DAYANANDA SAGAR COLLEGE OF ENGINEERING

(An Autonomous Institute affiliated to VTU, Belagavi - 590018)
Accredited by National Assessment & Accreditation Council (NAAC) with 'A' grade
Shavige Malleshwara Hills, Kumaraswamy Layout
Bengaluru-560111

Mini Project Report on

Effective automatic solar tracking system for powering household appliances

Submitted in partial fulfillment for the award of degree of

Bachelor of Engineering
in
Electrical and Electronics Engineering

Submitted by

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VISVESVARAYA TECHNOLOGICAL UNIVERSITY
JNANASANGAMA, BELAGAVI-590018
2024-25

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Bengaluru-560111
2024-2025

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

CERTIFICATE

Certified that the mini project report entitled **"Effective automatic solar tracking system for powering household appliances"** carried out by **SPANDANA A, SUMANGALA POLICE PATIL, VIDYAPOGULA PRASHAMSHI, ZOYATAJ S** bearing **USN:1DS22EE088, 1DS22EE091, 1DS22EE101, 1DS22EE110** are bonafide students of **DAYANANDA SAGAR COLLEGE OF ENGINEERING**, an autonomous institution affiliated to VTU, Belagavi in partial fulfillment for the award of Degree of **Bachelor of Engineering in Electrical and Electronics Engineering** during the year **2024-2025**. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the report deposited in the departmental library. The mini project report has been approved as it satisfies the academic requirements in respect of work prescribed for the said Degree.

Signature of the Guide	Signature of the HOD
Dr.Suvetha P S	**Dr. Premkumar M.**
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Name of the Examiners	Signature with date
1.	....
2.	....

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DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

DECLARATION

We, Spandana A(1DS22EE088), Sumangala Police Patil (1DS22EE091), Vidyapogula Prashamshi (1DS22EE101) and Zoyataj S (1DS22EE110) respectively, hereby declare that the mini project work entitled " Effective automatic solar tracking system for powering household appliances" has been independently done by us under the guidance of 'Dr.Suvetha P S', Assistant Professor, EEE department and submitted in partial fulfillment of the requirement for the award of the degree of Bachelor of Engineering in Electrical & Electronics Engineering, at Dayananda Sagar College of Engineering, an autonomous institution affiliated to VTU, Belagavi during the academic year 2024-2025.

We further declare that we have not submitted this report either in part or in full to any other university for the award of any degree.

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PLACE:

DATE:

ACKNOWLEDGEMENT

The satisfaction and euphoria that accompany the successful completion of any task would be incomplete without the mention of people who made it possible and under whose constant guidance and encouragement the task was completed. We express our sincere regards to the **Management of Dayananda Sagar College of Engineering, Bengaluru.**

We express our sincere regards and thanks to **Dr. B G Prasad, Principal, Dayananda Sagar College of Engineering, Bengaluru.** His incessant encouragement, guidance and valuable support have been an immense help in realizing this mini project.

We express our sincere regards and thanks to **Dr. Premkumar M, Professor & HOD, Department of Electrical and Electronics Engineering, Dayananda Sagar College of Engineering, Bengaluru.** His incessant encouragement, guidance and valuable technical support have been of immense help in realizing this mini project. His guidance gave us the environment to enhance our knowledge, skills and to reach the pinnacle with sheer determination, dedicated and hard work.

We would like to express profound gratitude to our guide **Dr.Suvetha P S, Assistant Professor, Department of Electrical and Electronics Engineering, Dayananda Sagar College of Engineering, Bengaluru** who has encouraged us throughout the mini project. Her moral support enabled us to complete our work successfully.

We express our sincere thanks to Mini project Coordinator **Dr. Suchana Mishra**, **Assistant Professor, Department of Electrical and Electronics Engineering** for her continued support and guidance. We thank all teaching and non-teaching staff of the Electrical and Electronics Engineering department for their kind and constant support throughout the academic Journey.

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Department of Electrical and Electronics Engineering

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CO-PO Mapping

COURSE OUTCOMES

CO1: Identify a research problem by doing literature survey with supervisor’s advice.

CO2: Apply the fundamental knowledge of mathematics, science and engineering principles in design of solutions of system components.

CO3: Select and apply a suitable engineering/IT tool in modeling/data interpretation /analytical studies, conduct experiments leading to a logical solution.

CO4: Design a system/ system component/process, build it and test its functioning as a solution to a complex engineering problem with sustainable practice.

CO5: Communicate effectively to a diverse audience about the outcome and societal impact; develop technical reports and publication.

CO-PO mapping:

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3
CO1		2											2	2	1
CO2	1												2	2	1
CO3	2				2								2	2	1
CO4		3	3	3	3	3	3						2	2	1
CO5						3		3		3		3	2	2	1

	PO1	PO2	PO3	PO4	PO5	PO6	PO8	PO9	PO10	PO11	PSO1	PSO2	PSO3
CO1		2									2	2	1
CO2	1										2	2	1
CO3	2				2						2	2	1
CO4		3	3	3	3	3					2	2	1
CO5						3	3		3	3	2	2	1

ABSTRACT

This project presents a design and implementation of an automatic single-axis solar tracking system to optimize energy generation for powering household appliances. The system utilizes a microcontroller-based control unit to track the sun's movement and adjust the solar panel's position accordingly, ensuring maximum energy absorption throughout the day. A comparison with a fixed-tilt solar panel system demonstrates the effectiveness of the single-axis tracker in increasing energy output and efficiency. The proposed system is suitable for residential applications, providing a reliable and sustainable source of renewable energy. The increasing demand for renewable energy has made solar power a key focus of modern energy solutions. However, the efficiency of solar panels is significantly affected by their orientation to the sun.

And also this project presents the design and implementation of a single-axis solar tracking system that automatically aligns a solar panel with the sun’s movement across the sky to maximize energy absorption. The system uses light-dependent resistors (LDRs) to detect sunlight intensity, a DC motor for panel movement, and an ESP32 microcontroller to process sensor data and control the motor through an L298N motor driver. A threshold logic is applied to avoid unnecessary movement, and sleep modes are utilized to conserve power when tracking is not needed. The tracking system is powered by a small DC source, such as a 9V battery, making it suitable for off-grid or educational applications. This project demonstrates a cost-effective and energy-efficient approach to improving solar panel output, laying the groundwork for more advanced solar tracking solutions.

Chapter 1 INTRODUCTION

1.1. Background:

The growing global demand for renewable energy has led to a significant focus on solar power, which is considered one of the most accessible and clean sources of energy. The introduction of the Internet of Things (IoT) has further transformed the landscape of solar energy systems. IoT-enabled trackers allow for real-time monitoring, remote control, and automated data analysis, which enhance both performance and maintenance efficiency [1]. Such systems typically employ microcontrollers like the ESP32 along with wireless communication modules and environmental sensors, enabling smart feedback and control loops [2]. However, the efficiency of photovoltaic (PV) systems is often limited due to their static nature, as fixed panels cannot maintain optimal alignment with the sun throughout the day. To overcome this limitation, solar tracking systems have been developed to enhance energy capture by allowing solar panels to follow the sun's trajectory [3]. Fixed PV installations are inherently inefficient during early mornings and late afternoons, resulting in significant energy loss. In contrast, solar tracking systems—especially those based on single or dual-axis mechanisms—can improve power generation by up to 30–40% by optimizing the incident angle of sunlight [4]. With the rise of smart technologies, the integration of microcontrollers and sensors has made these systems more intelligent and adaptive. Recent implementations demonstrate various approaches to achieving efficient solar tracking. For instance, the use of light-dependent resistors (LDRs) for directional tracking has been explored with ESP32 modules for simplified control and communication [5]. Others have taken a more comprehensive approach by integrating additional sensors for temperature, voltage, and current, thereby offering full-system monitoring capabilities via IoT platforms [6]. In contrast, a novel design utilizing a power feedback mechanism was introduced to maximize energy output without relying on LDRs [7].

These advancements underscore the importance of combining mechanical tracking with digital intelligence to improve solar power generation. IoT-based solar tracking systems not only enhance energy efficiency but also pave the way for more autonomous and resilient renewable energy infrastructure.

1.2. Objectives of research:

The primary objective of this research is to design, develop, and evaluate a cost-effective and efficient single-axis automatic solar tracking system tailored for residential energy needs.

The main objective of this work

- Improve the overall efficiency of solar power generation compared to fixed panel systems.

1.3. Motivation

In the face of rising energy costs, growing environmental concerns, and the increasing demand for clean and renewable energy, there is a critical need to develop efficient solar power systems, especially for residential use. While fixed solar panels are widely used, they often fail to utilize the full potential of solar energy due to their inability to adapt to the sun's position throughout the day. This results in lower energy yields and longer payback periods.

An automatic solar tracking system, especially one using a cost-effective single-axis design, offers a practical solution to this limitation by dynamically adjusting the panel's orientation to follow the sun. This maximizes energy capture without requiring expensive dual-axis mechanisms.

Chapter 2 LITERATURE REVIEW

2.1. Introduction

The Single-axis solar tracking systems represent a significant advancement in solar technology, offering improved efficiency at a manageable cost. With continued development in control algorithms, sensor technology, and materials, these systems are poised to play a critical role in future renewable energy infrastructure .

- Parveen et al. [1] proposed an IoT-based solar tracking system that employs wireless modules and light sensors to automate the panel orientation process. The system enables remote monitoring and enhances energy efficiency by aligning the panel with the highest sunlight intensity. Similarly, el Hammoumi et al. [2] presented a comprehensive IoT-integrated tracking system, which includes remote monitoring, sensor-based control, and real-time communication for smart energy management. Their work emphasized the flexibility and scalability of such systems within modern smart grid environments.
- A foundational review by Racharla and Rajan [3] categorized various tracking systems—fixed, single-axis, and dual-axis—highlighting their relative performance under different environmental conditions. Their study concluded that tracking systems offer significant gains in energy yield, with single-axis trackers offering a balance between complexity and efficiency.
- Iqbal et al. [4] developed a simple yet functional single-axis automatic solar tracker using light-dependent resistors (LDRs) and basic control logic. Their cost-effective design proved particularly suitable for small-scale or educational applications, offering a practical alternative to expensive commercial systems.
- Borade et al. [5] introduced a sun-tracking panel based on the ESP32 microcontroller. This implementation utilized LDR sensors for sun detection and leveraged the ESP32's wireless capabilities for real-time data transmission. In a similar domain, Sankpal et al. [6] developed an IoT-based monitoring and tracking system that integrates voltage, current, and temperature sensors with ESP32 to provide comprehensive data for both control and diagnostics, effectively turning the solar tracker into a smart monitoring system.
- Harshavardhan et al. [7] took a different approach by eliminating LDRs and instead implementing a power feedback mechanism to guide panel orientation. This method ensures the panel always adjusts to maximize real-time power output, enhancing performance even under varying light conditions such as cloud cover or indirect sunlight.

Chapter 3 SYSTEM ANALYSIS AND DESIGN

The block diagram is essential for visualizing the overall working of the single-axis solar tracking system. It highlights the flow of signals and power between components like the ESP32, LDR sensors, motor driver, inverter, and load. This helps in understanding how the system responds to changing light conditions and controls both the solar panel orientation and power delivery to the load. It serves as a simplified guide for design, implementation, and debugging of the project.

3.1. BLOCK DIAGRAM

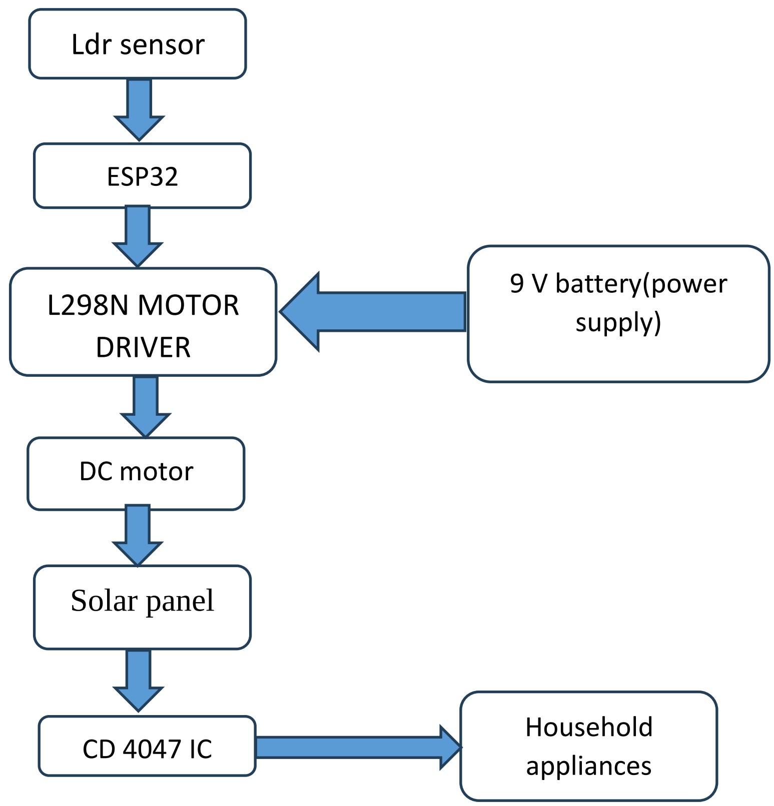


Fig.3.1Block diagram

The Fig.3.1 shows a solar tracking system using an ESP32, two LDRs, and a DC motor controlled via an L298N driver. The ESP32 adjusts the panel’s position based on light intensity. A 5V solar panel powers the system, while a 9V battery provides backup. A CD4047 IC acts as an inverter to control a bulb as the load.

3.2. COMPONENT SELECTION

3.2.1 SOLAR PANEL

70x70 mm solar panel is a small photovoltaic panel, usually generating around 5V and 80–150 mA under direct sunlight. It is responsible for converting solar energy into electrical energy and can also be monitored to verify the effectiveness of the tracking mechanism. Together, these components form a simple yet efficient single-axis solar tracking system.

Fig 3.2.1 Solar Panel

3.2.2 ESP32-The ESP32 is a powerful microcontroller that features dual-core processing with integrated Wi-Fi and Bluetooth capabilities. It is well-suited for IoT and automation projects due to its multiple GPIO pins, ADC channels, PWM outputs, and communication interfaces like I2C, SPI, and UART. In a solar tracking system, the ESP32 serves as the central controller, processing sensor data and issuing commands to control the panel's movement.

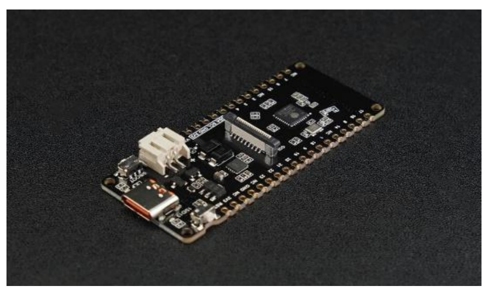


Fig 3.2.2 ESP32

3.2.3 L298N MOTOR DRIVER: The L298N motor driver is used to drive DC motors and operates as a dual H-bridge, allowing control of motor direction and speed. It can handle voltages from 5V to 35V and up to 2A per channel, making it suitable for small to medium motors. This driver takes control signals from the ESP32 and powers the DC motor accordingly.

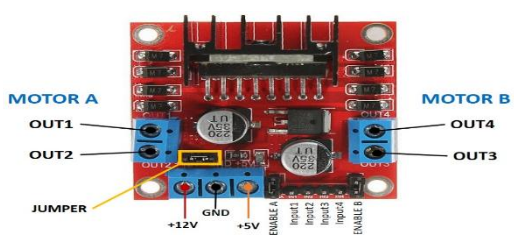


Fig 3.2.3 L298N

3.2.4. LDR

A Light Dependent Resistor (LDR) is a light-sensitive sensor whose resistance changes with varying light intensity. In a solar tracker, multiple LDRs are used to detect the direction of maximum sunlight. By comparing the light levels from different directions, the ESP32 can decide how to move the solar panel.

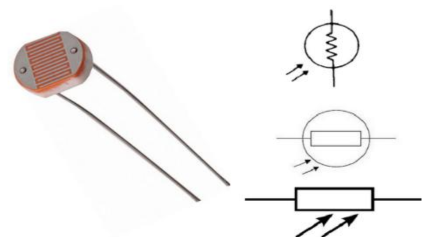


Fig 3.2.4 LDR

3.2.5. DC MOTOR

In a single-axis solar tracker, a DC motor is used to rotate the solar panel either horizontally or vertically to align it with the sun's movement throughout the day, thereby maximizing sunlight exposure and energy generation. Typically, a brushed DC motor operating at 6V to 12V is used due to its simplicity, affordability, and ease of control. The motor is connected to a motor driver, such as the L298N, which receives signals from a microcontroller like the ESP32 to control the direction and speed of rotation using GPIO and PWM signals.

Fig 3.2.5 DC Motor

3.2.6. 9V BATTERY

In a single-axis solar tracker, a 9V battery can be used as a portable power source to supply the motor driver and the DC motor responsible for adjusting the solar panel's position. The 9V battery provides a convenient and compact voltage source, typically suitable for small motors and low-power motor drivers like the L298N. However, because 9V batteries generally have limited current capacity and discharge relatively quickly under high loads, they are best suited for low-power or intermittent operation in solar trackers, such as moving the motor only when adjustment is needed.. Additionally, proper voltage regulation and current considerations must be taken into account to ensure stable motor performance and to avoid rapid battery drain.

Fig 3.2.6 9V Battery

3.2.7. CD4047 IC Inverter-The CD4047 IC is a versatile and low-cost CMOS device commonly used to build simple square wave inverters in electronics and student projects. It can be configured in astable mode to generate continuous square wavesignalsat a desired frequency, typically 50Hz or 60Hz, making it suitable for DC to AC conversion when paired with MOSFETs and a step-up transformer.

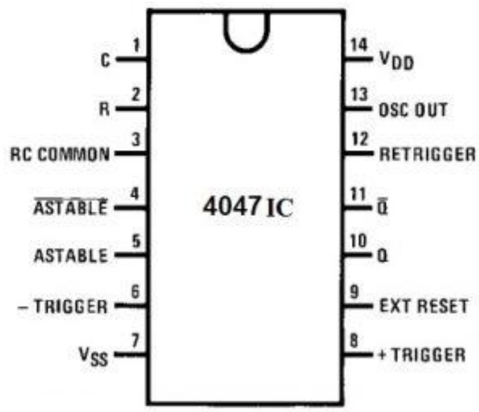


Fig 3.2.7 CD4047 IC

3.2.8. Household Appliance(Bulb):A bulb can serve as a load to demonstrate power generation or as an indicator for system status. It may also be powered via an inverter circuit (e.g., CD4047) to simulate real appliance usage.

Fig:3.2.8 Bulb

3.3. CIRCUIT DIAGRAM

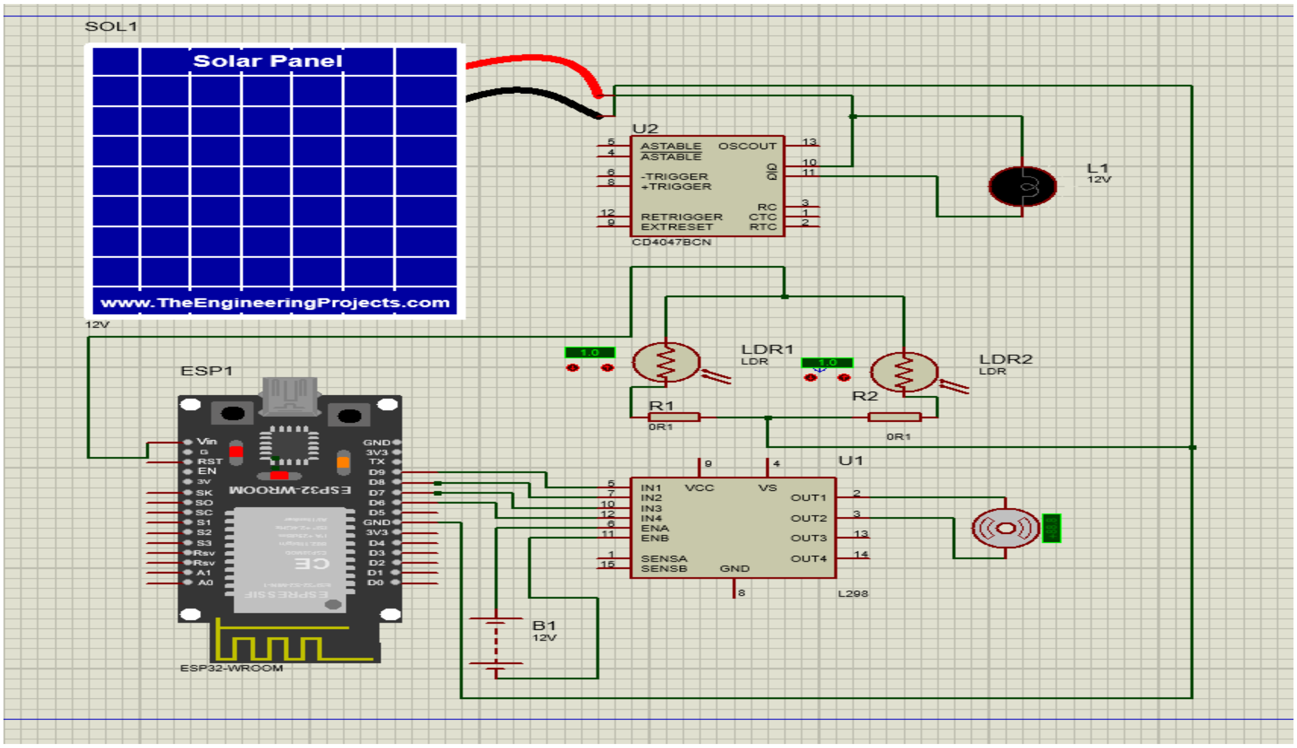


Fig 3.3. Circuit Diagram

Chapter 4 IMPLEMENTATION

4.1. Program for Solar tracking system

```
 #define uS_TO_S_FACTOR 1000000ULL
#define SLEEP_TIME 300  // Sleep for 5 minutes
// Light sensors
const int LDR_Left = 34;
const int LDR_Right = 35;
// Motor driver pins
const int ENA = 14;
const int IN1 = 27;
const int IN2 = 26;
// Thresholds
const int lightDiffThreshold = 100;   // Difference between LDRs to trigger movement
const int ambientLightThreshold = 1000; // Minimum light to operate (to skip movement at night)
void setup() {
  Serial.begin(115200);
  delay(1000);
 // Initialize motor pins
  pinMode(ENA, OUTPUT);
  pinMode(IN1, OUTPUT);
  pinMode(IN2, OUTPUT);
  stopMotor();
 // Read LDR values
  int leftLDR = analogRead(LDR_Left);
  int rightLDR = analogRead(LDR_Right);
  int lightDifference = leftLDR - rightLDR;
 Serial.print("LDR Left: ");
  Serial.print(leftLDR);
  Serial.print(" | LDR Right: ");
  Serial.println(rightLDR);
// Check if ambient light is high enough to track
  if (leftLDR > ambientLightThreshold || rightLDR > ambientLightThreshold) {
```

```
    // Now check if there's enough difference to adjust
    if (abs(lightDifference) > lightDiffThreshold) {
      if (lightDifference > 0) {
        Serial.println("More light on left → rotating left");
        rotateLeft();
      } else {
        Serial.println("More light on right → rotating right");
        rotateRight();
      }
      delay(300);  // Move briefly
      stopMotor();
    } else {
      Serial.println("Light difference is small → no movement");
    }
  } else {
    Serial.println("Ambient light is too low → skipping tracking");
  }
 // Sleep
  Serial.println("Sleeping for 5 minutes...");
  esp_sleep_enable_timer_wakeup(SLEEP_TIME * uS_TO_S_FACTOR);
  esp_deep_sleep_start();
}
void loop() {
  // Will not be used — ESP32 resets on wakeup
}
// === Motor control functions ===
void rotateLeft() {
  digitalWrite(IN1, HIGH);
  digitalWrite(IN2, LOW);
  analogWrite(ENA, 180);
}
void rotateRight() {
  digitalWrite(IN1, LOW);
```

```
  digitalWrite(IN2, HIGH);
  analogWrite(ENA, 180);
}
void stopMotor() {
  digitalWrite(IN1, LOW);
  digitalWrite(IN2, LOW);
  analogWrite(ENA, 0);
}
```

4.2. EXECUTION PROCESS

The working procedure of a single-axis solar tracker system begins with initialization, where the solar panel is positioned facing east at the start of each day, prepared to follow the sun's movement. Sun detection is achieved using light sensors (LDRs) or through a programmed time-based algorithm in a microcontroller, which determines the sun's current position. Based on this input, the system performs panel adjustment using a motor controlled by a microcontroller such as an ESP32 or Arduino. This motor rotates the panel along a single axis, typically from east to west, ensuring continuous alignment with the sun throughout the day.

As the panel maintains optimal orientation, power generation is maximized, as it receives the highest possible intensity of sunlight, resulting in increased solar energy output. The generated DC power is either stored in a battery for later use or converted directly to AC using an inverter, enabling the system to power household appliances efficiently. At the end of the day, once sunlight diminishes, the system either resets automatically to its starting east position or prepares to reset the following morning at sunrise.

The entire operation is automated, utilizing sensors, motors, and a control unit to manage tracking and energy management without the need for manual input, ensuring high reliability and low maintenance.

4.3. IMAGES OF PROTOTYPE

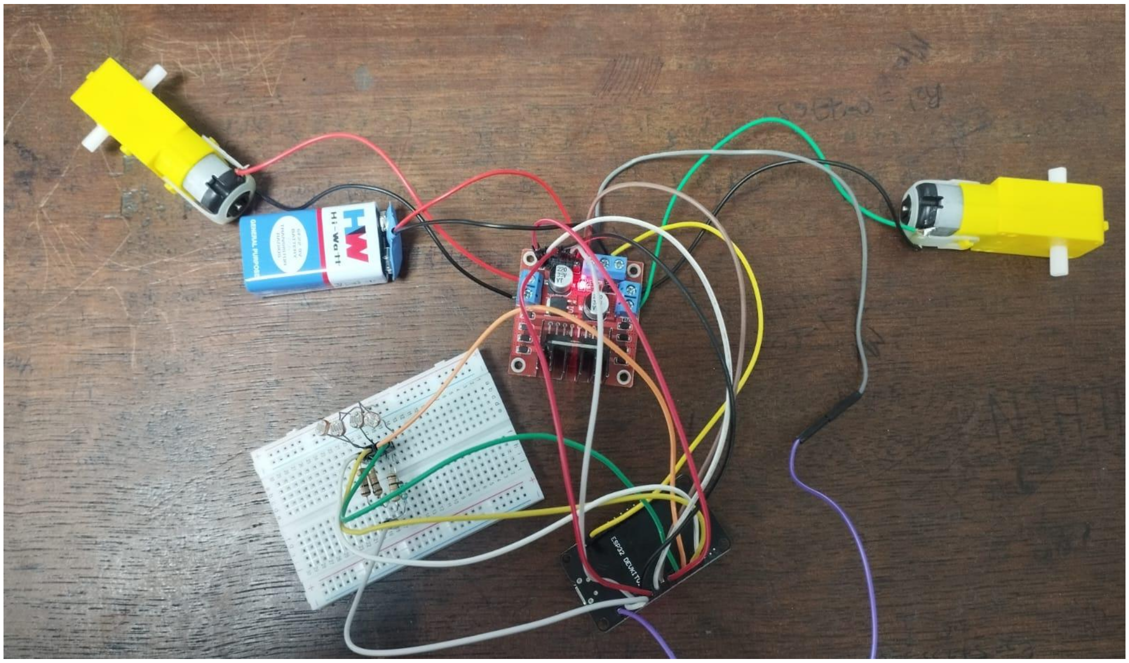
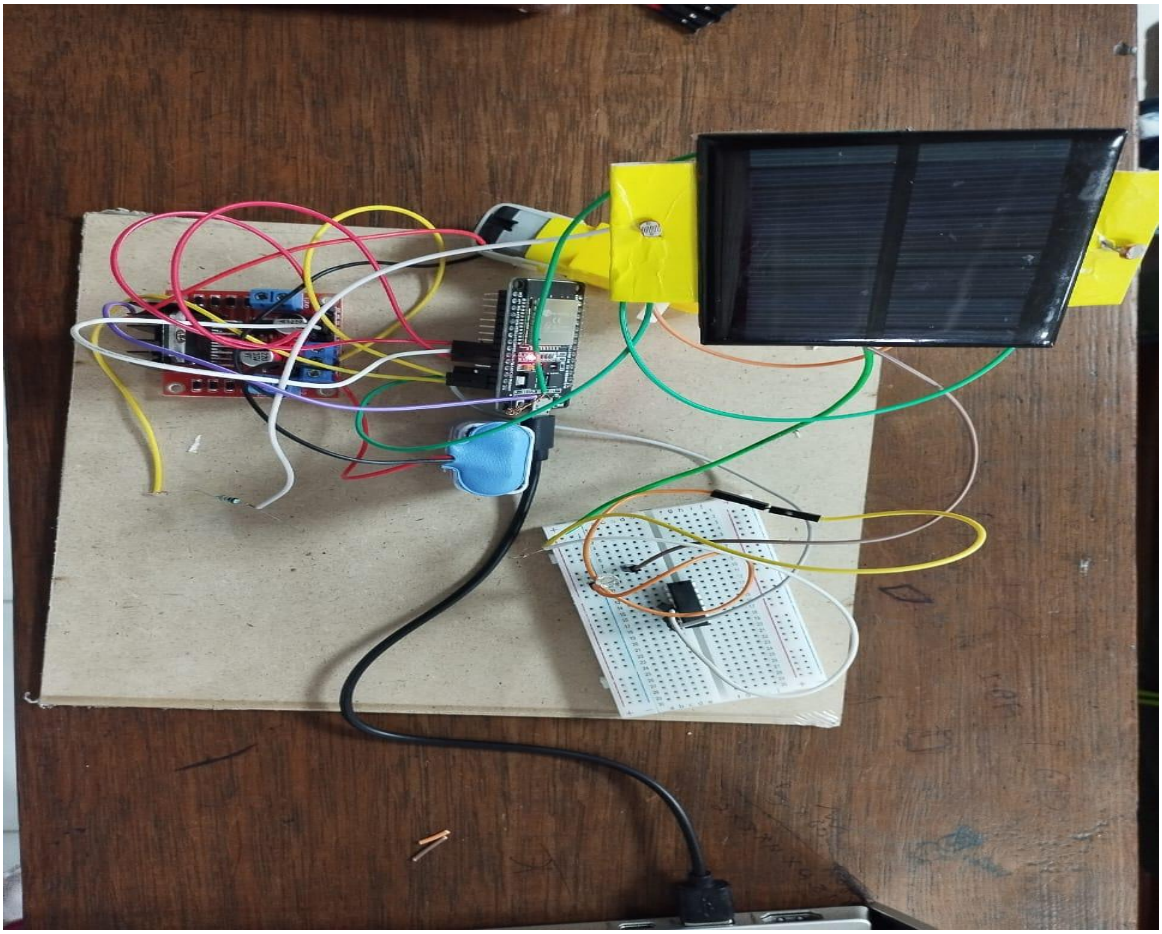


Fig 4.3 Solar tracking system

The circuit is designed to automatically adjust the position of a solar panel to follow the sun’s movement across the sky in a single axis (east to west). Uses an ESP32 microcontroller, two LDR sensors, and a servo motor to track the sun's movement from east to west. The LDRs are placed on either side of a divider and connected to the ESP32 through voltage dividers. The microcontroller reads light intensity from both sensors and compares the values to determine the direction of stronger sunlight.

Chapter 5 RESULT

5.1. RESULT



The single-axis solar tracker is designed and implemented to improve the efficiency of solar energy collection. By using two LDR sensors, the ESP32 microcontroller accurately detected the direction of maximum sunlight and controlled the DC motor via the L298N driver to adjust the solar panel's position in real-time.

This dynamic tracking ensured that the panel consistently faced the brightest light source, leading to a noticeable improvement in solar energy capture compared to a fixed panel. The integration of a CD4047 inverter allowed the harvested energy to be utilized efficiently by powering a bulb, simulating a household load.

The system operated reliably using power from the 5V solar panel and 9V battery, demonstrating its effectiveness in enhancing the overall energy output and usage efficiency of the solar panel.

The efficiency of the solar tracking system is significantly improved through the implementation of control logic in the ESP32 code. The program continuously reads real-time light intensity values from two LDR sensors and compares them to determine the optimal direction for maximum sunlight. Based on this comparison, the code activates the motor only when necessary, reducing unnecessary movement and conserving energy.

Chapter 6 APPLICATIONS AND ADVANTAGES

6.1. Applications

1.Home Rooftop Solar Power Generation: Ground-mounted arrays in larger residential properties can use single-axis trackers to increase daily energy output. Less common for rooftops due to space and structural limitations, but possible with flat roofs.

Case study: A case study of grid type solar panel on the roof top of block-7 at Chandigarh University, so that can supply energy to grid when it's a holiday and if consumption increases and can also take it from the grid.

2.Off-grid Homes or Cabins: Essential for homes relying entirely on solar, especially in remote areas.Increases energy yield without needing to add more panels.

Case study: In this case study the setup of an islanded off-grid house using new sustainable technologies developed in the Netherlands ,which uses various technologies to generate the electricity needed for a house.So solar PV is used coupled with a battery.

3.Battery Charging Systems: More efficient charging of home energy storage systems (e.g., Tesla Powerwall).Helps ensure batteries are fully charged even during shorter winter days.

Case study: Nashville's First Solar Power + Tesla Powerwall System.In 2019, LightWave Solar installed the first solar + Tesla Powerwall battery system in Nashville for the Gilbert family. This system reduces their reliance on the grid, powering about 75% of the home's total electricity use.

4.Solar Water Heating assist: solar-assisted water heating system is type of system integrates solar energy with a backup heat source (electric or gas) to ensure continuous hot water availability.

Case study: In 2021, a 30-apartment residential complex in Pune, Maharashtra, India, implemented a solar-assisted water heating system to reduce dependency on conventional energy sources and lower utility bills. The project involved installing solar flat plate collectors integrated with electric backup heaters.

6.2 Advantages

- Cost-Effectiveness: While there's an initial investment, the increased energy production and reduced energy consumption can lead to long-term cost savings and a quicker payback on investment.
- Simplified Operation: These systems are designed for ease of use and maintenance, automatically adjusting to the sun's position without manual intervention.
- Environmental Benefits: By increasing solar energy production, these systems contribute to a cleaner and more sustainable energy future, reducing reliance on fossil fuels.

6.3. SDG Mapping

1. SDG 7 – Affordable and Clean Energy. Promotes the use of renewable solar energy for homes. Increases energy efficiency and access to clean, reliable, and affordable energy.
2. SDG 11 – Sustainable Cities and Communities. Helps create energy-resilient communities by reducing reliance on centralized power grids. Supports the development of smart and sustainable homes.
3. SDG 13:Climate action. Take urgent action to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy.

Chapter 7 CONCLUSION

The implementation of a single-axis solar tracking system plays a vital role in enhancing the overall efficiency and output of solar energy harvesting. By allowing the solar panel to rotate along one axis (typically east to west), the system ensures that the panel remains aligned with the sun throughout the day, thereby maximizing the amount of solar radiation absorbed. This leads to a noticeable improvement in energy conversion when compared to a stationary panel, especially in locations with high sun movement variability.

This project successfully demonstrates how a microcontroller-based tracking system, using components such as ESP32, LDR sensors, DC motors, and a motor driver (like L298N), can be designed to automatically detect and respond to changes in sunlight intensity. The use of threshold logic ensures that the motor activates only when there is a significant difference in light levels, reducing unnecessary movement and conserving energy. Additionally, features like deep sleep mode in the ESP32 help minimize power consumption during low-light conditions (e.g., nighttime), making the system more efficient and battery-friendly.

A 9V battery or small solar-powered battery pack can power the control circuit and motor for demonstration purposes. While this is sufficient for small-scale models or educational projects, real-world implementations typically require stronger batteries and weatherproof components.

Moreover, the system avoids the need for complex and costly components such as a full inverter by efficiently using DC power to drive the tracking mechanism. While 555 timer circuits and other analog alternatives are available, the use of programmable microcontrollers offers greater flexibility, accuracy, and expandability — such as logging data, adding dual-axis tracking, or integrating with IoT platforms.

In conclusion, this single-axis solar tracking project is a practical, scalable, and effective approach to improving solar panel performance. It is well-suited for educational demonstrations, prototype development, and renewable energy applications in remote or off-grid areas, where efficient solar energy use is crucial. It also lays the foundation for further innovation, such as adding dual-axis tracking, smart sensors, or real-time monitoring systems.

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