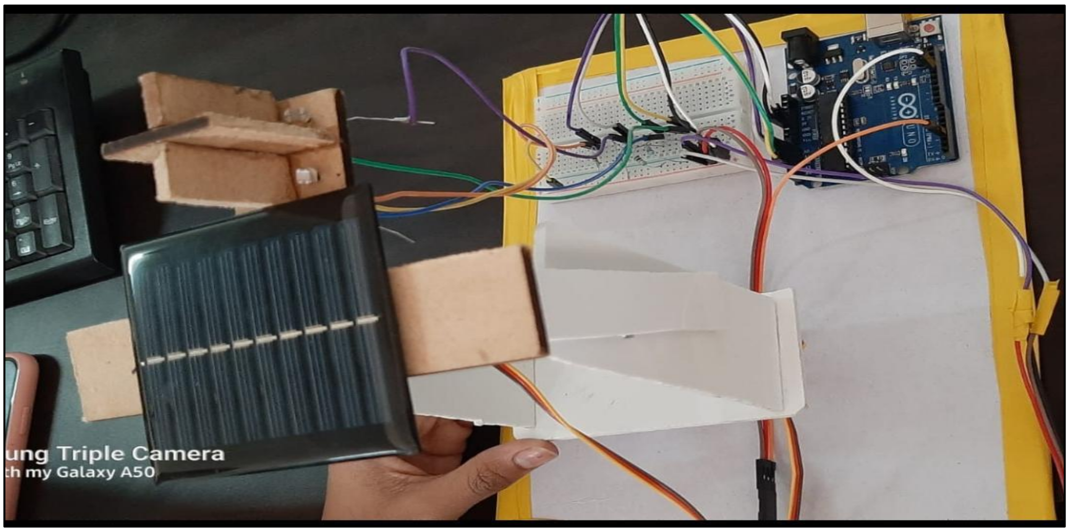
VIII. HARDWARE AND SOFTWARE IMPLEMENTATION

The hardware implementation of the dual axis solar tracking system is carried out using Arduino UNO, LDR sensors, servo motors, solar panel, resistors, breadboard, and connecting wires. The entire system is designed to automatically track the position of the sun for maximum absorption of solar energy. In the hardware setup, four LDR sensors are placed around the solar panel to detect the intensity of sunlight from different directions. These sensors continuously sense the variation in light intensity and generate corresponding electrical signals. The generated signals are provided as input to the Arduino UNO microcontroller. The Arduino UNO acts as the central controlling unit of the system. It processes the input data received from the LDR sensors and compares the light intensity values. Depending on the difference in sensor readings, the Arduino generates control signals for the servo motors. Two servo motors are used to rotate the solar panel in horizontal and vertical directions. This enables dual axis movement of the solar panel so that it continuously faces the direction of maximum sunlight throughout the day. The complete circuit connections are made using a breadboard and jumper wires.

The software implementation of the system is performed using Arduino IDE. The control program is written in Embedded C language and uploaded into the Arduino UNO through a USB cable. The program continuously reads the sensor values and controls the movement of the servo motors according to the intensity of sunlight detected by the LDR sensors. The developed hardware model successfully demonstrates automatic solar tracking and improves the efficiency of solar energy collection compared to fixed solar panel systems.

IX. RESULTS

The developed dual axis solar tracking system was successfully implemented and tested under different lighting conditions. The system was able to automatically detect the direction of maximum sunlight and rotate the solar panel accordingly using servo motors. The LDR sensors accurately sensed the variation in sunlight intensity, and the Arduino UNO processed the sensor data effectively to control the movement of the solar panel along both horizontal and vertical axes. The tracking mechanism enabled continuous alignment of the solar panel with the sun throughout the day. The experimental results showed that the dual axis solar tracking system received greater sunlight exposure compared to a fixed solar panel system. This resulted in improved solar energy absorption and increased efficiency of power generation. The hardware model operated successfully with stable performance and demonstrated the practical implementation of an automatic solar tracking system using Arduino UNO.



X. Advantages and Disadvantages

A. *Advantages*

1) Increases the efficiency of solar power generation – The solar panel continuously tracks the sun, which helps in generating more electrical energy.
2) Provides maximum exposure to sunlight – The panel automatically aligns itself in the direction of maximum sunlight throughout the day.
3) Automatic tracking reduces manual effort – The system operates automatically without the need for manual adjustment of the solar panel position.
4) Improves energy absorption compared to fixed solar panels – Since the panel follows the sun's movement, it absorbs more solar energy than stationary panels.
5) Low power consumption – The Arduino UNO and servo motors consume comparatively less electrical power during operation.
6) Dual axis movement provides better tracking accuracy – The solar panel moves in both horizontal and vertical directions, resulting in accurate sunlight tracking.
7) Simple and cost-effective system using Arduino UNO – The system can be implemented easily using affordable electronic components and simple programming.

B. *Disadvantages*

1) More complex than fixed solar panel systems – Additional sensors, motors, and control circuits increase the complexity of the system.
2) Requires regular maintenance of moving parts – Servo motors and mechanical joints may require maintenance after long-term usage.
3) Initial setup cost is higher – The use of extra electronic and mechanical components increases the installation cost.
4) Servo motors require continuous power supply – The motors need electrical power for continuous movement and operation.
5) System performance may be affected during cloudy weather – Low sunlight intensity can reduce the accuracy of light detection by LDR sensors.
6) Circuit connections become more complex due to additional components – Multiple sensors and motors make the circuit design more complicated compared to fixed systems.

XI. Applications

1) Solar power generation systems – Used in solar plants to improve the efficiency of electricity generation by tracking sunlight continuously.

2) Street lighting systems – Can be used in solar street lights to maximize solar energy collection during daytime.
3) Solar water pumping systems – Helps in increasing the efficiency of solar-powered water pumps used in agricultural applications.
4) Industrial solar tracking applications – Used in industries where large-scale solar energy systems require efficient sunlight tracking.
5) Residential and commercial solar energy systems – Can be implemented in homes and commercial buildings to improve solar panel performance.
6) Educational and research projects – Widely used in engineering and renewable energy projects for learning and experimental purposes.

XII. CONCLUSION

The dual axis solar tracking system using Arduino UNO was successfully designed, developed, and implemented. The main objective of the project was to improve the efficiency of solar energy generation by continuously tracking the position of the sun throughout the day. In conventional fixed solar panel systems, the panel receives maximum sunlight only for a limited period of time, which reduces the overall efficiency of power generation. To overcome this limitation, the proposed system automatically adjusts the position of the solar panel according to the movement of the sun. The developed system uses four LDR sensors to detect the intensity and direction of sunlight. The Arduino UNO microcontroller continuously processes the sensor values and controls the movement of two servo motors connected to the solar panel. The servo motors rotate the panel along both horizontal and vertical axes, enabling dual-axis movement and accurate sunlight tracking. This automatic adjustment ensures maximum exposure of the solar panel to sunlight throughout the day. The hardware model of the system was successfully tested and demonstrated stable operation under different lighting conditions. The results obtained from the project showed that the dual axis solar tracking system provides better solar energy absorption and improved efficiency compared to fixed solar panel systems. The use of Arduino UNO and simple electronic components makes the system economical, reliable, and easy to implement the project also demonstrates the practical application of embedded systems and renewable energy technologies in modern power generation systems. Therefore, the proposed dual axis solar tracking system can be effectively used in various solar energy applications to maximize power generation and improve the utilization of renewable energy resources.

XIII. FUTURE SCOPE

The developed dual axis solar tracking system can be further improved and enhanced in several ways to increase its performance, efficiency, and practical applications. In the future, more advanced sensors and control techniques can be used to improve the accuracy of sunlight detection and solar panel movement. The use of high-precision motors can also provide smoother and more efficient tracking of the sun. The system can be integrated with Internet of Things (IoT) technology for remote monitoring and control through mobile applications or web-based platforms. This would allow users to monitor the performance of the solar tracking system from any location. Wireless communication technologies can also be implemented for better data transmission and system automation. Battery storage systems can be incorporated into the project for efficient storage and utilization of the generated solar energy. The developed system can also be implemented on a larger scale in solar power plants, industries, residential buildings, and commercial applications to improve overall energy generation efficiency. In future developments, Artificial Intelligence (AI) and machine learning algorithms can be used to predict sunlight intensity and optimize solar tracking performance automatically. Weather monitoring systems can also be added to protect the solar panels during rain, storms, or extreme environmental conditions. Thus, the proposed dual axis solar tracking system has significant potential for further development and can play an important role in the advancement of renewable energy technologies and sustainable power generation systems.

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