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Design And Implementation Of Heliotrophic Solar Panel System For Enhanced Energy Harvesting

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Abstract: This project aims to develop a heliotropic system that enhance the performance of panels. It achieves this by using Light Dependent Resistor (LDR) sensors to detect sunlight intensity. Since the orientation of panels significantly impacts the amount of energy they collect, this system incorporates four LDR sensors positioned in different directions—North, South, East, and West. These sensors monitors sunlight levels from various angles, ensuring optimal positioning for greater energy absorption.
The goal here is to design a heliotropic tracker that improves the panels performance using light sensors called Light Dependent Resistors (LDRs). It's well-known that light travels in straight lines from its source. In solar power systems, the alignment of solar panels with the setting sun is vital for maximizing energy capture. To achieve this, the project uses four LDR sensors arranged in a cross configuration, each facing North, South, East, and West. This is accomplished with the help of three servo motors that allow the solar panels to rotate. These motors control the horizontal (East-West) and vertical (North-South) movements, as well as the tilt of the system panels in relation to the sun's position. An Arduino microcontroller will manage the servo motors, directing the movement of the system panels based on the data received from the LDR sensors.

Index Terms – Component Solar Tracking System, Arduino Nano, Light Dependent Resistors (LDRs), Servo Motors, Solar Panel Orientation, Maximum Energy Absorption, Sunlight Intensity Detection, Buck Converter, Power Regulation, Automatic Sun Tracking, Real-Time Panel Adjustment, Renewable Energy Optimization, Dual-Axis Tracking, Efficiency Enhancement, Smart Solar Technology.

I. Introduction

The demand for unconventional renewable energy solutions has grown substantially because of the mounting concerns related to sustainability of the environment and depleting non-renewable energy sources. Of all the renewable energy resources, solar energy or the solar power has been one of the most widely available and abundant sources. However, the efficiency of the generation of solar power depends extensively on the direction and alignment of the panels towards the direction of sunlight during daylight [1-5]. In such cases, heliotropic systems provide a remedy where the solar panels' movement is created in synchrony with the motion of the sun to maximize power output and enhance energy harvesting [6-7]. A tracker system is a blend of mechanical and electrical components with sensors that manage the relative solar panels' motion so that the angle of the incident solar radiation remains 90 degrees at all times.

Unlike static installations of panels that are rigid and stand in one fixed position, tracking systems enable solar plates to adjust in the sun's direction, thereby maximizing the collection of energy [8]. Studies indicate that solar tracking devices generate 40% more solar energy than static systems, making them suitable for large solar power plants and other photovoltaic systems utilizing high sunlight density [9-12].

Types of solar tracking systems are:

1. Single Axis Trackers – These types of systems are capable of rotation over a specified radius following the sunlight from east to west thus maximizing energy absorption.

2. Dual Axis Trackers – They are more intricate as they adjust both horizontally and vertically, making it possible for a more accurate angle of the panel compared to the position of the sun [13-18].

While they have their own benefits, tracking systems come with mechanical sophistication due to the presence of motors, sensors, and control systems that enable panel reorientation. The greatest challenge with solar tracking is to create a system that is economical, energy-efficient, and highly reliable but gives precise real- time tracking. Advanced sensor-based control systems play a key role in making this feasible [19- 20]. The system in [24] integrates temperature and light intensity sensors with microcontroller based automation to dynamically adjust fan speed and curtain positioning. The proposed system offers an affordable and sustainable solution for home automation applications, combining ease of use with significant energy savings [24].

They are sensors of sunlight intensity and direction that provide signals to a controller, which initiates corrective action orientations of the solar panel .In addition to this, high-end tracking systems integrate automation, machine learning algorithms, and IoT-based control technologies to further improve energy efficiency and operational reliability [21-22]. As the global drift towards using the renewable energy increases in momentum, studies of efficient and intelligent solar tracking systems remain high on the agenda

Through the maximization of solar power generation potential, such systems maximize energy security, reduce dependence on fossil fuels, and build a more sustainable [23]

II. LITERATURE SURVEY

[1] The System discusses a method to improve panel performance by automatically adjusting their position to follow the sun. It highlights different tracking types and presents a sensor-based prototype that boosts energy output compared to fixed systems.

[2] Review on Automatic Solar Radiation Tracking System explores different methods of solar tracking to improve the efficiency of photovoltaic systems. They focus on automatic tracking systems that make adjustments of panel angles based on sunlight direction. The review compares single-axis and dual-axis trackers, as well as sensor-based and programmed systems. It highlights the benefits of increased energy output and better utilization of solar power. Challenges such as cost, maintenance, and complexity are also discussed. Overall, this paper provides valuable insights into optimizing solar energy capture through automated tracking.

[3]Tracking System, A Review provides a comprehensive overview of solar tracking technologies. The authors discuss the need for tracking systems to enhance solar panel efficiency by maintaining direct alignment with the sun. They examine both passive and active tracking mechanisms, including single-axis and dual-axis systems. The review highlights the performance benefits of these systems and their energy yield improvement. It also covers the design considerations, control methods, and economic aspects. The paper concludes by emphasizing the role of tracking systems in advancing sustainable solar power.

[4] Automatic energy tracker explores various tracking methods that help solar panels to follow the sun to increase energy output. The authors analyse sensor-based, time-based, and hybrid tracking systems. They also discuss implementation challenges, cost-effectiveness, and system efficiency. The paper highlights how automatic tracking can significantly enhance solar power generation. It concludes by suggesting future improvements and research directions for smarter solar tracking.

[5] Analysis of Solar Panel Tracker System to maximize the Efficiency of Solar Panel analyse how tracking systems enhance solar panel efficiency. The study focuses on designing a solar tracker that follows the sun’s movement throughout the day. It compares fixed panels with tracking ones, showing notable improvements in energy generation. The authors discuss sensor integration, control logic, and mechanical setup. Efficiency data and performance metrics are also presented. The paper concludes that solar trackers are a practical way to boost energy output.

[6] A Review on Solar Panel Tracking System and Their Classification provides an overview of various tracking systems. The authors classify tracking systems into active, passive, manual, and hybrid types. Each type is evaluated based on efficiency, complexity, and suitability for different applications. The review emphasizes the role of dual-axis trackers in maximizing solar energy capture. Key technological components and control strategies are also discussed. The paper concludes by highlighting the need for cost-effective and efficient tracking solutions.

[7] Technologies of Solar Tracker Systems: A Review reviews various technologies used in solar tracking systems. The authors explore single-axis and dual-axis tracking systems and their advantages in improving solar panel efficiency. They analyse different tracking techniques, including mechanical and electronic systems, as well as their control mechanisms. The paper also discusses the economic considerations and challenges of implementing tracking systems. The review concludes by suggesting advancements needed to increase the performance and affordability of solar tracker technologies.

[8] Review of Programmable Tracking System for Finest Power Supply reviews programmable solar tracking systems aimed at optimizing solar energy generation. They discuss the benefits of programmable systems, including higher energy yield and better alignment with the sun. The paper covers various control methods, such as microcontroller-based programming and sensor integration, to automate tracking. It highlights the advantages of dynamic adjustments to enhance power supply consistency. The authors also address the challenges of implementation and maintenance. The review concludes by emphasizing the future potential of programmable tracking for sustainable energy solutions.

[9] A Review Paper on Panel Tracker System for Photovoltaic Power Plant examines the role of panel tracking systems in enhancing the performance of photovoltaic (PV) power plants. The authors review various tracking mechanisms, including single-axis and dual-axis systems, and their impact on energy production. They discuss the design considerations, control systems, and integration of sensors for automatic tracking. The paper also highlights the challenges and costs associated with tracking systems. It concludes by recommending improvements for optimal energy generation and better scalability of PV plants.

[10] Single Axis Tracker of Solar Panel focuses on single-axis energy tracking systems. They discuss how these systems improve solar panel efficiency by adjusting the panel's orientation to follow the sun's path. The paper highlights the design of a low-cost, microcontroller-based tracker using Light Dependent Resistors (LDRs). It examines the advantages of single-axis trackers over fixed systems, such as increased energy output and simplicity. The authors also review the system's control mechanism and challenges related to implementation. The paper concludes by suggesting ways to enhance the performance of such tracking systems.

III. METHODOLOGY

The methodology for this automated heliotropic tracking system involves integrating key components such as Light Dependent Resistor (LDR) sensors, a microcontroller for data processing, servo motors for panel adjustments, and a feedback mechanism to optimize the panel's orientation. The goal is to continuously align the panel with the location of the sun to maximize energy absorption whole day.

The four LDR sensors are positioned around the panel to measure sunlight intensity from different directions. The front LDR detects the intensity from the panel's current orientation, while the back LDR senses light from the opposite direction. Similarly, the left and right LDRs help in detecting sunlight from their respective sides. This data is crucial in determining the necessary adjustments for the panel.

To process sensor inputs effectively, the microcontroller first converts the analog signals from the LDRs into digital data using its built-in Analog-to-Digital Conversion (ADC) channels. Based on these readings, the microcontroller calculates the optimal angles for adjusting the solar panel. By continuously analyzing real-time data, the system ensures the panel remains aligned to the sun throughout the day.

To improve energy efficiency, the system incorporates a panel folding mechanism that activates under low sunlight conditions, such as during nighttime or cloudy weather. If all four LDR sensors detect minimal sunlight, the system triggers a motorized mechanism to fold the panel into a compact position, conserving energy and space. Once sunlight is detected again, the panel unfolds and reorients itself to the optimal position.

To ensure optimal performance, the system undergoes thorough calibration and testing. The LDR sensors are calibrated against known light sources to fine-tune their responsiveness to sunlight intensity.

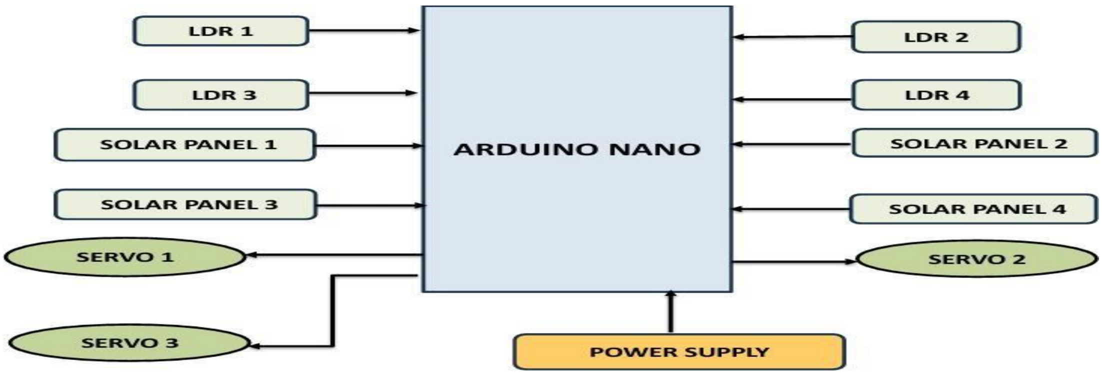

Fig 3.1: Block Diagram of Heliotropic Solar Panel

This heliotropic system is implemented to improve the efficiency of solar energy absorption by dynamically adjusting the position of a panel based on sunlight intensity. The system continuously tracks the movement of sunlight using Light Dependent Resistors (LDRs) and adjusts the panel's position using servo motors.

Flowchart

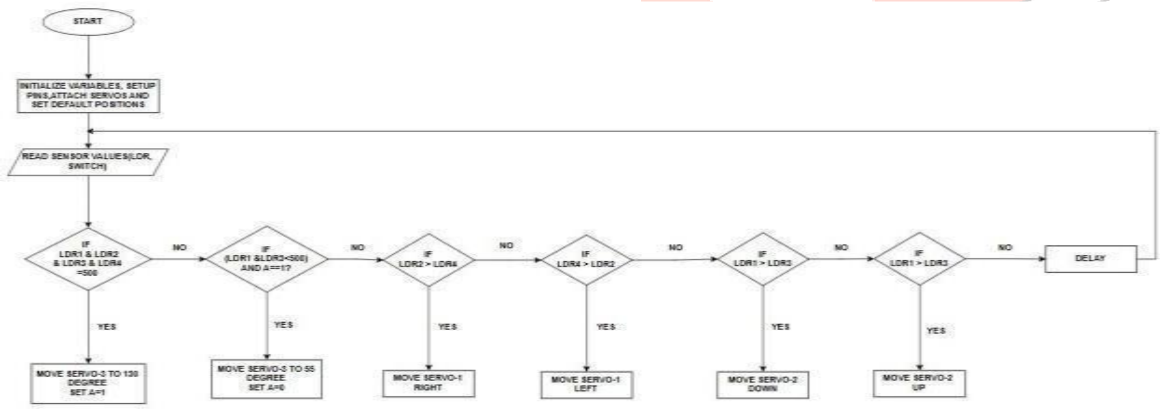

Fig 3.2: Flow Chart of Heliotropic Solar Panel

The flowchart represents the control logic for a heliotropic system using LDR sensors and servo motors. Here's how the process flows:

1. Initialization Stage:
 •The system starts and initializes variables.
 •It sets up pin configurations, attaches servos and positions them to default angles.
2. Sensor Reading Stage:
 •The Light Dependent Resistors (LDR1, LDR2, LDR3, and LDR4) detect the intensity of sunlight.
 •The system reads their values and determines the position of the strongest light source.
3. Decision-Making & Servo Movement:
 •If LDR2 > LDR4, move Servo-1 right (adjusts horizontally).
 •If LDR4 > LDR2, move Servo-1 left.
 •If LDR3 > LDR1, move Servo-2 up.
 •If LDR1 > LDR3, move Servo-2 down (adjusts vertically).

4. Loop & Delay:

•After adjusting the servos, the system enters a delay loop .The process repeats, continuously tracking the sun's position.

IV. RESULTS AND CALCULATION

4.1 Calculation of Solar Panel Efficiency:

The efficiency of the panel was tested under two lighting levels: natural sunlight and torchlight.

$\eta=(Pout/Pin)\times100$ ………………(1)

where:

•Pin is the input power incident on the panel.

•Pout is the output power generated.

4.2 Efficiency Under Sunlight:

The solar panel was exposed to direct sunlight with an intensity of 1000 W/m^2. The input power received by the panel was 19.6 W, and the output power generated was 12W. Using the efficiency formula from (1)

$\eta= (12/19.6)\times100=61.22\%$

Thus, the panel achieved an efficiency of 61.22% under sunlight.

4.3 Efficiency Under Torchlight

The panel was also tested under artificial light using a torch with an intensity of 3.95 W/m^2. The input power received was 0.000774 W, while the output power generated was 0.02 W. The efficiency was calculated as:

$\eta= (0.02/0.000774)\times100=15.8\%$

The efficiency under torchlight was significantly 15.8%

4.4 Comparison and Analysis

The results shows that the solar panel operates with high efficiency under natural sunlight, converting a significant portion of the incident power into usable electrical energy.

4.5 Tabulated Results

The efficiency calculations are summarized in Table below

Lighting Condition	Intensity (W/m^2)	Input Power (W)	Output Voltage (V)	Output Current (A)	Output Power (W)	Efficiency (%)
Sunlight	1000	19.6	12	1	12	61.22%
Torchlight	3.95	0.00077 4	0.2	0.1	0.02	15.8%

Fig 4.1: Solar Panel Tracking System with Exposed Panels

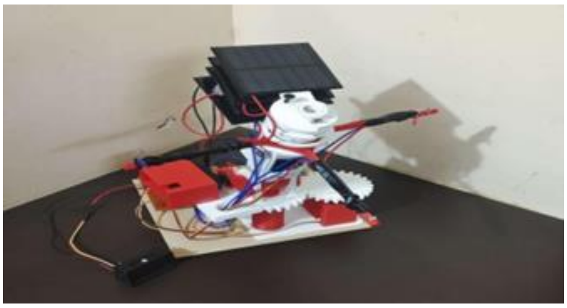

Fig 4.2: Solar Panel Tracking System with closed Panels

Fig 4.3 : Solar Panel Tracking System, If all LDR values ≤ 500

In Case 1, the system is monitoring Light Dependent Resistors (LDRs) to determine the ambient light level. If all LDR values are ≤ 500, this indicates low light conditions.

Fig 4.4 : Solar Panel Tracking System, If the LDR values are ≤ 500 ,but A == 1

In Case 2, If all LDR values are ≤ 500 (indicating low light conditions), but A is already set to 1, the system performs the following actions:

1. Move Servo-3 to 55°
2. Set A = 0 , The variable A is reset to 0, possibly to toggle between different states of operation.

Fig 4.5 : Solar Panel Tracking System, If LDR2 > LDR4, move Servo-1 right

In Case 3, If LDR2 > LDR4, this implies that the light intensity at LDR2 is greater than at LDR4.

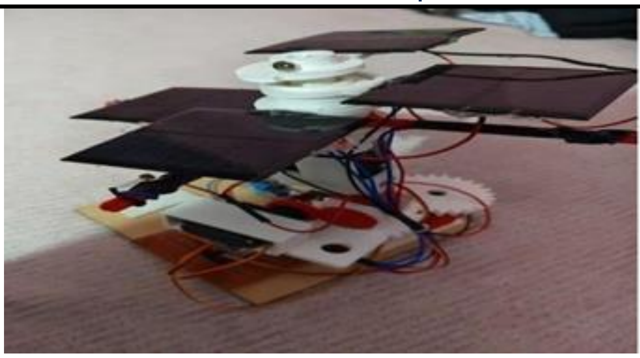

Fig .4.6 : Solar Tracking System, If LDR4 > LDR2, move Servo-1 left.
In Case 4 ,If LDR4 > LDR2, i.e, LDR4 detects more than LDR2.

Fig 4.7 : Solar Panel Tracking System, If LDR1 > LDR3, move Servo-2 down
In Case 5 , If LDR1 > LDR3, it means that LDR1 is detecting more light than LDR3. Based on this condition, the system moves Servo-2 downward.

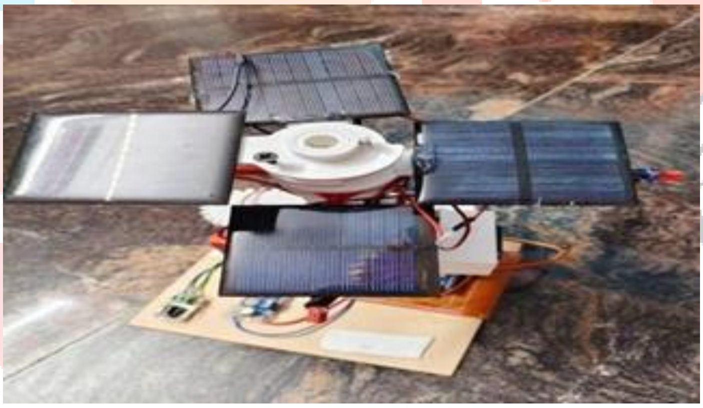

Fig 4.8 : Solar Panel Tracking System, If LDR3 > LDR1, move Servo-2 up

In Case 6, If LDR3 > LDR1, it means that LDR3 is detecting more light than LDR1. Based on this condition, the system moves Servo-2 upward.

V. CONCLUSION

The heliotropic solar panel system effectively boosts energy harvesting efficiency by dynamically tracking the sun's path throughout the day. By a dual axis tracker mechanism, the system optimizes the absorption of solar energy, thus resulting in higher power output than fixed solar panels. Real-time tracking and responsiveness to different environmental conditions are ensured with sensors and microcontrollers, further improving performance.

VI. APPLICATIONS

1. Heliotropic systems can be implemented in large scale solar firms to increase the efficiency of electricity generation by up to 30-40%.
2. Advanced heliotropic systems can be installed on residential buildings particularly in urban areas, where maximizing energy yield from limited space is essential.
3. System enhances the efficiency of EV charging solution, particularly in remote or off grid locations.
4. Heliotropic solar panels are employed in satellite to ensure continuous power supply by tracking the sunlight in space.

VII. FUTURE SCOPE

1. Integration with IoT and AI: IOT can enable remote monitoring and control of solar tracking systems through mobile apps or web interfaces.
2. Advanced Materials for Enhanced Efficiency: Use of perovskite solar cells, multi-junction cells, or anti-reflective coatings can significantly boost energy conversion rates.
3. Optimized Energy Storage Solutions: Integrating the system with smart battery management systems (BMS) ensures optimal charging and discharging cycles, extending battery life.
4. Cost-Effective Manufacturing and Scalability: Future designs could focus on 3D-printed components or modular kits to reduce production costs and simplify assembly.

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