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Single Axis Solar Tracking System

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Abstract: This paper presents a comprehensive review of single-axis solar tracking systems, analyzing their impact on photovoltaic efficiency. By examining various tracking mechanisms, including sensor-based and preprogrammed control strategies, the study highlights advancements in tracking accuracy, energy optimization, and system reliability. A comparative analysis with fixed-panel systems underscores the efficiency gains and practical challenges associated with single-axis tracking. The review further explores improvements in motor control, sensor integration, and power management, providing insights for future advancements in solar energy harvesting.
Keywords: Tracking System, Microcontroller, LDR Sensor, Geared Motor, PWM Controller , Efficiency. optimization of solar energy capture. Additionally, the charge

I. INTRODUCTION

The most promising alternative to conventionally used fossil fuels is solar energy which is renewable and naturally replenished in nature Solar irradiation which is dependent upon panel orientation influences the efficiency of system. To address this limitation, solar tracking systems have been developed to dynamically adjust the panel's position, ensuring maximum solar irradiance absorption. Among various tracking mechanisms, single-axis solar tracking offers a balance between efficiency improvement and system complexity. These systems typically employ sensors such as Light Dependent Resistors (LDRs) and microcontrollers like Arduino to adjust the panel's tilt based on real-time sunlight intensity. Compared to fixed solar panels, single-axis trackers can enhance energy yield by approximately 20-30%, making them a viable solution for residential and commercial applications.

II. SYSTEM DESCRIPTION

The block diagram of the Single-Axis Solar Tracking System represents its functional architecture, showcasing the seamless coordination of various essential components to maximize solar energy harnessing. The system comprises a solar panel, charge controller, battery, Arduino UNO, motor driver, stepper/geared motor, and LDR (Light Dependent Resistor) sensors, each playing a pivotal role in enhancing efficiency. The LDR sensors serve as the system's eyes, continuously monitoring sunlight intensity. These sensors detect variations in solar radiation and send signals to the Arduino UNO, the system's central processing unit. The Arduino, equipped with pre-programmed logic, processes the incoming data and determines the optimal panel orientation to ensure maximum exposure to sunlight. Once the calculations are complete, the Arduino UNO transmits precise control signals to the motor driver, which then directs the geared motor so that panel can be adjusted dynamically. This real-time movement allows the panel to track the sun's movement from dawn to dusk, ensuring continuous controller manages power distribution and regulates power flow between panel and the battery. It prevents overvoltage, deep discharge, and power fluctuations, thereby safeguarding the system's longevity and maintaining stable operation. The block diagram is shown below -

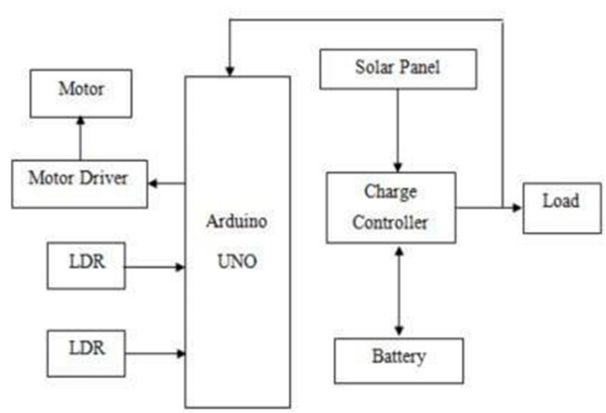

Figure 1. Block diagram of Solar Tracking System

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A. Arduino UNO

The Arduino UNO, powered by the ATmega328 microcontroller, is a widely used open-source development board designed for embedded system applications. It features a 16 MHz clock speed, 32 KB flash memory, 2 KB SRAM, and 1 KB EEPROM, making it suitable for real-time processing. The board provides 14 digital I/O pins (6 PWM-capable) and 6 analog input pins, facilitating sensor interfacing and actuator control. It operates on 5V logic and supports both USB and external DC power (7-12V). The ATmega328 processes input signals, executes programmed instructions, and generates output signals, enabling precise motor control and sensor data acquisition in applications like solar tracking systems. Its compatibility with multiple programming environments and communication protocols, such as I2C, SPI, and UART, enhances its versatility in automation and control systems. Additionally, its extensive community support and open-source nature make it an excellent choice for both beginners and experienced developers. The board can be easily programmed using the Arduino IDE, which simplifies coding and debugging. It also supports numerous libraries that enable seamless integration with various sensors, displays, and wireless communication modules. Due to its low cost and reliability, the Arduino UNO remains a preferred choice for prototyping and educational purposes in electronics and embedded system development.

Figure 2. Arduino Uno

B. Solar Panel

The 30W polycrystalline solar panel used in this project serves as the primary energy conversion unit. It consists of multiple silicon crystal structures, optimizing cost and performance. The panel operates at a nominal voltage of 18V and a current of 1.67A under standard test conditions (STC). It is mounted on a metal frame with a mechanical linkage system, allowing controlled rotation for efficient solar tracking. The panel's orientation is dynamically adjusted using a motor-driven mechanism, enhancing solar energy capture. Its integration with the tracking system ensures improved power output compared to a fixed-panel setup.

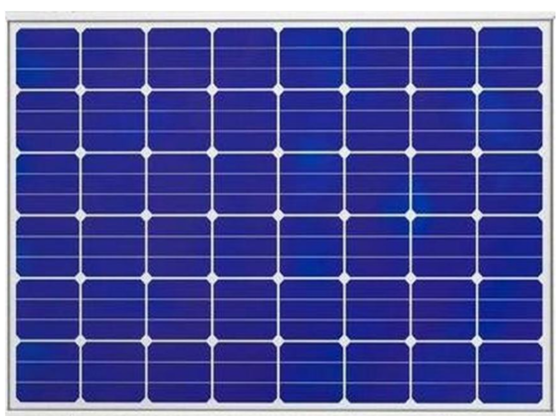

Figure 3. Solar cell

C. Geared Motor

The geared motor used in this project facilitates the controlled movement of the solar panel along a single axis. It consists of a DC motor coupled with a gearbox, which reduces speed while increasing torque, ensuring precise panel orientation. The motor is driven by a motor driver circuit, receiving control signals from the Arduino UNO based on LDR sensor inputs. A chain-and-sprocket mechanism transmits motion from the motor shaft to the panel’s rotating frame, enabling smooth and stable tracking. To enhance efficiency, limit switches or feedback sensors can be integrated to prevent over-rotation and ensure accurate positioning. The motor driver circuit regulates voltage and current flow, protecting the motor from overheating or damage.

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Additionally, using a PWM signal from the Arduino allows speed control, ensuring smooth and energy-efficient operation.
These features make the tracking system reliable and effective in maximizing solar energy utilization. The use of a geared motor also minimizes power consumption by providing the necessary torque at lower speeds, reducing unnecessary energy loss. Incorporating a sturdy mounting structure ensures stability and durability, even in varying weather conditions. Furthermore, regular calibration of the system enhances accuracy, maintaining optimal alignment with the sun throughout the day.

Figure 4. Stepper motor

D. PWM Controller

The Pulse Width Modulation (PWM) controller plays a crucial role in regulating the movement of the geared motor in our solar tracking system. The Arduino UNO generates a PWM signal, which is fed into a motor driver, such as the L298N, so that motor's speed and direction can be controlled.
PWM modulates duty cycle of frequency signal to facilitate precise control over the motor's speed without excessive power dissipation.
By setting duty cycle at high value, speed of motor is increased while for reducing speed duty cycle is set at low value.

Figure: PWM Controller

E. LDR Sensors

An LDR is a passive electronic component whose resistance decreases with increasing light intensity. Typically, its resistance ranges from 1 MΩ in darkness to a few hundred ohms under strong illumination. In solar tracking systems, LDRs are used to detect the direction of maximum sunlight. Two LDRs are placed on opposite sides of a vertical barrier. When sunlight falls unevenly, a voltage difference is generated due to unequal resistance values. These voltages are fed into the analog pins of an Arduino UNO, which processes the readings on a 10-bit scale (0–1023). The microcontroller then drives a motor to rotate the solar panel toward the LDR receiving less light. This realignment continues until both LDRs receive equal light, minimizing the voltage difference. The system ensures real-time solar tracking based on ambient light levels.
Proper positioning and shielding of LDRs are important for reducing errors due to reflections or shadows. LDR-based tracking is a cost-effective method but can be affected by sudden changes in light intensity.

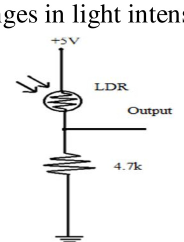

Figure 6. LDR sensor circuit

F. Overall Circuit Diagram

The circuit consists of three primary components: LDR sensors, a microcontroller (Arduino UNO), and a motor driver (L298N) controlling a stepper motor. The LDR sensors detect sunlight intensity and send analog signals to the microcontroller. The microcontroller processes this data and generates control signals for the motor driver, which adjusts the position of the solar panel accordingly. The stepper motor enables precise movement, ensuring the panel aligns with maximum sunlight exposure. A charge controller regulates power flow, preventing over charging and ensuring stable energy storage. The system optimizes solar energy capture through automated real-time adjustments.

The power supply unit provides the necessary voltage levels for all components to function efficiently. A relay module can be incorporated to disconnect the motor when no movement is required, preventing unnecessary power consumption. Proper grounding and circuit protection components, such as fuses and diodes, safeguard the system against voltage spikes and short circuits. The connections between the microcontroller and motor driver are carefully designed to ensure minimal signal loss and efficient operation. Additionally, an LCD display or LED indicators can be added to show system status and real-time tracking information.

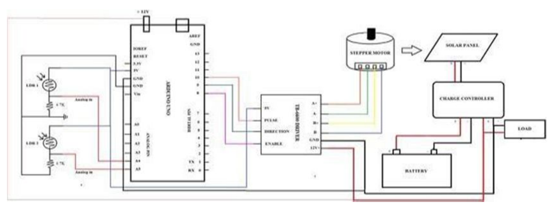

Figure 7. Overall Circuit of Single Axis Solar Tracking System

III. SOFTWARE IMPLEMENTATION

A. Flowchart of Solar Tracking System

The flowchart outlines the logical sequence of operations in the single-axis solar tracking system. It starts with sunlight detection using LDR sensors, which provide analog voltage signals corresponding to light intensity. The Arduino UNO microcontroller processes this data, converting the analog values to digital format.

1) If LDR1 receives more light than LDR2, the motor rotates towards LDR1 to align the solar panel.
2) If LDR2 receives more light than LDR1, the motor rotates in the opposite direction.
3) If both sensors detect equal light intensity, the panel remains stationary, ensuring stability.

This closed-loop feedback system ensures that the solar panel continuously tracks the sun’s movement, maximizing energy absorption.

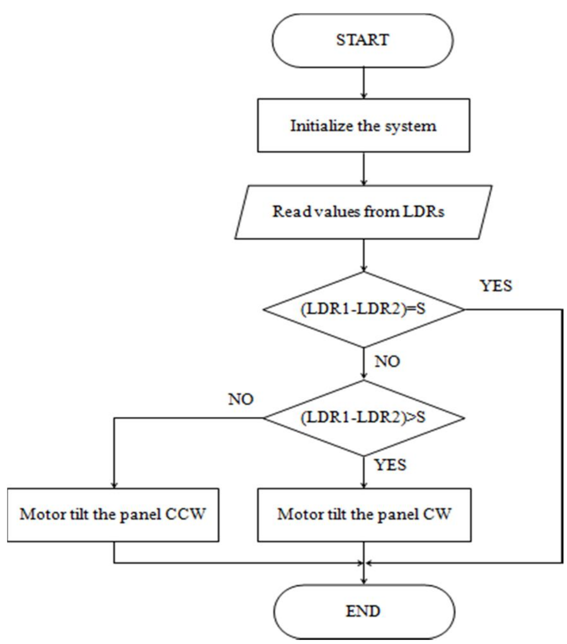

Figure 8. Program flowchart of the solar tracking

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B. Code Compilation and Result

The code is written in Arduino IDE and uploaded to the Arduino UNO. It reads LDR sensor values, compares light intensities, and controls the motor accordingly. If one LDR detects higher intensity, the motor rotates the panel in that direction; otherwise, it remains stationary. The code compiles successfully, and upon execution, the panel accurately tracks sunlight, optimizing energy absorption throughout the day The program utilizes analog-to- digital conversion (ADC) to accurately read LDR sensor values. A predefined threshold prevents unnecessary motor movements due to minor light fluctuations. Pulse Width Modulation (PWM) is used to control motor speed, ensuring smooth adjustments. Conditional statements within the code determine the direction of rotation based on real-time sensor data. Additionally, a delay function is implemented to avoid rapid oscillations, enhancing system stability and efficiency.

IV. EXPERIMENTAL SETUP

The experimental setup comprises a 30W polycrystalline solar panel mounted on a single-axis tracking mechanism, which is driven by a geared motor. The panel's movement is controlled by an Arduino UNO, which processes real-time light intensity data from LDR sensors placed at opposite ends of the panel. The motor is actuated using a motor driver circuit, transmitting motion via a chain-sprocket mechanism to ensure smooth and controlled rotation.

The system operates in two modes: fixed incremental rotation (rotating 15° at fixed intervals) and LDR-based tracking, where the panel aligns itself dynamically based on differential light intensity. A PWM-based control strategy regulates the motor speed, ensuring precision in tracking. A charge controller manages the energy output, preventing overcharging and maintaining efficient power regulation. The setup is designed to maximize solar energy capture by continuously adjusting the panel's orientation for optimal sunlight exposure.

V. CONCLUSION AND FUTURE SCOPE

The developed single-axis solar tracking system successfully enhances the efficiency of solar energy capture by dynamically adjusting the panel's orientation based on sunlight intensity. The integration of LDR sensors, Arduino UNO, and a geared motor enables precise tracking, ensuring maximum power generation compared to a fixed solar panel. The system operates in two modes—fixed incremental rotation and real-time LDR-based tracking—offering flexibility in implementation. The experimental results demonstrate that the tracking mechanism significantly improves energy output, making it a cost-effective and practical solution for renewable energy applications.

Future scope of this project includes:
- Upgrade to dual-axis tracking for higher efficiency.
- Integrate IoT for remote monitoring and control.
- Use AI for real-time optimization of tracking angles Implement.

VI. ACKNOWLEDGMENTS

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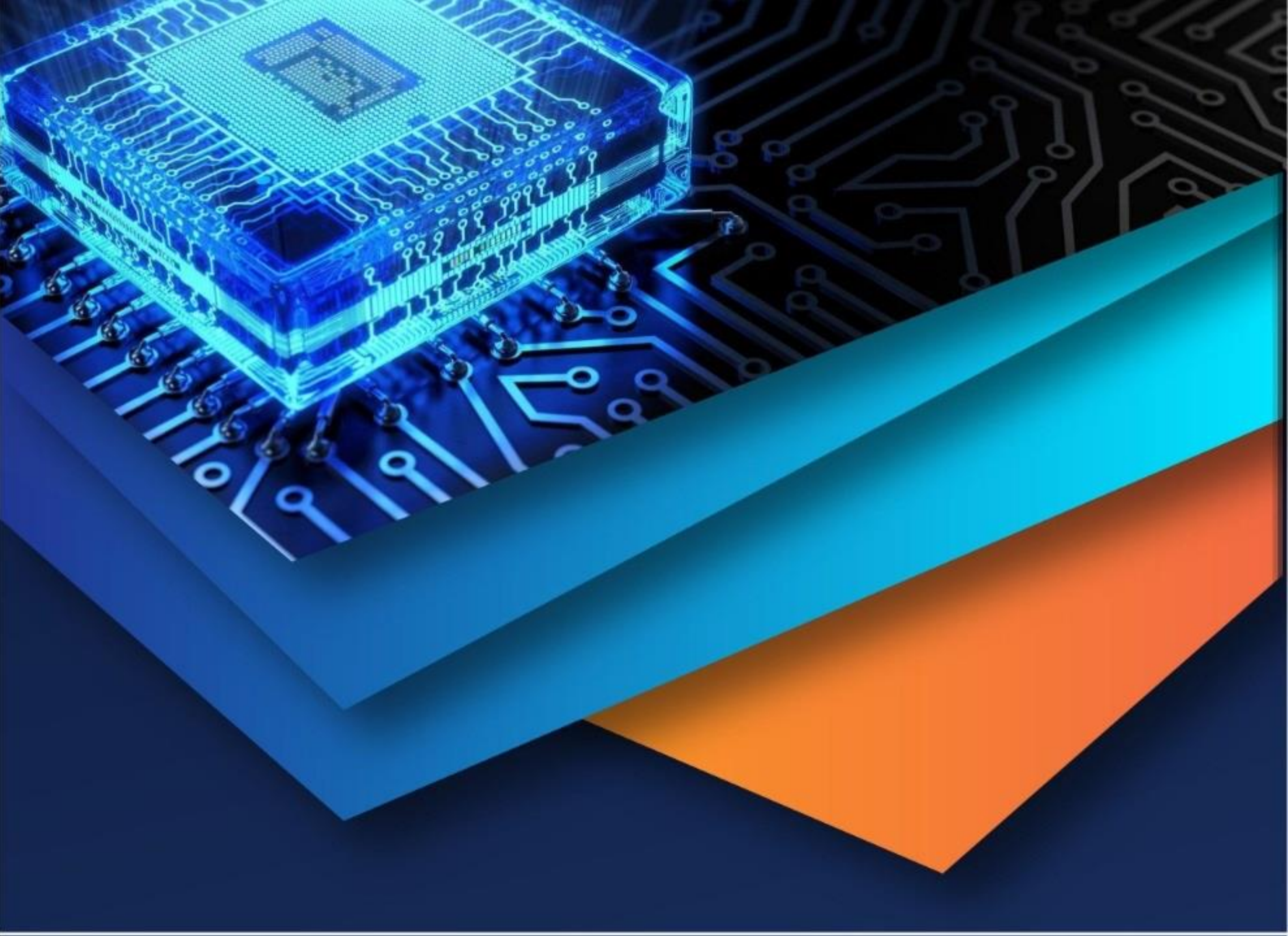

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