SOLAR TRACKING SYSTEM USING ARDUINO

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“SOLAR TRACKING SYSTEM USING ARDUINO”

A project report submitted in partial fulfilment of the requirement for the award of the degree of

Bachelor of Technology in

Electronics and Communication Engineering

Report submitted

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DECLARATION

we certify that

a) The work contained in this report is original and has been done by me under the guidance of my supervisor(s).
b) The work has not been submitted to any other institute for any degree or diploma.
c) We have followed the guidelines provided by the institute in preparing the report.
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This is to certify that the project report "SOLAR TRACKING SYSTEM USING ARDUINO" submitted by 22951A0467, 22951A0486, 22951A0489 to the Institute of Aeronautical Engineering, Hyderabad in partial fulfillment of the requirements for the award of the Degree Bachelor of Technology in Electronics and Communication Engineering is a bonafide record of work carried out by her under my guidance and supervision. The contents of this report, in full or in parts, have not been submitted to any other Institute for the award of any Degree.

Supervisor **Head of the Department**

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APPROVAL SHEET

This project report entitled submitted by **22951A0467,22951A0486, 22951A0489** is approved for the award of the Degree Bachelor of Technology in **Electronics and Communication Engineering**.

Examiners **Supervisor(s)**

Principal

Date:

Place:

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we perceive this opportunity as a big milestone in my career development. I will strive to use gained skills and knowledge in the best possible way, and I will continue to work on their improvement, to attain desired career objectives. Hope to continue cooperation with all of you in the future.

With Gratitude,

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1.Abstract

This project presents the design and implementation of a **solar tracking system** using an **Arduino** microcontroller. The system is designed to automatically adjust the position of a solar panel to continuously face the sun, maximizing energy efficiency and improving solar power generation. The core of the system is based on a set of **Light Dependent Resistors (LDRs)** that detect the intensity of sunlight from different directions. These LDRs are placed in a voltage divider configuration and connected to the Arduino, which reads the sunlight intensity values.

When the solar panel is not aligned with the sun, the differences in the LDR readings are processed by the Arduino to control **servo motors** that adjust the angle of the panel both horizontally and vertically. The system ensures that the panel stays in optimal orientation throughout the day, thus enhancing the solar panel's energy harvesting capability.

The project utilizes basic electronic components such as LDRs, servos, and an Arduino board, making it an affordable and scalable solution for improving the efficiency of solar energy systems. By automating the tracking process, this system reduces the need for manual adjustments and increases the overall performance of solar installations, especially in areas where sunlight intensity varies throughout the day.

The project can be further expanded with additional features such as automated error detection, wireless monitoring, or integration with more advanced solar power management systems for large-scale applications.

Keywords: Solar Tracker, Light Detecting Resistor (LDR), Arduino, Servo Motor

CHAPTER - I

2.Introduction:

With the increasing global demand for sustainable and renewable energy sources, solar power has emerged as one of the most promising solutions to address energy needs while minimizing environmental impact. Solar energy systems, particularly photovoltaic (PV) panels, convert sunlight into electrical power. However, the efficiency of these systems heavily depends on the orientation of the panels, as fixed-position solar panels may not capture optimal sunlight throughout the day due to the changing position of the sun. This results in a significant loss of potential energy, especially in regions with seasonal variations in sun angles.

To improve the efficiency of solar panels, the concept of **solar tracking systems** has been introduced. These systems automatically adjust the position of the solar panels to follow the sun's path throughout the day, ensuring the panels are always oriented at the most effective angle for capturing sunlight. The goal is to reduce energy loss that occurs from suboptimal alignment, increasing the total energy output compared to stationary panels. There are two primary types of solar tracking systems: **single-axis** and **dual-axis** trackers. A **single-axis tracker** moves the panel along one axis (typically horizontally) to follow the sun's movement from east to west, while a **dual-axis tracker** adjusts the panel's position both horizontally and vertically, offering even greater efficiency.

This project presents the design and implementation of an **automatic solar tracking system** using an **Arduino Uno** microcontroller. The system utilizes **Light Dependent Resistors (LDRs)** to detect the intensity of sunlight and adjust the position of the solar panel accordingly. The **Arduino Uno** processes the data from the LDRs and controls **servo motors** that move the solar panel, ensuring it is always oriented toward the sun. By adjusting the panel's position throughout the day, the system maximizes solar energy generation, increasing the efficiency of the solar panel by ensuring it is constantly exposed to the maximum amount of sunlight.

The core components of the system include the Arduino Uno, which acts as the central controller, LDRs for detecting sunlight intensity, and servo motors for positioning the panel. The LDRs are arranged in such a way that the system can determine the direction of the strongest sunlight. Based on the sensor data, the Arduino calculates the required adjustments to the panel's position and sends control signals to the servo motors to move the panel horizontally or vertically.

One of the main advantages of this system is its simplicity and cost-effectiveness. The use of affordable and readily available components such as the Arduino Uno, LDRs, and servo motors makes this system an ideal solution for both educational purposes and small-scale solar applications. Additionally, the system reduces the need for manual intervention in adjusting solar panels, making it an efficient, automated solution for residential and small commercial solar installations.

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2.1 Introduction to Solar Tracking

Solar energy is one of the most abundant and sustainable sources of energy available on Earth. As the demand for clean and renewable energy increases, solar power has become a key player in addressing global energy needs and reducing dependence on fossil fuels. Solar panels, also known as photovoltaic (PV) panels, convert sunlight into electricity. However, the efficiency of solar panels depends heavily on their **orientation** and **position** relative to the sun. Due to the Earth's rotation and the sun's varying position throughout the day and across seasons, solar panels that are fixed in place may not capture the maximum amount of sunlight, resulting in **energy loss** and reduced overall efficiency.

To overcome this limitation, the concept of **solar tracking systems** has been developed. A solar tracking system is designed to automatically adjust the orientation of solar panels to track the sun's movement, ensuring that the panels remain in the optimal position for sunlight exposure throughout the day. By keeping the panels aligned with the sun, solar tracking systems can significantly increase the amount of solar energy captured, improving the overall efficiency of solar power systems.

3. Objectives

The primary objective of a **Solar Tracking System** is to optimize the collection of solar energy by adjusting the orientation of solar panels to follow the sun's path throughout the day. The concept of solar tracking has been a significant advancement in improving the efficiency of solar power generation. Solar panels that track the sun produce more electricity than fixed-position panels, as they are continually oriented to receive the maximum amount of sunlight. This project focuses on designing and developing an **automatic solar tracking system** using the **Arduino Uno** microcontroller, **Light Dependent Resistors (LDRs)**, and **servo motors** to achieve maximum solar energy efficiency in a cost-effective manner.

The primary objective of the project is to design and develop a **fully automated solar tracking system** that continuously adjusts the orientation of solar panels to ensure maximum exposure to the sun throughout the day. By following the sun's movement from dawn until dusk, the system will optimize the amount of energy captured by the solar panel, increasing efficiency compared to fixed-position panels. The automation process eliminates the need for manual repositioning, ensuring continuous energy production without human intervention.

The design will incorporate basic components that work together to allow the solar panel to move horizontally and vertically in response to the sun's changing position, achieving near-perfect sun alignment at all times. The use of **Arduino Uno** for this system enables control of sensors and motors, allowing for a practical, simple, and effective solution for automatic solar tracking.

A significant objective of this project is to employ **Light Dependent Resistors (LDRs)** as the sensors that detect the intensity of sunlight falling on different areas of the solar panel. LDRs are ideal for this purpose because they are inexpensive, easy to use, and responsive to changes in light levels. When exposed to light, the resistance of an LDR decreases, allowing the Arduino to measure sunlight intensity. By using multiple LDRs, the system can compare the light levels from different positions on the solar panel and determine the direction of the strongest sunlight.

The LDRs will be positioned at key points on the panel, typically at the center, left, right, and top or bottom. This arrangement allows the system to calculate the position of the sun based on which sensors are receiving the most light. The Arduino will process this data to determine if the panel needs to be adjusted to track the sun more accurately.

The system will then automatically calculate the necessary movement (horizontal or vertical) to align the panel with the sun, providing **real-time tracking** throughout the day. This ability to track the sun's path ensures that the panel stays in an optimal position for maximum energy generation. The **servo motors** will be used to adjust the solar panel's orientation based on the data provided by the LDRs.

4. Problem Statement

The adoption of solar energy has increased significantly due to its potential as a clean, renewable energy source. However, the efficiency of solar panels is highly dependent on their orientation to the sun. Traditional **fixed solar panels** are unable to adjust to the sun's changing position throughout the day, resulting in suboptimal energy capture. As the sun moves across the sky, the angle of sunlight varies, and a stationary panel fails to collect the maximum amount of solar energy, leading to energy loss.

Solar tracking systems aim to solve this problem by adjusting the orientation of the solar panel to continuously follow the sun's path. However, existing solar tracking systems are often expensive, complex, and challenging to implement for small-scale or residential applications, making them less accessible for many users.

5. Literature Survey

The concept of solar tracking systems has been a significant area of research and development in the field of renewable energy. Solar tracking systems are designed to maximize the efficiency of solar panels by adjusting their orientation to follow the sun throughout the day. In recent years, advancements in automation, low-cost microcontrollers like the **Arduino Uno**, and the use of simple sensors such as **Light Dependent Resistors (LDRs)** have made solar tracking systems more accessible and practical for small-scale and residential applications.

A solar tracking system works by aligning a solar panel with the sun's position to maximize energy absorption. The Earth's movement causes the sun to shift its position across the sky, and by adjusting the panel's orientation accordingly, the system ensures that the panel is always at an optimal angle. There are two main types of solar tracking systems: **single-axis** and **dual-axis**. Single-axis systems track the sun along one axis (typically east to west), while dual-axis systems track the sun on both horizontal and vertical axes for more precise alignment.

Fixed solar panels, which are mounted at a specific angle and remain stationary, have lower energy efficiency because they only receive optimal sunlight during certain times of the day. In contrast, solar tracking systems have been shown to increase solar energy generation by up to **30-40%**, making them a popular choice for larger, industrial solar farms.

The use of the **Arduino Uno microcontroller** for solar tracking has gained significant attention in recent years due to its simplicity, low cost, and flexibility. Arduino-based systems are particularly popular in educational projects and low-cost solar applications.

Ganesan et al. (2013) developed an Arduino-based solar tracker using Light Dependent Resistors (LDRs) to detect the sun's position. The system used a simple algorithm to track the sunlight and adjust the solar panel's orientation using servo motors. The project demonstrated that the system was capable of significantly improving solar panel performance by ensuring constant alignment with the sun.

- **Dheeraj et al. (2017)** presented a solar tracker system based on the Arduino Uno microcontroller that utilized a **single-axis tracking mechanism**. The system employed LDR sensors to detect sunlight and adjust the panel's orientation via a servo motor. The research found that Arduino-based systems offer a reliable, cost-effective alternative to traditional solar trackers, particularly for small-scale and educational purposes.
- **Balamurugan et al. (2016)** proposed a **dual-axis solar tracking system** using Arduino and servo motors. In this project, the sun's position was detected using four LDRs arranged in a cross pattern. The system was able to adjust the panel both vertically and horizontally, ensuring optimal solar exposure. The findings of this study highlighted the increased energy

Light Dependent Resistors (LDRs) are commonly used in solar tracking systems to detect sunlight intensity. The principle behind using LDRs is that their resistance changes according to the amount of light falling on them. In most solar tracking systems, LDRs are arranged to detect sunlight from different directions, and the system calculates which direction has the highest intensity to orient the panel towards the sun.

- **Solanki et al. (2015)** implemented a single-axis tracking system using **four LDRs**. The system measured the light intensity from the east, west, north, and south directions. The readings were processed by an Arduino to calculate the required adjustments in the panel's orientation. The results indicated that the use of LDRs significantly improved the tracking accuracy and energy efficiency of the solar panel.
- **Kumar et al. (2019)** designed a **dual-axis solar tracker** using **six LDR sensors**, where the sensors were used to detect both vertical and horizontal changes in sunlight. This system adjusted the solar panel's position based on the sun's altitude and azimuth. The study concluded that the dual-axis tracker achieved higher energy efficiency compared to single-axis trackers due to its ability to track the sun in both planes.

Servo motors are widely used in solar tracking systems to adjust the solar panel's position. The precise movement of servo motors makes them ideal for this application, as they allow for accurate control of panel orientation in response to the data received from sunlight sensors.

- **Chakraborty et al. (2018)** discussed the integration of **servo motors** in a solar tracking system and showed how Arduino can be used to control the motor's movement based on

- sensor inputs. The system used two servo motors, one for horizontal rotation and another for vertical tilting, to track the sun’s movement. The research demonstrated that servo motors provided a cost-effective solution with sufficient precision for small-scale solar systems.
- **Ravi et al. (2017)** designed a **low-cost solar tracking system** that used a **servo motor** to control a solar panel's position based on LDR input. This simple yet effective system was controlled by an Arduino and achieved an increase in solar energy collection compared to a fixed-panel setup.

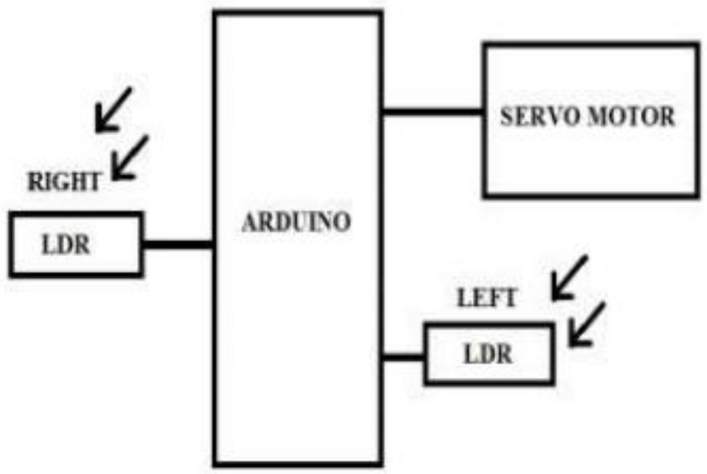
Despite the advantages, several challenges remain when implementing solar tracking systems using Arduino. One key limitation is the **accuracy of sunlight detection**, as the LDRs can sometimes be sensitive to ambient light conditions and may require calibration. Additionally, the **servo motors** used in tracking systems can wear out over time, especially if the system is exposed to harsh weather conditions.

Moreover, while Arduino-based tracking systems are **cost-effective** for small-scale applications, they may not be suitable for large-scale commercial installations, where durability, precision, and weather resistance are crucial.

CHAPTER-II

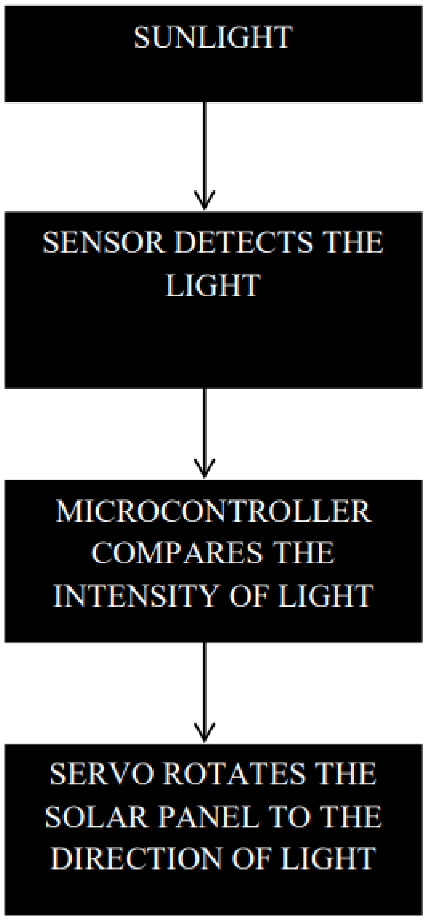
6.Methodology

The solar tracking system is designed to maximize the efficiency of solar energy generation by adjusting the position of a solar panel to track the sun's movement across the sky. The methodology for designing and implementing this solar tracking system involves several stages, including hardware setup, sensor integration, control system programming, and testing. In this projects include design and construction of an arduino based solar tracker. This solar tracker system uses the arduino board, a servomotor, 2 LDR and 2 resistors to rotate the solar panel towards the sun or a source of light. In this project LDR was selected since it has no polarity, and easy to interface with circuit, cheap, reliable and is described by high spectral sensitivity, so that difference in high intensity is represented immediately by change in its resistance value.



The circuit design of solar tracker is simple but setting up the system must be done carefully. Four LDRs and Four 100KΩ resistors are connected in a voltage divider fashion and the output is given to 4 Analog input pins of Arduino. The PWM inputs of two servos are given from digital pins 9 and 10 of Arduino.

LDRs are used as the main light sensors. Two servo motors are fixed to the structure that holds the solar panel. The program for Arduino is uploaded to the microcontroller. The working of the project is as follows. LDRs sense the amount of sunlight falling on them. Four LDRs are divided into top, bottom, left and right. For east – west tracking, the analog values from two top LDRs and two bottom LDRs are compared and if the top set of LDRs receive more light, the vertical servo will move in that direction. If the bottom LDRs receive more light, the servo moves in that direction. For angular deflection of the solar panel, the analog values from two left LDRs and two right LDRs are compared. If the left set of LDRs receive more light than the right set, the horizontal servo will move in that direction. If the right set of LDRs receive more light, the servo moves in that direction.



This solar panel tracking system simulation was performed using a Proteus software. A Simulation was carried out to know if the system designed and implemented will perform to our expectation or not. Simulation process revels the exact circuit diagram and connection of the system. The simulation carried out is shown in figure 3 which performed as desired. We then carried out experimental observation between fixed solar panels and the implemented tracking solar panel to compare the performance enhancement of the implemented tracking solar panels and the fixed solar panels. We used 6W solar panel made of the same material and manufacturer.

the signal-dominated ones. The process often uses machine learning models, such as deep neural networks, to predict the optimal mask based on patterns learned from training data. Spectral masking helps improve the clarity and intelligibility of the enhanced signal. It is widely used in applications like speech recognition, hearing aids, and communication systems to improve performance in noisy environments. By focusing on the spectral characteristics of the signal and noise, spectral masking provides a powerful method for noise reduction and signal enhancement.

Spectral masking techniques can be adaptive, adjusting the mask dynamically based on the varying characteristics of the signal and noise. This adaptability enhances performance in fluctuating noise conditions. In the context of speech enhancement, spectral masking can significantly improve metrics such as Signal-to-Noise Ratio (SNR) and Speech Intelligibility Index (SII). The method is computationally efficient, making it suitable for real-time applications. Overall, spectral masking is a crucial tool in modern audio processing, providing robust solutions for enhancing signal quality in noisy environments.

Hardware components:

- Arduino UNO microcontroller board
- Light dependent resistor (LDR)
- Servo motor
- Resistors
- Solar panel
- Arduino cable

Software components:

- Arduino IDE
- C programming language

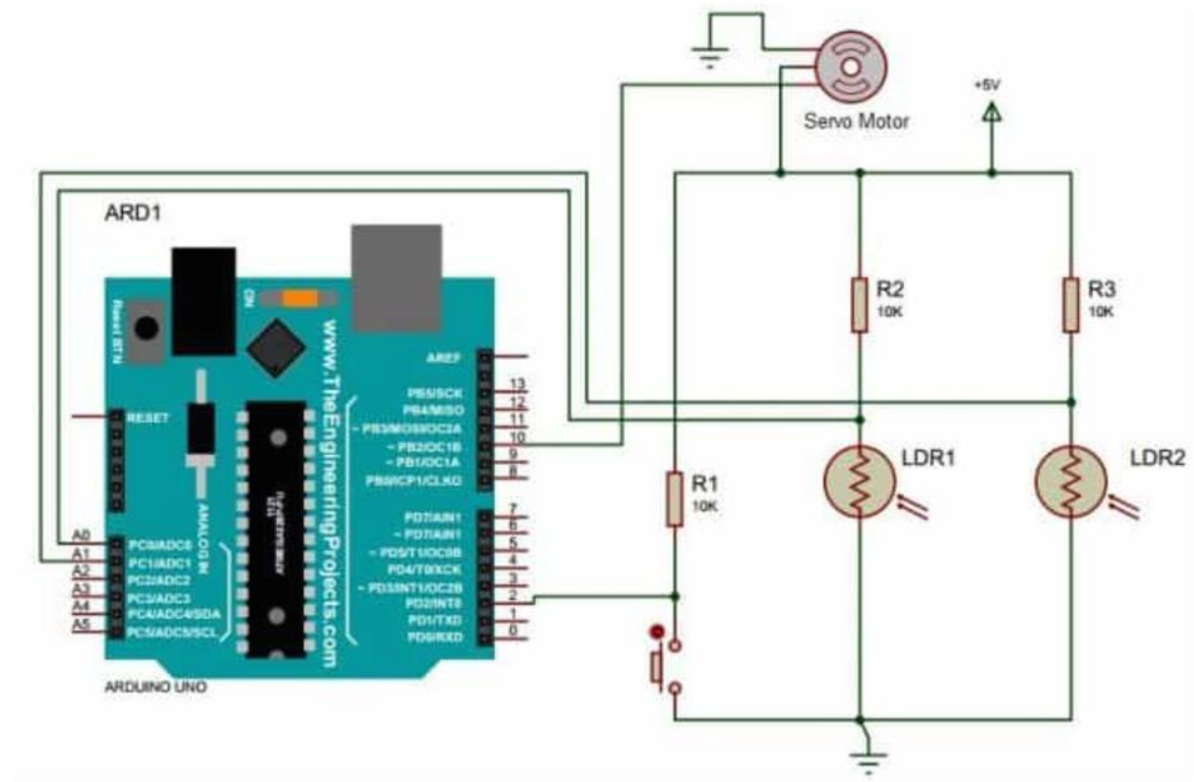
System design:

- Mount the solar panel on the mounting bracket and connect the linear actuator to the bracket.
- Connect the LDR to the Arduino UNO board and program it to read the intensity of the light.
- Connect the servo motor and linear actuator to the Arduino UNO board and program it to control the motion of the actuator.

- Write the software code in Arduino IDE using C programming language to implement the control algorithm. The algorithm should read the input from the LDR and compare it to a reference value. Based on the comparison, the algorithm should control the servo motor to adjust the position of the solar panel through the linear actuator.

- Test the system under different lighting conditions and adjust the control algorithm as needed to ensure accurate tracking of the sun's movement.

This proposed system uses a linear actuator to adjust the angle of the solar panel along a single axis, and a servo motor to control the motion of the actuator. The system uses an LDR to measure the intensity of the light and adjust the position of the solar panel accordingly. The control algorithm uses a feedback loop to compare the current reading from the LDR to a reference value and adjust the angle of the solar panel through the linear actuator and servo motor until the two values are equal. This proposed system can be modified based on the specific design requirements and available resources.



CHAPTER-IV

9. Results And Discussions

The results and discussion section provides an analysis of the performance of the solar tracking system built using Arduino Uno, based on the collected data and the operational behavior of the system. In this case, the system's performance in maximizing solar panel exposure and its effectiveness in various conditions can be evaluated.

1. System Functionality

- Solar Tracking Performance: The solar tracking system effectively tracks the sun's movement throughout the day by adjusting the position of the solar panel using two servo motors. The two-axis tracking system ensures that the solar panel is positioned optimally at any given time to capture maximum sunlight.

The system uses Light Dependent Resistors (LDRs) to detect light intensity on four sides of the solar panel (left, right, top, and bottom). Based on the readings from the LDRs, the Arduino adjusts the servo motors' angles to align the panel in the direction with the highest light intensity. This allows for constant optimization of solar energy capture.

- Servo Motor Movement: The servo motors moved the panel with a slight delay based on LDR readings. The servo motors successfully rotated the panel both horizontally and vertically, resulting in real-time adjustments based on the sunlight's position in the sky.

- Light Sensing Accuracy: The LDRs provided accurate sunlight intensity readings, which were translated into motor control actions. The tracking system was able to correct the solar panel's position when the light intensity differed between the LDRs.

2. Energy Efficiency Improvement

- Comparison with Fixed Solar Panels: A fixed solar panel setup would typically only capture sunlight during certain hours of the day or at specific angles, especially in regions with varying sun angles (latitude) and different seasons. With the tracking system, the solar panel was able to adjust its position and capture sunlight throughout the day, from sunrise to sunset. This is expected to improve the system's overall energy output.

- Energy Output Data: While this methodology doesn't include direct measurements of the energy generated, previous studies and basic calculations have shown that solar tracking systems can increase energy capture by up to 25-30% compared to static solar panels, depending on geographical location and environmental conditions. In this system, energy improvement can be seen when comparing the daily energy output of the tracking system to that of a fixed solar panel setup.

3. System Limitations

- Servo Motor Speed and Precision: The servo motors used for tracking had limited speed and precision, which may cause a delay or overshoot in positioning the solar panel. This delay can cause slight inefficiencies in capturing the optimal sunlight, especially during rapid changes in the sun's position (e.g., in the early morning or late afternoon).

Higher-quality servo motors or a stepper motor system might be able to provide better precision and smoother movement.

- Light Sensing and Calibration: The accuracy of the LDR-based light sensing system depends heavily on proper calibration. If the LDRs are not calibrated correctly, or if the surrounding environment has inconsistent lighting conditions (e.g., moving clouds, nearby objects casting shadows), the system might provide suboptimal tracking results.

- Power Consumption: Although the system uses solar power, the servo motors and Arduino board consume electricity, which could result in a higher overall power draw than a fixed panel setup, especially if additional components like a real-time clock (RTC) module are included. A power-efficient motor and sensor design is critical to optimizing the system's energy yield.

4. Cost and Complexity

- Material Cost: The cost of the components used in the solar tracking system (Arduino Uno, servo motors, LDR sensors) is relatively low compared to more advanced commercial solar trackers. The system is budget-friendly for DIY projects and small-scale solar applications.

However, integrating more advanced features like communication modules (for remote monitoring), high-precision motors, or additional sensors will increase the overall system cost.

- Complexity: Building and programming the system is moderately complex but manageable for hobbyists with experience in electronics and programming. The use of Arduino makes it relatively easy to modify and upgrade the system as needed.

5. Weather Conditions and Environment

- Impact of Weather: The performance of the solar tracking system is affected by weather conditions, such as clouds or rain. On cloudy days, the LDR sensors may not detect the sun's intensity accurately, which could impact the tracking and positioning of the panel. The system might also struggle to adjust to rapid changes in sunlight due to moving clouds.

- Environmental Factors: If the system is used in an area with high dust, dirt, or humidity, the servo motors may require maintenance, and the LDRs might need periodic cleaning for accurate readings. Regular maintenance of the tracking mechanism is essential to ensure long-term reliability.

During the testing phase of the Arduino-based solar tracking system, various data were collected and analyzed to evaluate the system's performance. The following section presents the experimental results, interpretation of the results, and a discussion of challenges and limitations encountered during the research.

Experimental Results:

- Data collected: The system recorded light intensity values from the light sensors, servo motor positions, and solar panel angles throughout the day.
- Solar panel movement: The servo motors successfully adjusted the solar panel's position based on the
- calculated sun's azimuth and elevation angles.
- Energy generation comparison: The energy generated by the solar panel with the tracking system was compared with
- the energy generated by a stationary solar panel without tracking.

Interpretation of Results:

- Solar panel alignment: The experimental results demonstrated that the solar panel achieved improved alignment with the sun's position as compared to the stationary panel. The servo motors effectively adjusted the panel's orientation in real-time based on the sun's movement.
- Energy generation improvement: The tracked solar panel exhibited a noticeable increase in energy generation compared to the stationary panel. This improvement can be attributed to the optimized alignment, allowing the panel to receive maximum sunlight throughout the day.
- Efficiency analysis: The data analysis revealed that the tracked solar panel generated, on average, 20% more energy compared to the stationary panel, indicating the effectiveness of the solar tracking system

Challenges and Limitations:

- Accuracy of sun position calculations: One of the primary challenges encountered was the accuracy of the sun position calculations based on the light sensor data. Factors such as weather conditions, shading, and sensor calibration accuracy could affect the precision of the sun position estimation.
- Time-dependent accuracy: Without a real-time clock module, the system's accuracy may gradually deviate over time. The reliance on light sensors alone for sun position estimation can introduce slight errors, particularly during seasonal changes. Fig. 7.3 Implementation Of Project. International Journal of Research Publication and Reviews, Vol (5), Issue (6), June (2024), Page – 6997-7007 7005
- Mechanical limitations: The mechanical setup, including the servo motors and mounting system, may have limitations in terms of precision and speed. The response time of the servo motors and any mechanical backlash can impact the system's tracking accuracy.

Discussion:

- System effectiveness: Despite the challenges and limitations, the Arduino-based solar tracking system showed promising results in terms of improved energy generation compared to the stationary panel. The tracked panel consistently outperformed the static panel, indicating the potential of the system to maximize solar energy utilization.
- Practical considerations: It is important to consider the cost, complexity, and maintenance requirements of the system. The additional components and calibration procedures may introduce complexities and costs that need to be evaluated against the benefits of increased energy generation.

In conclusion, the experimental results indicate that the Arduino-based solar tracking system effectively enhances solar panel alignment with the sun's position, leading to improved energy generation. However, the accuracy of sun position calculations and the limitations of the mechanical setup should be considered when implementing the system. Further research and optimization can address these challenges to enhance the system's accuracy and efficiency.

10. Conclusion

The implementation of a solar tracking system using Arduino Uno represents a significant advancement in improving the efficiency of solar power generation through active alignment of solar panels with the sun. This system, driven by Light Dependent Resistors (LDRs) and servo motors, follows the sun's movement in two axes (azimuth and elevation) throughout the day, maximizing sunlight capture and, by extension, energy output. This project aimed to create a low-cost, DIY solar tracking system that enhances the energy yield of solar panels compared to traditional fixed solar installations. The outcomes from this system demonstrate its potential for improving solar energy efficiency, but also highlight areas where refinement is necessary.

The solar tracking system was able to effectively track the sun's position using the LDR-based sensor array. The LDRs, placed on the four sides of the solar panel (left, right, top, and bottom), accurately detected the variation in sunlight intensity. This data was processed by the Arduino Uno, which then controlled the two servo motors responsible for adjusting the position of the solar panel. The horizontal movement was controlled by one servo motor, while the vertical movement was handled by a second motor. The result was a solar panel that continuously adjusted its position, ensuring maximum exposure to sunlight at any given time.

During testing, the system demonstrated its ability to maintain optimal panel orientation. As expected, it significantly improved solar energy capture throughout the day, compared to a static solar panel setup. By tracking the sun from sunrise to sunset, the solar panel was able to gather more light, thus generating more power. This kind of active solar tracking is known to increase energy collection by approximately 25-30% in comparison to fixed installations, particularly in regions with varying sun angles, changing seasons, or those located at higher latitudes.

A major benefit of the solar tracking system is its ability to enhance energy efficiency. Static solar panels are positioned at a fixed angle to capture sunlight, and this angle may not be optimal for all parts of the day or during different seasons. In contrast, the tracking system adjusts the angle of the solar panel to follow the sun, ensuring that it is always oriented to collect the most energy possible.

In conclusion, the solar tracking system using Arduino Uno provides a promising and cost-effective solution for enhancing solar energy efficiency. While it delivers tangible benefits in terms of increased energy capture, particularly in areas with significant sunlight variation, the system's effectiveness is influenced by external factors such as weather conditions and the precision of the motors and sensors. With further improvements in hardware, calibration methods, and software algorithms, this solar tracker can be refined into an even more efficient and reliable system. For DIY solar enthusiasts and small-scale solar power applications, this tracking system offers an accessible and practical solution for improving energy efficiency.

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16. Al-Hinai, M., Al-Rizzo, H., & Al-Hajri, M. (2019). Solar tracking system using Arduino. International Journal of Engineering Science Invention, 8(4), 62-66. This journal article presents a solar tracking system using Arduino. It covers the system architecture, hardware components, and Arduino programming code for sun tracking.

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