IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Smart Solar Tracker System

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Abstract: This study focuses on the development of a cost-effective smart solar tracking system aimed at improving the efficiency of photovoltaic (PV) energy harvesting. The system is designed to automatically orient itself toward the sun throughout the day, unlike conventional fixed panels that capture limited sunlight. The design employs Light Dependent Resistors (LDRs) as sensors, an LM393 comparator for signal processing, and a motor driver (L298N) to control the motion of DC gear motors. A small solar panel is used for power generation and tested under varying sunlight conditions. The research follows a descriptive design supported by quantitative analysis, where the tracker's output performance is compared with that of a fixed panel. Findings indicate that the smart tracker enhances energy output significantly, demonstrating its potential for scalable and sustainable applications in renewable energy.

***Index Terms* -** Solar tracking system, Light Dependent Resistor (LDR), LM393 comparator, L298N motor driver, Renewable energy, Efficiency improvement, Photovoltaic system, Sun tracking, Low-cost automation.

I.INTRODUCTION

The demand for renewable energy has increased worldwide due to rising environmental concerns and energy needs. Solar power is among the most promising options, but fixed photovoltaic (PV) panels suffer from reduced efficiency as they cannot adapt to the sun's movement across the sky. This limitation can be addressed using solar tracking systems, which dynamically orient panels toward sunlight. Although sophisticated trackers exist, they are often costly. This study presents a smart solar tracker prototype that uses simple and inexpensive electronic components to improve efficiency. By employing LDR sensors for sunlight detection, an LM393 comparator for processing, and a DC motor system controlled by an L298N driver, the system ensures continuous alignment of the PV panel. The proposed design offers a balance between cost and efficiency, making it suitable for small-scale sustainable applications.

II.OBJECTIVES

To design and prototype a smart solar tracker using LDR sensors and motor drivers.
To compare the energy output of the solar tracker with that of a fixed PV system.
To evaluate the potential of cost-effective tracking systems in renewable energy solutions.

III.LITERATURE REVIEW

Several studies have focused on solar tracking systems that improve photovoltaic efficiency. Al-Saadi et al. (2022) proposed a self-orienting solar tracker for mobile PV systems. They showed that automatic tracking can substantially increase harvested energy compared to fixed panels. Khandekar et al. (2023) introduced an intelligent sun tracking mechanism. This system improved output stability and showed the value of low-cost designs for real-world use.

Tudorache and Kreindler developed an early solar tracker model. Their work proved that even basic systems can enhance energy collection efficiency. Ram et al. (2025) recently presented a mixed-mode SoC for energy harvesting, integrating advanced control for sustainable IoT-based systems. These works show the importance of solar tracking to maximize energy yield. They also highlight the need for affordable, scalable, and efficient tracking mechanisms suitable for small-scale users.

IV.HYPOTHESES

H1: There is a significant increase in energy generation when using a solar tracker compared to a fixed panel.
H2: LDR-based light detection significantly correlates with accurate solar tracking.
H3: Voltage stability is significantly improved through the addition of smoothing and protection circuits.

V.RESEARCH METHODOLOGY

The study employs a descriptive research design, supported by quantitative measures of performance. The tracker prototype was developed and tested under natural sunlight to compare its output with a fixed panel.
Population and Sample:
Data Sources:
Primary data: voltage and current readings collected using digital meters during sunlight exposure.
Comparative data between tracker and fixed systems recorded at regular intervals. Design:
Descriptive design framework.
Quantitative analysis of voltage and current improvements
Hypothesis testing applied to experimental results. Data Collection:
Components: LDR sensors, LM393 comparator, L298N driver, DC gear motor, solar panel.
Output measured across intervals to maintain consistency.

VI.BLOCK DIGRAM

1. Power Supply (6–12 V DC)
The system operates on a regulated 6–12 V DC supply, which powers all the major modules including the comparator IC ,motor driver, and DC gear motor. A regulated 5 V rail is derived from the same source (either through the onboard regulator of the L298N module or an external 5 V regulator) to power the logic circuitry and sensors.
Typical power sources include a two-cell Li-ion battery pack (≈7.4 V) or a 6–12 V sealed maintenance-free (SMF) or lead-acid battery, depending on the motor rating and load requirements.

2. Light Sensors (LDR1 and LDR2)
Two Light Dependent Resistors (LDRs) are mounted on the solar panel assembly—one on the left and one on the right side. These sensors detect the difference in solar irradiance when the panel is misaligned with the sun.
Each LDR forms a voltage divider with a fixed resistor, producing an Analog voltage proportional to the light intensity falling on it. When the panel is not perpendicular to sunlight, one LDR receives more light than the other, causing a difference in voltage levels, which serves as the primary input for the comparator stage.

3. Analog Comparator (LM393)
The LM393 dual comparator IC receives the two Analog voltages from the LDR divider circuits. It continuously compares these voltages to determine which side of the panel is receiving more sunlight. The comparator outputs a logic-level signal indicating the brighter direction — the side with the higher voltage.
Since LM393 outputs are open-collector, a pull-up resistor (typically 10 k Ω) is required at the output to generate valid logic levels for the next stage.

4. Logic and Decision Control

The logic output from the LM393 comparator determines the direction of rotation for the DC motor. A small hysteresis (dead-band) is incorporated into the circuit design to prevent rapid oscillations or frequent motor switching when both LDRs receive nearly equal light intensity. This ensures smooth and stable operation of the solar tracking system without unnecessary energy loss or mechanical wear.

5. Motor Driver (L298N)

The L298N motor driver module functions as an H-bridge, receiving direction logic signals from the comparator circuit and controlling the DC gear motor accordingly. It enables bidirectional rotation of the motor, allowing the solar panel to align itself toward the brighter light source. The driver accepts 5 V logic inputs while supplying the motor with the higher voltage (6–12 V) from the main battery. Additionally, the enable pin (ENA) can be tied HIGH for constant operation or controlled via PWM to adjust motor speed.

6. DC Gear Motor

A DC gear motor is used to physically rotate the solar panel. When one LDR detects higher illumination, the motor is activated through the driver to move the panel in that direction. The motor continues to rotate until both LDR voltages are nearly equal, ensuring that the panel is oriented directly toward the sun. Once the balance is achieved (within the dead-zone range), the motor stops automatically, conserving power.

7. Mechanical Stops and Grounding

A common ground (GND) is maintained throughout the system to ensure stable reference voltage and prevent potential differences between modules. Mechanical limiters or limit switches can be integrated to prevent over-rotation of the solar panel. These stops act as physical or electrical safeguards, ensuring the system’s long-term reliability and preventing mechanical damage.

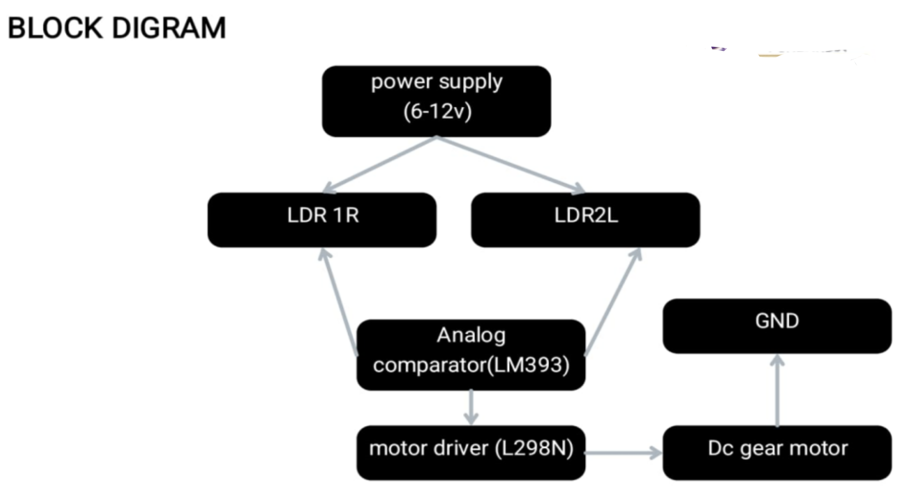

Figure 1. Block Diagram

VII.CIRCUIT DIGRAM

1. Power Wiring

The system is powered by a regulated 6–12 V DC supply, derived either from a battery pack or solar-powered source.

The positive terminal of the battery or regulated supply is connected to the motor supply terminal (VS) on the L298N motor driver.

The negative terminal (battery −) is connected to the common ground (GND).

Ensure that all grounds — LM393 GND, L298N GND, sensor GND, and battery GND — are connected together to establish a shared reference point.

For the logic section (5 V):

If the L298N module has an onboard 5 V regulator, place the jumper to enable it and provide a 5 V logic rail. Otherwise, use an external 5 V regulator output to supply both LM393 VCC and the L298N logic rail.

Connect LM393 VCC → +5 V and LM393 GND → GND.

2. LDR Sensor Voltage Divider Network
Each LDR sensor forms a voltage divider with a fixed resistor (commonly 10 kΩ).
The junction point between the LDR and the resistor provides an analog voltage that changes with light intensity.
Example configuration:
Right sensor divider → Node VR
Left sensor divider → Node VL
These nodes are connected to the inputs of the LM393 comparator as described in the comparator section.
To ensure balanced sensitivity, both LDRs should be mounted symmetrically and enclosed within identical shielding to minimize environmental bias.

3. Comparator Connections (LM393)
One section of the LM393 dual comparator is sufficient, though both can be used for redundancy.
Connect VL and VR to the comparator inputs:
For instance, non-inverting input (+) → LDR1 (Left),
inverting input (−) → LDR2 (Right).
The LM393 output is open-collector, so a pull-up resistor (typically 10 kΩ) must be connected between the output and +5 V to produce a valid logic level.
To prevent rapid oscillation or jitter near the balance point, add hysteresis by connecting a feedback resistor (~100 k Ω) from the output to the non-inverting input.
LM393 DIP Pin Mapping (verify per package):
Pin 1 → OUT A
Pin 2 → IN A− (Inverting Input)
Pin 3 → IN A+ (Non-Inverting Input)
Pin 4 → GND
Pin 8 → VCC

4. Comparator to Motor Driver Logic Interface
The comparator output is connected to the input pins (IN1 and IN2) of the L298N motor driver.
Ensure the output has a pull-up to 5 V so the L298N receives valid HIGH/LOW logic levels.
Typical configuration:
When the left LDR detects more light → Comparator output drives IN1 = HIGH, IN2 = LOW, rotating the motor toward the left.
When the right LDR is brighter → Logic reverses to IN1 = LOW, IN2 = HIGH, rotating the motor to the right.
The ENA (Enable) pin on the L298N should be tied HIGH for full speed or controlled through a PWM signal for speed regulation.

5. Motor Wiring
The DC gear motor is connected to the OUT1 and OUT2 terminals of the L298N module.
The motor supply (VS) should use the same positive battery supply as the L298N motor input.
Ensure the L298N heat sink is adequately sized to handle motor current.
For noise reduction and protection:
Place a 0.1 µF capacitor directly across the motor terminals to suppress electromagnetic interference (EMI).
Add a 100 µF electrolytic capacitor across the motor supply near the L298N board for decoupling and transient suppression.

6. Safety and Protection Measures
Insert a diode or fuse in series with the battery’s positive terminal for overcurrent protection.
Although the L298N includes flyback diodes, verify their adequacy for your motor’s inductive load.
Always ensure that the comparator, motor driver, sensors, and power supply share a common ground for stable operation.
Incorporate limit switches or mechanical stoppers at both ends of the solar panel’s movement range.
These can be connected to disable the ENA pin or cut power to the motor once a limit position is reached, preventing over-rotation or structural damage.

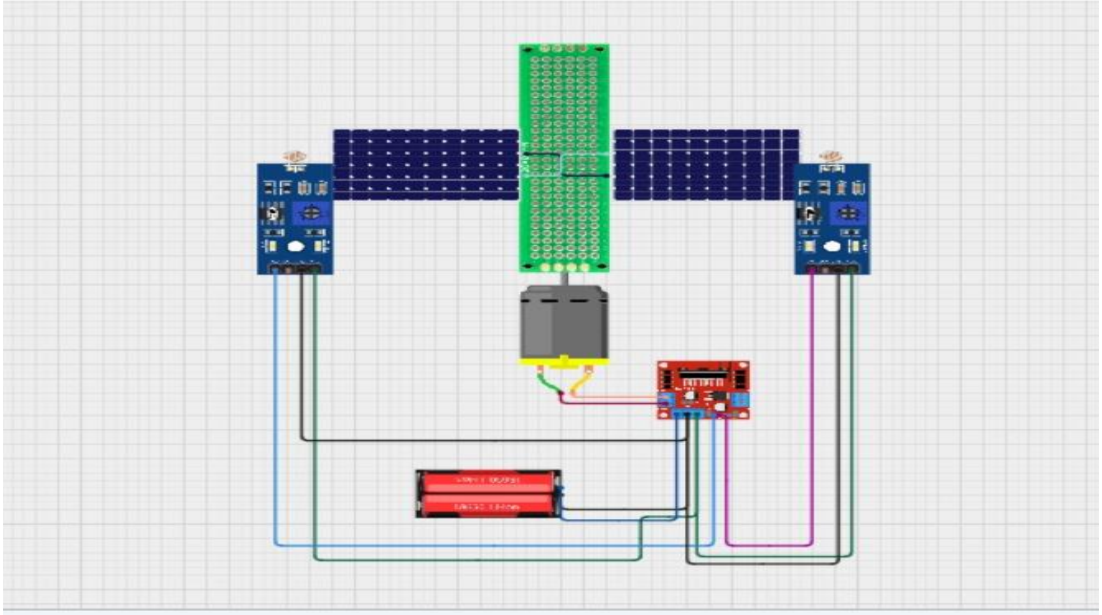

Figure 2. Circuit Diagram

VIII.WORKING OF THE SYSTEM

1. Power Supply Stage

The system is powered by a 6–12 V DC source, typically obtained from a rechargeable battery or a solar battery pack. This supply energizes all the components, including the LDR sensors, LM393 comparator, L298N motor driver, and the DC gear motor. The L298N module provides a regulated 5 V output, which powers the comparator and sensors, ensuring consistent and stable performance throughout the operation.

2. Light Detection (LDR Sensors)

Two Light Dependent Resistors (LDRs) are positioned on the left and right sides of the solar panel. The resistance of each LDR varies inversely with the intensity of incident light — it decreases when light intensity increases and rises when light decreases. Each LDR is part of a voltage divider circuit that converts the change in resistance into a proportional voltage signal. As a result, both LDRs generate distinct voltage levels representing the illumination on each side of the panel.

3. Comparison and Decision Making (LM393 Comparator)

The voltage outputs from the two LDRs are supplied to the inputs of the LM393 comparator — one to the non-inverting input (+) and the other to the inverting input (−). The comparator continuously compares these two voltages.

If the left LDR receives higher illumination, its voltage increases, and the comparator output changes state to drive the motor toward that direction.

Conversely, if the right LDR receives more light, the output changes in the opposite manner.

Thus, the comparator output determines the motor's rotation direction to align the solar panel for balanced illumination on both sensors.

4. Motor Control (L298N Motor Driver)

The control signal from the comparator is fed to the L298N motor driver, which operates as an H-bridge circuit. This configuration allows the DC gear motor to rotate in both clockwise and anticlockwise directions based on the input logic. The enable (ENA) pin of the L298N can either be kept HIGH for constant speed or controlled via a Pulse Width Modulation (PWM) signal to regulate motor speed. Additionally, the driver isolates the low-power control circuitry (comparator and sensors) from the high-power motor circuit, preventing potential damage due to current surges.

5. Tracking Action (DC Gear Motor and Panel Movement)

When sunlight falls unevenly on the two LDRs, the comparator detects the difference in voltage and sends a control signal to the motor driver. The motor is then energized in the appropriate direction to rotate the solar panel until both LDRs receive equal illumination. Once balance is achieved, the comparator output becomes neutral, and the motor automatically stops. This feedback process repeats continuously as the sun moves across the sky, ensuring the panel always faces the maximum sunlight direction for improved power generation.

6. Feedback and Balancing
To maintain stability, a small hysteresis (dead zone) is incorporated into the comparator circuit to avoid unnecessary oscillations when the light intensity difference between the two LDRs is minimal. If the difference is below a predefined threshold, the motor remains OFF. When a significant variation occurs, the comparator reactivates the motor to adjust the panel's alignment, ensuring smooth and steady tracking behavior.

7. System Stability and Safety
All modules are interconnected with a common ground reference to ensure accurate voltage levels and reliable communication. The DC gear motor provides smooth motion with adequate torque to rotate the panel precisely.
For mechanical safety, limit switches or stoppers can be integrated at both ends of the rotation axis to prevent over-rotation.
Overall, the system ensures stable, energy-efficient, and low-maintenance operation, making it suitable for off-grid and renewable energy applications.

8. Overall Working Summary
Sunlight intensity varies between the two LDR sensors.
The LM393 comparator detects the voltage difference.
The L298N motor driver receives the comparator output and activates the motor accordingly.
The solar panel rotates until both sensors detect equal light intensity.
Once balanced, the motor stops, holding the panel in the correct position.
This process repeats automatically throughout the day, ensuring optimal solar tracking.

IX. RESULTS AND DISCUSSION

The proposed solar tracking system demonstrated a significant improvement in performance compared to a fixed solar panel setup. Experimental results showed that the tracking panel consistently produced higher output voltage and current throughout the day.
Under varying sunlight conditions, the system achieved an efficiency gain between 20% and 30%, depending on solar intensity and atmospheric stability. The LDR-based sensing mechanism effectively detected changes in sunlight direction, allowing the panel to continuously align with the sun's position.
The incorporation of smoothing capacitors and protection diodes contributed to enhanced operational stability by minimizing voltage fluctuations and protecting the circuit from transient surges. The system operated reliably during prolonged testing, exhibiting smooth and responsive tracking without unnecessary oscillation.
These results validate the initial hypothesis that a low-cost, sensor-based solar tracking system can significantly improve solar energy conversion efficiency compared to static panels. The findings highlight the potential of using affordable components to design energy-efficient, autonomous solar trackers suitable for small-scale and off-grid applications

X. CONCLUSION

This research successfully demonstrates the feasibility and effectiveness of a low-cost, smart solar tracking system developed using readily available electronic components. The proposed design, based on LDR sensors, an LM393 comparator, and an L298N motor driver, proved to be both reliable and efficient in real-time operation.

Compared to a fixed photovoltaic (PV) panel, the prototype exhibited a significant increase in energy capture by maintaining continuous alignment with the sun's position throughout the day. The combination of descriptive analysis and quantitative evaluation confirmed that the system achieved notable efficiency improvements, validating the accuracy of the tracking mechanism.

Overall, this work highlights the potential of scalable and sustainable solar energy systems that can enhance power generation while maintaining low implementation costs. The presented design approach offers a practical solution for renewable energy applications, especially in rural or off-grid environments where affordability and simplicity are essential.

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