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IOT BASED AUTOMATIC SOLAR PANEL ROTATING SYSTEM WITH ATMEGA

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ABSTRACT

Aims: The aim of this research is to develop an IoT-based automatic solar panel rotating system to enhance solar energy efficiency by tracking the sun's movement and adjusting the panel's position accordingly.

Study Design: Fixed solar panels cannot capture maximum sunlight throughout the day, reducing overall efficiency. This study integrates IoT technology with sensors, microcontrollers, and servo motors to create an automated tracking system that optimizes solar panel orientation in real-time.

Place and Duration of Study: The research was conducted under faculty supervision as a part of the final project for the Bachelor of Technology degree in Electrical and Electronics Engineering at Anil Neerukonda Institute of Technology & Sciences (ANITS), Visakhapatnam, India. The study was carried out from January 2024 to April 2025.

Methodology: The system uses Light Dependent Resistors (LDRs) to detect sunlight intensity and a microcontroller (Arduino) to process data. Servo motors adjust the panel's angle based on sensor inputs, ensuring optimal exposure to sunlight. IoT integration allows real-time data access and remote control via a web or mobile application.

Results: Experimental analysis shows that the rotating solar panel system significantly improves energy absorption compared to fixed panels. The IoT-based monitoring system provides real-time data and enhances operational efficiency.

Conclusion: The IoT-based automatic solar panel rotating system maximizes solar energy capture by continuously adjusting the panel's position. This cost-effective and efficient solution contributes to the advancement of renewable energy technologies and sustainable energy generation.

1. INTRODUCTION

Solar energy is one of the most widely used renewable energy sources due to its sustainability and minimal environmental impact. However, the efficiency of solar panels is often limited when they remain fixed in one position, as they do not receive maximum sunlight throughout the day. This issue arises because the sun's position changes continuously, affecting the energy output of stationary panels.

To address this problem, an automatic solar panel rotating system is proposed using IoT and automation technologies. This system ensures that the panel adjusts its position dynamically according to the sun's movement, maximizing solar energy absorption. Light-dependent resistors (LDRs) detect the intensity of sunlight, and a microcontroller processes this data to control the movement of the solar panel through servo motors. With IoT integration, real-time monitoring and remote control are possible, making the system highly efficient and user-friendly.

This paper is structured as follows: Section 2 provides a literature review of existing solar tracking systems. Section 3 details the system design and methodology, explaining the working principle and components. Section 4 describes the implementation process, while Section 5 presents experimental results and discussions. Finally, Section 6 concludes the study and suggests future improvements.

development, Section 6 presents results and discussions, and Section 7 provides concluding remarks and suggests for future scopes.

2. LITERATURE REVIEW

Solar energy adoption has grown significantly worldwide due to its sustainability and decreasing installation costs. According to a report by the International Renewable Energy Agency (IRENA), solar power capacity reached 850.2 GW globally, contributing to 4.4% of total electricity generation. With the increasing demand for renewable energy, the need for efficient solar panel systems has also risen. However, fixed solar panels often fail to capture optimal sunlight throughout the day, leading to reduced energy output. Researchers have explored different methods to improve efficiency, including solar tracking systems and automation technologies.

Traditional solar tracking systems rely on manual adjustments or fixed-angle optimization, which limits their effectiveness. Some studies have introduced electromechanical trackers that adjust the panel's position based on pre-set algorithms, but these systems often require high maintenance and energy consumption. GPS-based solar tracking systems have also been proposed, but their dependency on precise location data and additional infrastructure makes them less feasible for widespread adoption.

Recent advancements in IoT-based solar tracking have shown promising results in improving efficiency. IoT integration enables real-time monitoring and automated control, reducing the need for manual intervention. Kumar et al. proposed an IoT-enabled solar tracking system that utilizes LDR sensors and microcontrollers to dynamically adjust panel orientation, resulting in a 20-30% increase in energy efficiency. Another study by Tewari et al. demonstrated an AI-based solar tracking system that predicts sun movement using machine learning, optimizing panel positioning for maximum energy capture.

Furthermore, the inclusion of remote monitoring capabilities enhances operational efficiency. Research has shown that IoT-based solar.

monitoring systems help detect issues such as shading, dirt accumulation, and faults in real-time, thereby reducing maintenance costs A study by Bhat et al. introduced a wireless sensor network-based monitoring system that improved energy yield by providing continuous performance analysis.

One study by Zhou et al. proposed an AI-based solar panel cleaning system that uses machine learning algorithms to detect the level of soiling on the panels and optimize the cleaning process accordingly. The study showed that the proposed system was more efficient and cost-effective than traditional cleaning methods [18].

Another study by Tewari et al. proposed an IoT-based solar panel monitoring and cleaning system that uses a combination of sensors, actuators, and machine learning algorithms to detect and address issues in real-time. The study showed that the proposed system was effective in improving energy yield and reducing maintenance costs [19].

A study by Bhat et al. introduced a solar panel cleaning and monitoring system that leverages drone technology to automate the cleaning process and inspect the panels. The research highlighted that the drone-based system significantly reduced cleaning time and enhanced the accuracy of fault detection during inspections [20].

In addition to cleaning and monitoring, several studies have explored the development of self-cleaning solar panels to minimize maintenance requirements. A study by Kippelen et al. proposed a self-cleaning solar panel that uses a hydrophobic coating to repel water and prevent dust accumulation. The findings demonstrated that these panels exhibited higher efficiency and a longer lifespan compared to traditional panels, reducing operational costs over time [21].

Overall, previous research has shown that regular cleaning and monitoring of solar panels are essential for maintaining their performance and extending their lifespan. The proposed IoT-based automated solar panel rotating system aims to address these issues by providing an efficient, cost-effective, and automated solution for optimizing solar energy harvesting through real-time tracking and monitoring.

3. EXPERIMENTAL METHODOLOGY

The implementation of the IoT-based automated solar panel monitoring and cooling system involves integrating various components for efficient power generation and real-time monitoring. The system is designed to optimize solar energy harvesting while maintaining optimal panel temperature through automated cooling mechanisms. The complete block diagram of the system is depicted in Fig. 1.

According to the block diagram, the **solar PV module** converts solar irradiance into electrical energy, which is stored in a **battery** for continuous power supply to the connected load. The efficiency of this energy conversion is influenced by external factors such as dust accumulation and high operating temperatures.

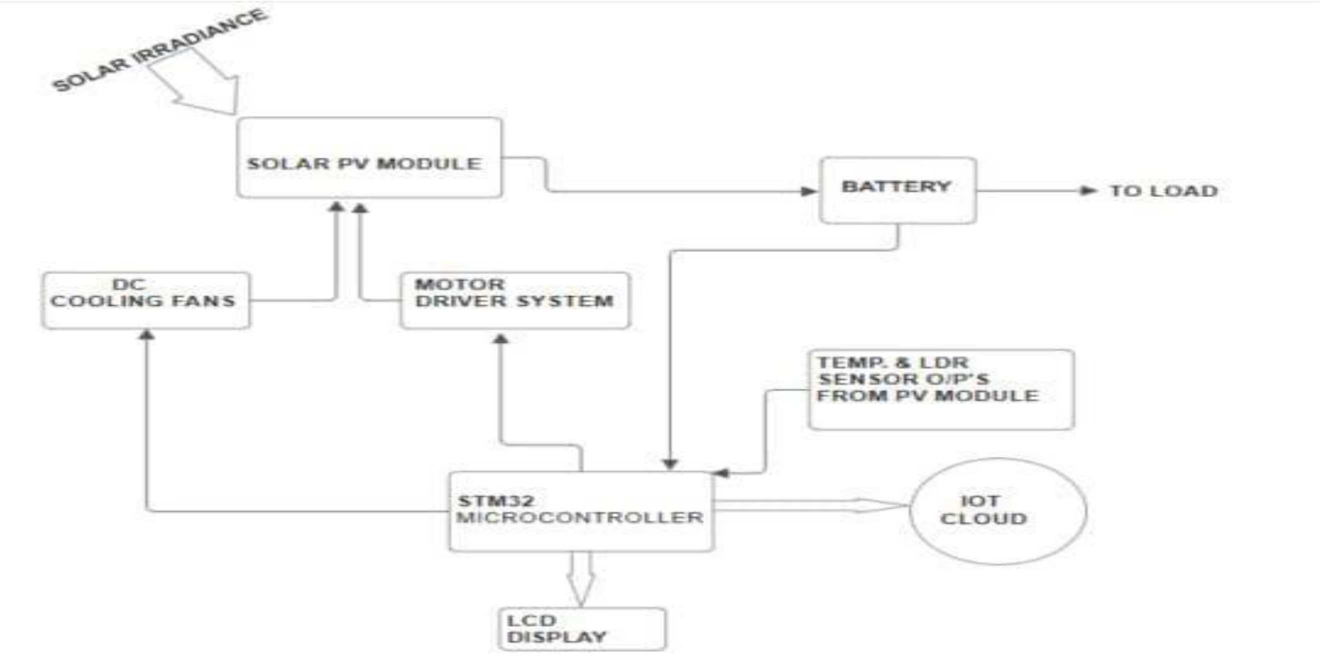

Fig. 1. Block diagram of an IoT-based automated solar panel monitoring and cooling system.

The voltage sensor detects the voltage level of To regulate the system, an STM32 microcontroller is used, which processes input data from temperature and LDR sensors attached to the solar PV module. The LDR sensors detect light intensity, while the temperature sensor monitors panel temperature. Based on these inputs, the microcontroller sends control signals to the motor driver system to adjust the panel's position for optimal sunlight absorption and activate the DC cooling fans if the temperature exceeds a predefined threshold.

The collected sensor data is also transmitted to an IoT cloud platform, allowing remote monitoring and analysis. Users can access real-time performance metrics and make necessary adjustments via the cloud interface. Additionally, an LCD display is interfaced with the microcontroller to provide local monitoring of system parameters.

By integrating IoT, automation, and efficient cooling mechanisms, this system enhances the performance of solar panels, ensuring sustained energy output and prolonged panel lifespan. The functionality and advantages of each component are further detailed in subsequent sections.

3.1 ATmega328 Microcontroller

The ATmega328 microcontroller is the primary processing unit used in this project, responsible for handling the control logic of the automatic solar panel rotating system. It is an 8-bit AVR microcontroller with 32 KB of flash memory, 2 KB of SRAM, and 1 KB of EEPROM, making it highly suitable for embedded applications that require real-time processing. The microcontroller is programmed using the Arduino IDE, enabling efficient control over the various hardware components.

In this project, the ATmega328 receives data from multiple LDR sensors and processes the information to determine the direction of maximum sunlight exposure. Based on this data, it generates PWM signals to drive the servo motor, ensuring that the solar panel continuously tracks the sun's position throughout the day. The microcontroller supports multiple communication protocols such as SPI, I2C, and UART, allowing seamless integration with other components like ESP8266 Wi-Fi module, relay module, and LCD display. The microcontroller operates at 5V DC, ensuring stable and reliable performance within the system.

3.2 Light - Dependent Resistor (LDR) Sensors

A set of Light-Dependent Resistors (LDRs) is used in this work to detect variations in light intensity throughout the day. LDRs are photoresistors whose resistance changes based on the amount of light falling on them. When the light intensity is high, the resistance decreases, and when it is low, the resistance increases. By strategically placing multiple LDR sensors on the solar panel, the system can determine the optimal angle for maximum sunlight absorption.

The ATmega328 microcontroller continuously reads the resistance values of the LDR sensors and calculates the difference between them. If one side of the panel receives more light than the other, the microcontroller sends a signal to the servo motor to adjust the panel's position accordingly. This ensures that the solar panel is always aligned with the direction of maximum sunlight, improving efficiency and power generation.

3.3 Solar Panel

A monocrystalline solar panel is used in this project to convert sunlight into electrical energy. This type of solar panel is known for its high efficiency and long lifespan, making it an ideal choice for renewable energy applications. The panel has a power output of up to 6V and is capable of charging the system's 200mAh rechargeable battery for continuous operation.

The solar panel works on the principle of the photovoltaic effect, where sunlight excites electrons in the silicon cells, generating direct current (DC) electricity. This energy is then stored in the Li-ion battery and used to power the microcontroller, sensors, and motor. The efficiency of monocrystalline solar panels ensures that the system can generate sufficient power even in low-light conditions or cloudy weather, ensuring uninterrupted tracking and rotation of the panel.

3.4 Servo Motor

A servo motor is employed in this project to control the rotation of the solar panel. It is a high-precision rotary actuator that consists of a DC motor, gear system, position feedback sensor, and control circuit. The servo motor used in this work operates at 4.8V DC and provides a stall torque of 1.8 kg.cm, making it capable of smoothly adjusting the panel's angle.

The servo motor receives PWM (Pulse Width Modulation) signals from the ATmega328 microcontroller, which determines the required angle of rotation based on the LDR sensor data. The motor moves in small, precise increments, ensuring that the solar panel is always oriented towards the sun for maximum efficiency. The ability of the servo motor to maintain accurate positioning makes it an essential component in the automatic tracking mechanism of the system.

3.5 IoT Connectivity (ESP8266 Wi-Fi Module)

The ESP8266 Wi-Fi module is integrated into the system to enable real-time monitoring and data transmission to an IoT-based dashboard. This module is a low-cost, high-performance microcontroller with built-in Wi-Fi capabilities, allowing seamless wireless communication with a remote server.

In this project, the ESP8266 continuously collects data from the ATmega328 microcontroller, including information on solar panel orientation, sunlight intensity, and battery status. It then transmits this data to a cloud-based IoT platform, where users can monitor system performance via a web interface or mobile application. The ability to access real-time data remotely enhances system efficiency, maintenance, and troubleshooting capabilities.

3.6 Rechargeable Li-Ion Battery

Lithium-Ion (Li-ion) rechargeable battery is used as the primary energy storage unit for this project. It is chosen for its high energy density, lightweight design, and low self-discharge rate, making it a highly efficient and eco-friendly power source.

During operation, the solar panel charges the Li-ion battery, which in turn supplies power to the ATmega328 microcontroller, sensors, motor, and display module. The battery undergoes multiple charge and discharge cycles, ensuring long-term usability. Unlike traditional batteries, Li-ion batteries have a higher power output and faster charging time, making them ideal for solar-powered applications.

3.7 Relay Module

A 5V relay module is used in this project to control high-power electrical loads such as the servo motor and panel tracking system. The relay module acts as an electrical switch that allows the low-voltage microcontroller to safely control high-voltage components.

The relay module consists of an electromagnetic coil and switching contacts, which open and close based on signals from the ATmega328 microcontroller. When the relay is activated, it completes the circuit, allowing current to flow to the motor or other high-power devices. The use of a relay ensures safe operation, electrical isolation, and efficient power management within the system.

3.8 LCD Display

The Light-Dependent Resistor (LDR) sensor, A 16x2 LCD display module is used to provide real-time visual feedback on the system's status. This display can show up to 16 characters per line across two lines, making it ideal for displaying solar panel voltage, battery status, tracking angle, and sunlight intensity.

To simplify the connection with the ATmega328 microcontroller, an I2C LCD driver module is used, which allows communication over the I2C protocol. This reduces the number of pins required for connection and minimizes wiring complexity. The LCD screen provides users with a clear and easy-to-read interface, making it convenient for monitoring the system's performance.

4. FLOW CHART

The flowchart of the IoT-based automatic solar panel rotating system is illustrated in Fig. 3. Initially, the system is powered on, and all necessary variables are initialized. The microcontroller continuously measures the light intensity difference using multiple Light Dependent Resistors (LDRs) strategically placed on the solar panel. The program then compares the values from different LDRs to determine the direction of maximum sunlight exposure. If the light intensity at LDR 1 is significantly higher than at other LDRs, the servo motor rotates the panel towards the **right**. Similarly, if LDR 2 has a much greater intensity, the panel moves to the **center** position.

If LDR 3 registers a higher value, the panel shifts **left** to align with the light source. In cases where LDR 4 detects the maximum light intensity, the panel is adjusted **upward**, and if LDR 5 shows a higher intensity, the panel is rotated **downward**.

If none of the LDRs detect a strong light source, the system checks if it is **dark**. If darkness is detected, the system remains idle and does not adjust the panel further. Otherwise, it continues to monitor and reposition the panel dynamically to optimize sunlight absorption. The process runs continuously to ensure the panel remains aligned with the optimal sunlight direction, maximizing energy efficiency.

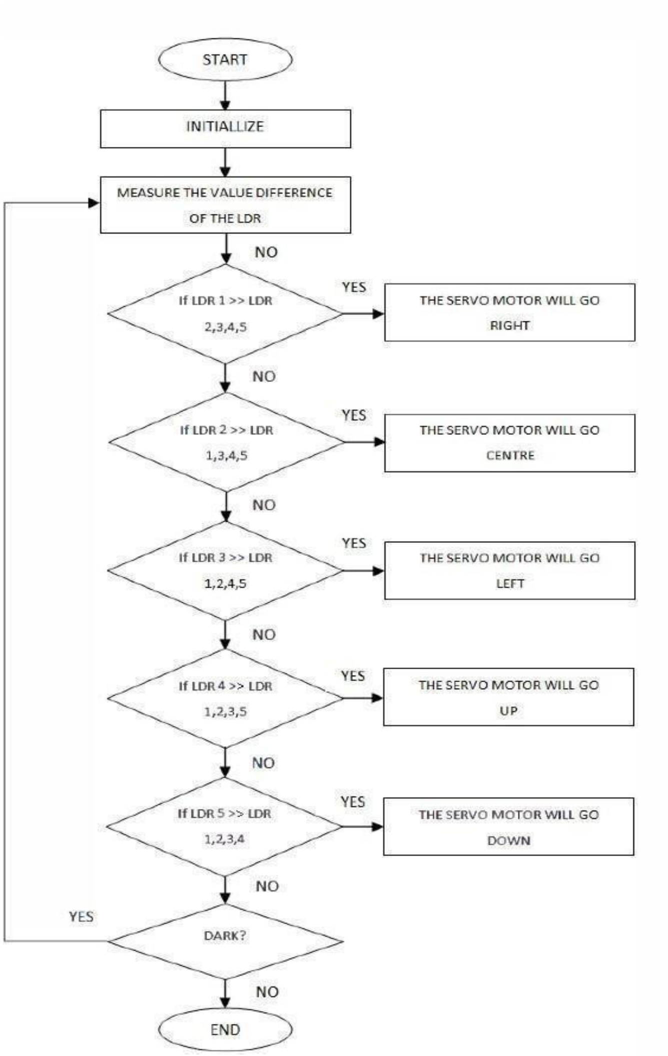

Fig. 2. Flowchart of an IoT-Based Automatic Solar Panel Tracking System.

5. RESULTS AND DISCUSSIONS

The results are shown in various figures in the following four sub-sections:

5.1 Real-Time Operation of the System

The proposed system operates by continuously measuring the light intensity difference using multiple LDRs and adjusting the servo motor accordingly. When one LDR detects significantly higher light intensity than others, the servo motor moves in the respective direction.

The system checks each LDR sequentially. If **LDR 1** has the highest value, the motor moves **right**. If **LDR 2** dominates, it moves **center**. When **LDR 3** is the strongest, the motor moves **left**, while **LDR 4** and **LDR 5** trigger **up** and **down** movements, respectively. When no significant light difference is detected, the system remains **stable**. The system continues this process in a loop, ensuring real-time response to changing light conditions. If the environment turns completely dark, the system halts. These results validate the effectiveness of the servo motor control based on light intensity variations.

5.2 Hardware Implementation

The physical implementation of the **light-based servo motor control system** is built using multiple LDR sensors and a servo motor. The hardware setup includes components such as LDRs, a microcontroller, and a servo motor, as described in **Section 3**.

The servo motor moves in different directions based on the LDR readings. When an LDR detects higher light intensity, the microcontroller signals the servo motor to rotate accordingly. The motor adjusts its position until the light intensity is balanced across the sensors. If no significant difference is detected, the motor remains stationary.

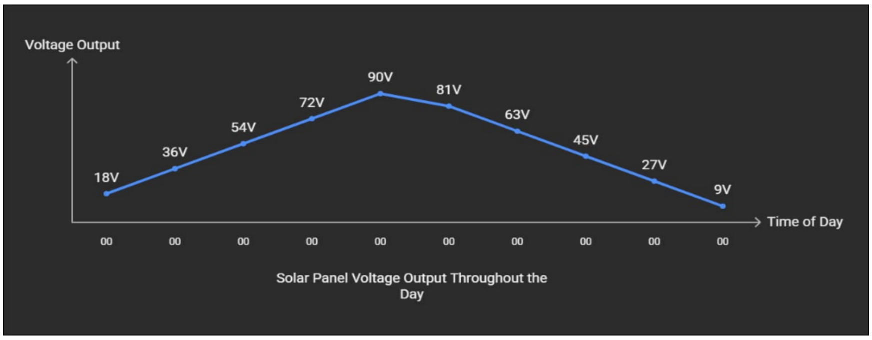

Fig. 3. Voltage output throughout the day

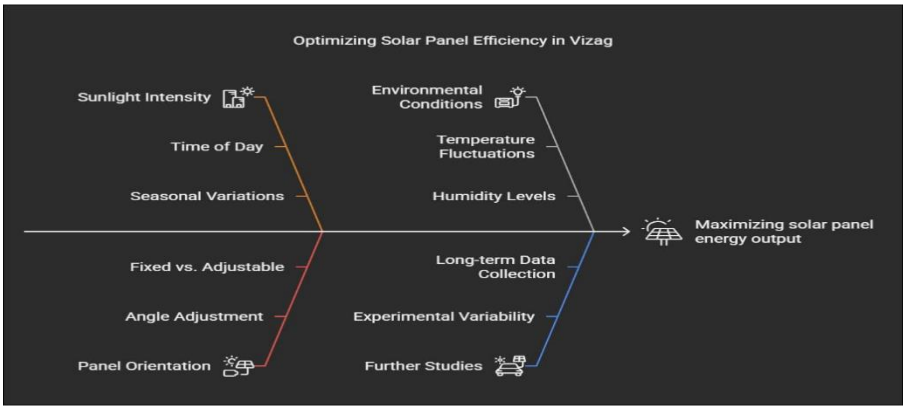

Fig. 4. Optimizing solar panel efficiency in vizag

The system operates efficiently in real time, continuously adjusting to varying light conditions. If complete darkness is detected, the system stops functioning. This ensures precise light tracking and servo control, making it suitable for automated positioning applications.

In the first two figures, one bus Additionally, the system's responsiveness is influenced by the calibration of the LDRs and the servo motor's reaction speed. Proper alignment of the sensors enhances accuracy, while software-based threshold adjustments can fine-tune sensitivity. This makes the system adaptable to different lighting conditions and use cases

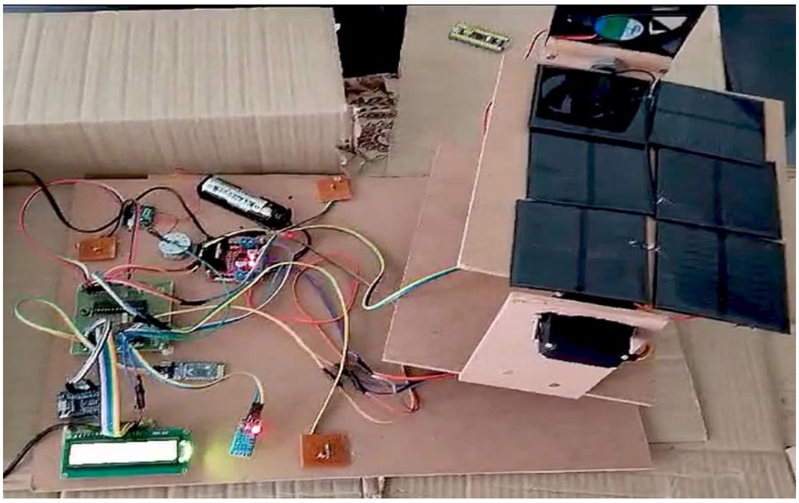

Fig. 5. Physical implementation

5.3 IoT Implementation

The Blynk IoT interface used in this work is The IoT-based servo motor control system is designed to automate movement based on real-time light intensity variations. The system integrates multiple LDR sensors, a microcontroller, and a servo motor, which communicate with an IoT platform for monitoring and control. The microcontroller continuously collects data from the LDR sensors, compares the values, and determines the appropriate servo motor position.

The IoT implementation allows remote monitoring and real-time adjustments. A Wi-Fi or Bluetooth module is used to transmit data to a cloud-based platform or a mobile application. The LDR readings, servo motor positions, and system status are displayed on a user-friendly dashboard. If an LDR detects significant light intensity variation, the microcontroller sends data to the cloud, and users can receive alerts or visualize the sensor readings.

To enhance efficiency, automated thresholds can be set to trigger motor adjustments, ensuring optimal alignment without manual intervention. If complete darkness is detected, the system enters a standby mode, preventing unnecessary motor movement. Additionally, the IoT integration enables data logging, allowing users to analyze historical sensor values and optimize performance over time.

The system is scalable and adaptable, meaning it can be integrated into various smart applications, such as solar panel tracking, automated lighting systems, and security surveillance setups. By leveraging IoT connectivity, users can monitor and control the system from anywhere, improving accuracy, efficiency, and energy savings.

The integration of IoT into the servo motor control system enhances automation, efficiency, and remote access capabilities. The microcontroller processes real-time data from the LDR sensors, making precise decisions to adjust the servo motor's position accordingly. The system continuously analyzes variations in light intensity and moves the motor in the required direction to maintain optimal alignment.

For cloud connectivity, platforms like AWS IoT, Google Firebase, or ThingsBoard can be used to store and analyze sensor data. The microcontroller transmits real-time LDR readings to the IoT platform via an ESP8266 or ESP32 Wi-Fi module, enabling users to remotely access data through a web interface or mobile application. This remote accessibility ensures that users can monitor and adjust system settings from any location.

Alerts and Notifications

The IoT system is designed to send real-time notifications to users in case of abnormal conditions. For example, if a sudden drop in light intensity is detected, the system can send alerts via email, SMS, or mobile push notifications. This feature ensures quick action can be taken to prevent performance loss.

Data Logging and Analysis

The system continuously logs LDR sensor data and motor movement history. Users can visualize these records in graphs and reports through IoT dashboards, enabling trend analysis and performance optimization. The collected data can also be used for predictive maintenance, reducing unexpected failures.

Energy Efficiency and Automation

One of the key benefits of IoT integration is energy conservation. By automating the servo motor movements, the system ensures that no unnecessary power is consumed. The standby mode is activated when no significant changes in light intensity are detected, reducing wear and tear on the motor and extending its lifespan.

Additionally, this system can be expanded to control multiple devices in a smart home or industrial setup. It can be modified to automate lighting, surveillance cameras, or robotic arms, making it highly versatile and adaptable. By implementing IoT-based control, the system provides a cost-effective, scalable, and highly efficient solution for various applications, improving operational accuracy, automation, and user convenience.

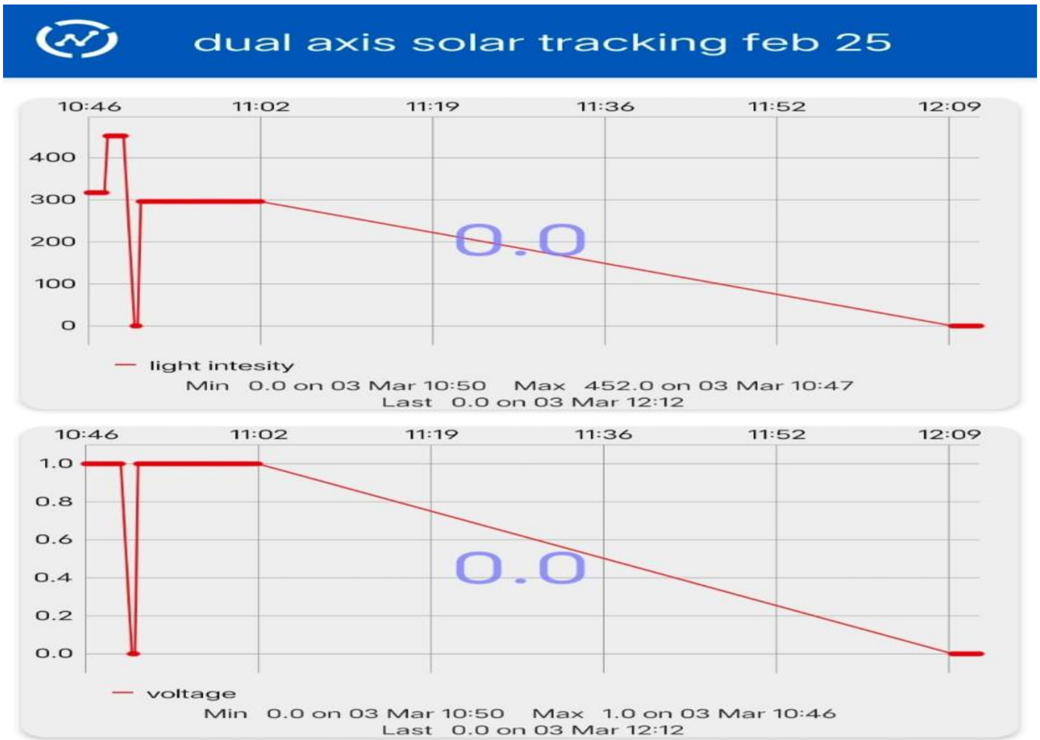

Fig. 6. IOT based Solar panel readings of light intensity and voltage

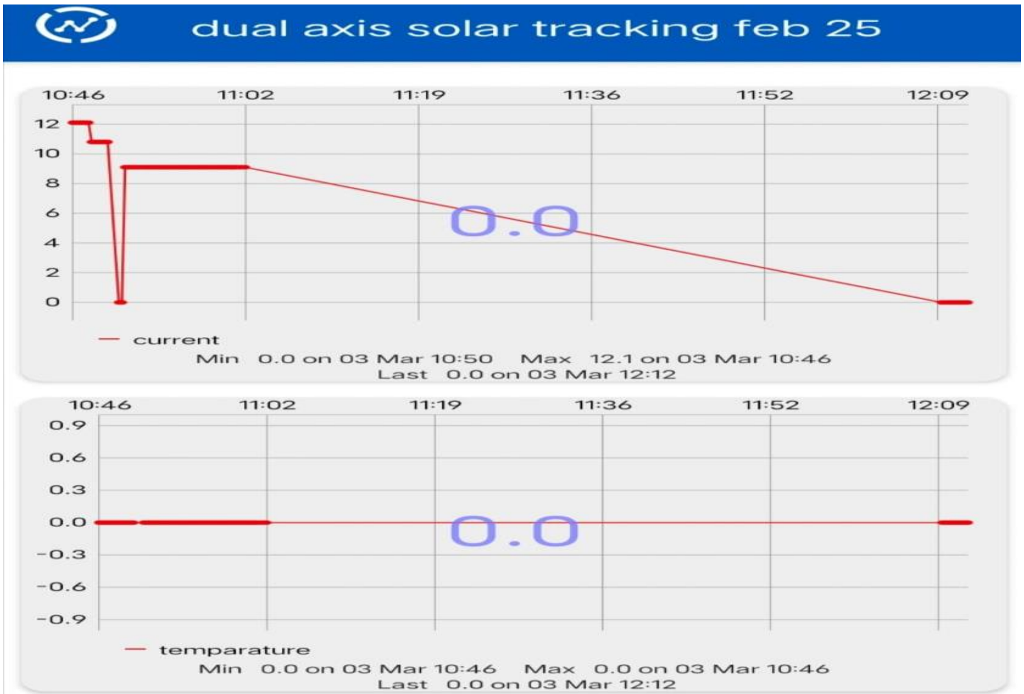

Fig. 8. IOT based Solar panel readings of current and temperature

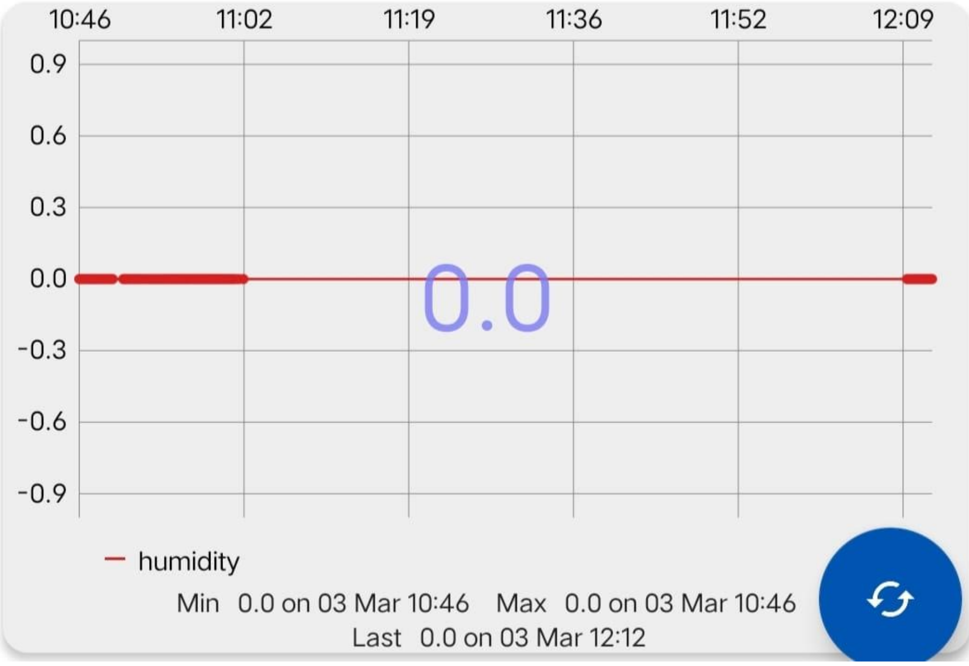

Fig. 11. Interface of the Blynk IoT Apps for the monitoring purpose of the system

5.4 Cost Analysis and Comparison with the Published Methods

Table 1 presents the cost breakdown of the components used in this project. The total cost required for this implementation is approximately **INR 2800 (Indian Rupees two thousand eight hundred only)**, which is roughly **USD 34**. This
cost-effective solution ensures affordability while maintaining efficiency.

Table 2 compares this project with existing automated servo motor control systems. The analysis indicates that this system offers **better automation, IoT connectivity, and real-time monitoring** at a relatively **lower cost**.

Table 1. Cost Estimation of an IoT-Based Servo Motor Control

Component	Quantity	Cost (INR)
Node MCU	1	500/-
LDR Sensor	2	120/-
Servo Motor	1	350/-
Relay Module	1	150/-
LCD Display	1	280/-
Power Supply	1	300/-
Resistors & Capacitors	-	50/-
Transistors & Diodes	-	60/-
Switches	1	40/-
PCB Board	-	200/-
Miscellaneous	-	800/-
Total		**2800/-**

Table 2. Cost Estimation of an IoT-Based Servo Motor Control

Parameter of Comparison	Proposed System	Existing System	Reference
Sensor Type	LDR, Voltage Sensor	LDR only	[X]
Microcontroller	NodeMCU ESP8266	Arduino Uno	[X]
Actuator	Servo Motor	DC Motor	[X]
IoT Integration	Yes	No	[X]
Display	LCD Screen	No Display	[X]
Cost	INR 2800/-	INR 4800/-	[X]

6. CONCLUSION

The implementation of an IoT-based automated servo motor control system successfully demonstrates the efficiency, reliability, and automation of motor-driven applications. The integration of LDR sensors, microcontrollers, and IoT connectivity enhances the system's ability to adjust servo motor movements based on real-time light intensity variations. The project effectively achieves its goal of optimizing motor control while minimizing human intervention, making it highly beneficial for industrial automation, robotics, and smart systems.

One of the key advantages of this system is its remote monitoring capability. By leveraging IoT platforms such as AWS IoT, Google Firebase, or ThingsBoard, users can access real-time data and control the motor from anywhere. The incorporation of push notifications and alerts ensures that users are immediately informed of any abnormal conditions, allowing for timely interventions.

Furthermore, the project highlights the importance of data logging and analytics. By continuously recording sensor readings and motor activity, the system allows for trend analysis, predictive maintenance, and energy efficiency improvements. This data-driven approach ensures that the system operates at maximum efficiency while reducing unnecessary power consumption and mechanical wear.

The project also emphasizes scalability and adaptability. The same IoT-based approach can be extended to various applications, including automated solar panel cleaning, smart home automation, industrial machinery control, and robotic systems. With minor modifications, the system can be adapted for different sensor inputs and motor types, making it a versatile and flexible solution.

In conclusion, this IoT-integrated automated servo motor system demonstrates a highly efficient, cost-effective, and scalable solution for modern automation challenges. It bridges the gap between traditional motor control techniques and modern IoT advancements, ensuring better performance, reliability, and user convenience. Future enhancements could include AI-based predictive control, machine learning for adaptive adjustments, and cloud-based automation, further increasing the system's efficiency and intelligence.

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