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Application of Iot in Monitoring and Tracking Small-Scale Solar Energy Systems

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ABSTRACT: Renewable energy, particularly solar energy, has been receiving increasing global attention for both research and application. There is a growing demand for efficient solar energy systems, especially in medium- and small-scale applications such as traffic lights, public lighting systems, marine vessels, and security devices. However, conventional fixed-position solar panels typically achieve peak power output during only a few hours of the day, resulting insuboptimal energy conversion efficiency.
This paper presents the design and implementation of a solar tracking system integrated with Internet of Things (IoT) technology, allowing users to remotely monitor system performance via a smartphone application. The system automatically adjusts the solar panel orientation throughout the day to follow the sun's path, thereby enhancing solar energy conversion efficiency.

KEYWORDS: Renewable energy; Solar energy; Sensors; Tracking system; Internet of Things (IoT)

I. INTRODUCTION

In recent decades, solar energy has emerged as one of the most promising and sustainable energy sources to meet the increasing global demand for electricity while simultaneously reducing greenhouse gas emissions and mitigating the environmental impact of conventional energy systems. Among various solar technologies, photovoltaic (PV) systems are widely adopted due to their modular structure, low operational cost, and adaptability to both centralized and decentralized applications.

Despite their advantages, the energy conversion efficiency of conventional PV systems remains relatively low, typically in the range of 15% to 25%. This limitation becomes more critical in applicationswhere installation area is restricted, such as in urban settings or mobile platforms. Therefore, enhancing the efficiency of PV systems, particularly for small- and medium-scale applications, has become an essential research objective.

One key factor affecting PV system performance is the angle at which solar irradiance strikes the panel surface. Maximum efficiency is achieved when the sunlight is perpendicular to the panel. However, due to the sun's continuous movement across the sky, fixed-tilt PV systems are unable to maintain optimal alignment, leading to significant energy losses. To overcome this issue, solar tracking systems have been developed to dynamically adjust the orientation of the panels in accordance with the sun's trajectory. By aligning the PV modules more accurately with the solar path, these systems can significantly improve energy capture and maintain power output closer to the maximum under clear-sky conditions.

In recent years, the integration of the Internet of Things (IoT) has further advanced the potential of solar tracking systems. IoT-enabled platforms allow real-time monitoring and control by utilizing sensor networks that collect data on environmental parameters and system performance, which is then transmitted to user interfaces such as smartphones via the Internet. This capability enables remote supervision, enhances operational safety, increases economic efficiency, and improves system responsiveness - ultimately contributing to the developmentof intelligent and high-performance solar energy solutions.

The remainder of this paper is organized as follows:

- **Section 2** presents an overview of related work involving IoT applications and solar tracking technologies.
- **Section 3** introduces the proposed IoT-based solar tracking and monitoring system.
- **Section 4** provides experimental results and compares the effectiveness of different system configurations.

- **Section 5** concludes the paper and outlines directions for future research.

II. RELATED WORK AND TECHNICAL BACKGROUND

1. IoT-Based Monitoring and Control Approach

The integration of Internet of Things (IoT) technology into photovoltaic (PV) systems offers a reliable and cost-effective solution for real-time remote monitoring and control. By enabling users to observe the system's operational status via internet-connected devices, such systems reduce operational costs and improve system efficiency. Through this intelligent control mechanism, solar energy can be utilized more effectively. Moreover, an IoT-enabled monitoring and tracking system enhances system safety and promotes higher economic returns.

The proposed system integrates multiple sensors, including current sensors, voltage sensors, and light intensity sensors. The data collected from these sensors are processed by a Raspberry Pi Pico microcontroller and transmitted to the user through the Internet.

A mobile application–Blynk-is used to visualize and monitor system parameters such as current, voltage, power output, and light intensity. Based on this real-time information, users can adjust the orientation of the solar panels to achieve maximum solar energy harvesting, optimized for each hour of the day and month of the year. The main features of the system include:

- **Real-time Monitoring**: Sensors such as light intensity, current, and voltage sensors are embedded into the system to continuously capture operational data. The IoT-based solar energy monitoring system provides centralized remote monitoring, allowing users to detect performance degradation, downtime, and energy loss in real time.
- **Data Logging**: All monitored data are logged and stored for future retrieval and performance analysis, enabling the evaluation of long-term system efficiency.
- **Performance Visualization**:The system includes a smart dashboard that displays sensor data and energy metrics via the mobile application. Recorded data are visualized in the form of daily and monthly performance charts and can be exported into reports upon request.
- **Fault Detection**: The system is equipped with an alert mechanism that notifies users in case of high-temperature conditions, sensor malfunctions, or other anomalies.

2. Solar Panel Tracking System Approach

2.1. Solar Panel Tracking System

The tracking system is designed to follow the sun's path throughout the year based on time-of-day and seasonal variations. The system performs two key functions: (1) adjusting the tilt angle of the panel monthly to match the sun's elevation angle, and (2) horizontally tracking the sun's movement across the sky during the day. These combined actions improve solar energy capture across daily and annual cycles. The collected tracking data are transmitted to a smartphone for monitoring purposes.

Sensor modules provide current and voltage readings, while a real-time clock (RTC) module supplies date and time information. These data are displayed on an LCD screen and simultaneously sent to the Blynk app for monitoring. The system uses the combined inputs from sensors and time-based logic to control stepper motors that dynamically orient the solar panel for maximum energy collection throughout the day.

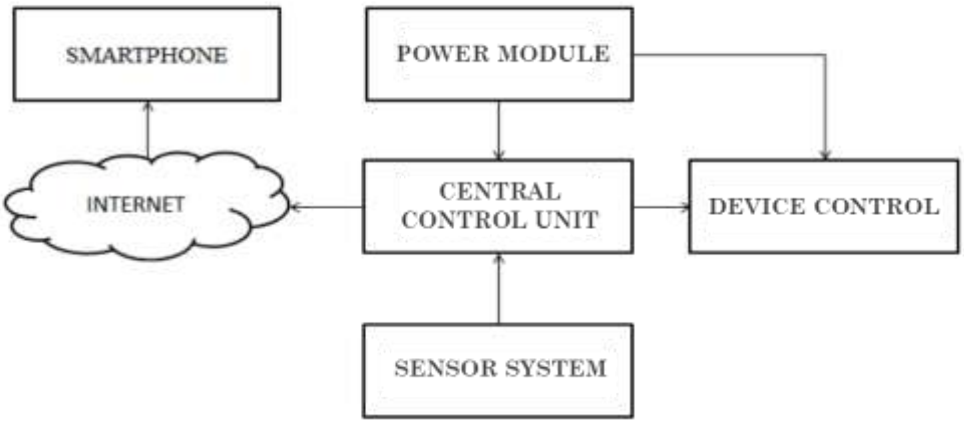

Figure 1. Illustrates the IoT-based solar panel tracking and monitoring system.

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Based on readings from the light intensity sensor and the solar irradiance profile over the course of a day, the system determines optimal positioning:

- The first stepper motor is programmed to rotate or halt depending on the light intensity (in lux) for specific time intervals throughout the day. A simplified light intensity schedule includes:
  - 06:00 — 5,000 to 25,000 lux
  - 07:00 — 10,000 to 55,000 lux
  - 08:00 — 15,000 to 85,000 lux
  - 09:00 — 30,000 to 115,000 lux
  - 10:00 — 55,000 to 140,000 lux
  - 11:00 — 65,000 to 150,000 lux
  - 12:00 — 75,000 to 160,000 lux
  - 13:00 — 75,000 to 155,000 lux
  - 14:00 — 65,000 to 150,000 lux
  - 15:00 — 55,000 to 135,000 lux
  - 16:00 — 35,000 to 115,000 lux
  - 17:00 — 10,000 to 90,000 lux
  - 18:00 — system returns the panel to its initial position and shuts down

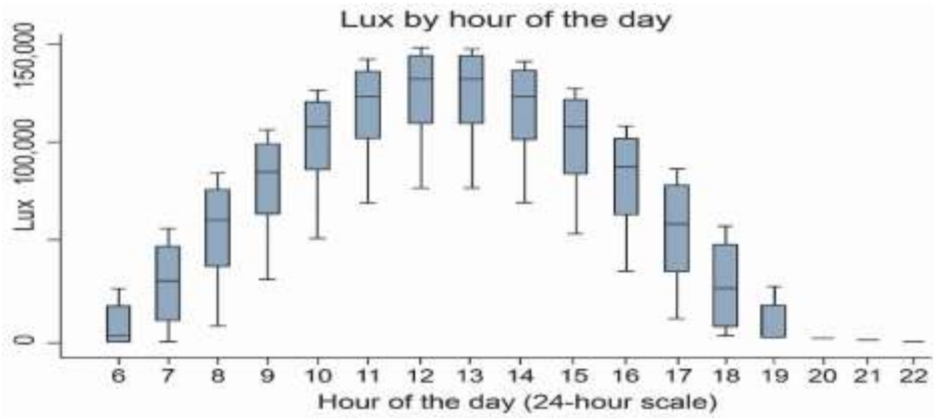

Figure 2. Shows the daily light intensity profile used to calibrate motor control behavior.

- The second stepper motor adjusts the panel's tilt angle on a monthly basis to align the panel perpendicular to the sun's path during each month, optimizing annual energy yield.

As the system begins tracking and harvesting solar energy, current and voltage sensors continuously record real-time data to calculate power output at each time point. These results are sent to the Blynk app for visualization and remote supervision.

2.2. Monthly Tilt Angle Calculation for Solar Panels

To determine the optimal monthly tilt angles of the solar panel, simulations of the sun's trajectory throughout the year were conducted using **PVSYST** and **Andrewmarsh.com**. These tools allow for 2D and 3D modeling of solar paths based on geographic location and time of year.

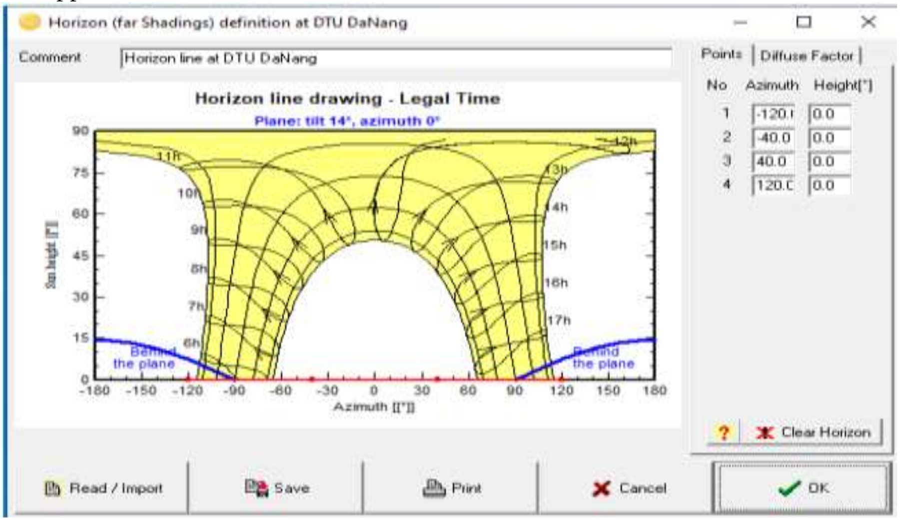

Figure 3.2D Model of the Sun Path Simulated Using PVSYST.

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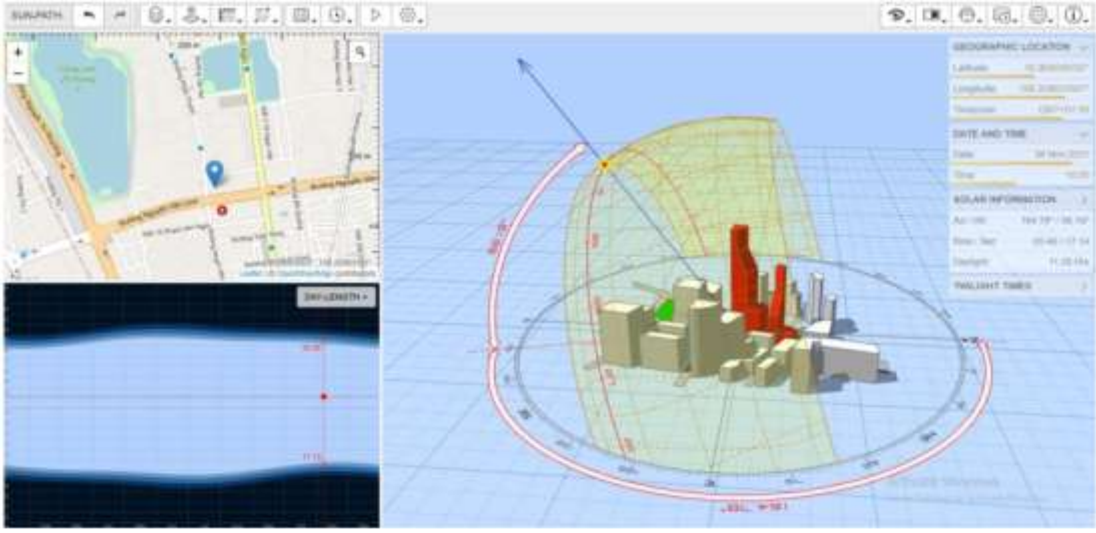

Figure 4.3D Model of the Sun Path Simulated Using AndrewMarsh.

These simulations provide valuable data including solar altitude and azimuth angles, which are essential for calculating the optimal tilt angles of the panel.

Once the annual solar path has been simulated and the sun's elevation angles for each month are known, the panel tilt angle can be determined to ensure that the panel surface remains as perpendicular as possible to the incident sunlight. This maximizes solar irradiance on the panel surface throughout the year.

$$\begin{cases} \text{Zenith angle}\,(\vartheta) + \text{Elevation angle}\,(\alpha) = 90^\circ \\ \text{Tilt angle}\,(t) + \text{Elevation angle}\,(\alpha) = 90^\circ \end{cases} \Rightarrow \text{Zenith angle}\,(\vartheta) = \text{Tilt angle}\,(t)$$

Figure 5 demonstrates the geometric method used to calculate the tilt angle, which is based on the sun's altitude at solar noon for each month.

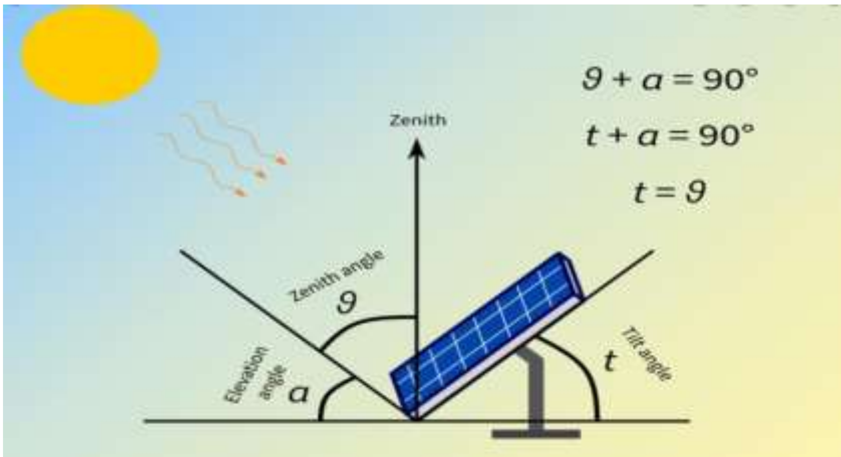

Figure 5. Calculation of the Solar Panel Tilt Angle.

By selecting a fixed geographical location for the solar tracking system, the optimal tilt angles for each month can be calculated using standard solar geometry formulas. These angles are used to program the tilt mechanism (second stepper motor) to adjust the panel elevation accordingly.

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Table 1 presents the calculated monthly tilt angles required to optimize solar energy harvesting by maintaining the panel surface perpendicular to the sun's rays throughout the year.

Date \ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	39°	33°	24°	12°	4°	70°	8°	3°	8°	20°	31°	38°
15	37°	29°	18°	70°	5°	8°	6°	3°	14°	25°	35°	39°
30	33°	24°	12°	4°	70°	8°	3°	8°	20°	31°	38°	39°

Table 1. Solar Panel Tilt Angles by Date and Month (degrees)

III. PROPOSED IOT-BASED SOLAR PANEL TRACKING SYSTEM

1. Hardware Architecture

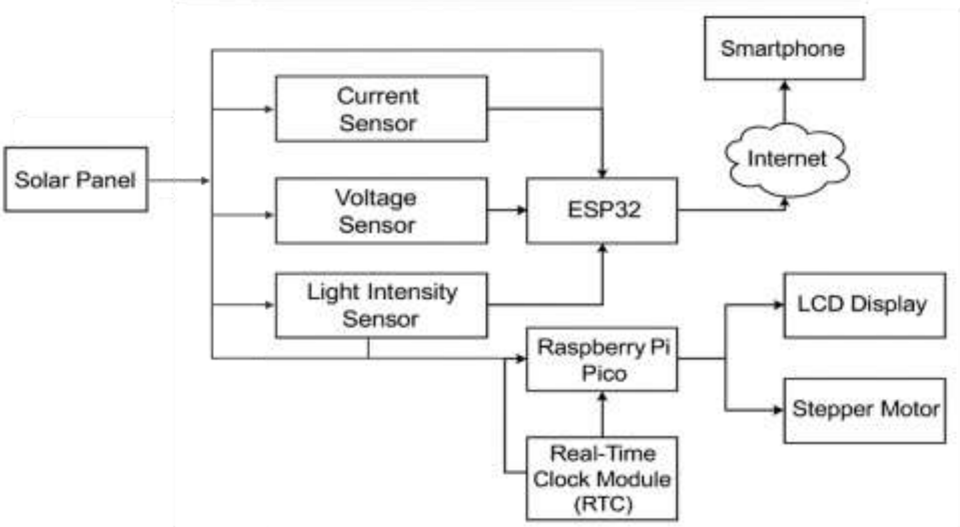

Figure 6. Hardware Implementation of the Solar Panel Tracking System.

Figure 6presents the hardware architecture of the proposed solar tracking system. The control system utilizes two microcontrollers: the **Raspberry Pi Pico** and the **ESP32**, each responsible for distinct system functions to enhance performance stability and minimize potential system failures.

- The **Raspberry Pi Pico** is responsible for acquiring data from the light intensity sensor and the real-time clock (RTC) module. Based on pre-programmed algorithms, it processes this data to determine the optimal orientation and controls the **stepper motors** accordingly to maximize solar energy absorption.
- The **ESP32**, on the other hand, is tasked with acquiring data from the current sensor, voltage sensor, and light intensity sensor, then transmitting this data to the user's smartphone via Wi-Fi.

Sensor Subsstem:

- **Current Sensor (INA219)**: Measures the current generated by the solar panel during energy absorption.
- **Voltage Sensor**: Measures the real-time voltage output of the solar panel.
- **Light Intensity Sensor (BH1750)**: Measures ambient light levels and reports them to the microcontroller, which uses this information to dynamically adjust the panel orientation through the stepper motor.

Smartphone Application:

The **Blynk app** is used to monitor and display real-time system performance metrics, including current, power output, voltage, and light intensity. Users can also remotely influence the panel's orientation based on real-time solar data, optimizing energy harvesting hour-by-hour and day-by-day throughout the month. All data is transmitted wirelessly to the smartphone via the Internet.

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Power Supply:

The system is powered by a **5V regulated supply**, delivered via a **buck converter (L7805)**, which converts the solar panel's output voltage (7V–12V) to a stable 5V DC. This 5V output is then distributed to all sensors and microcontrollers.

2. System Schematic Diagram

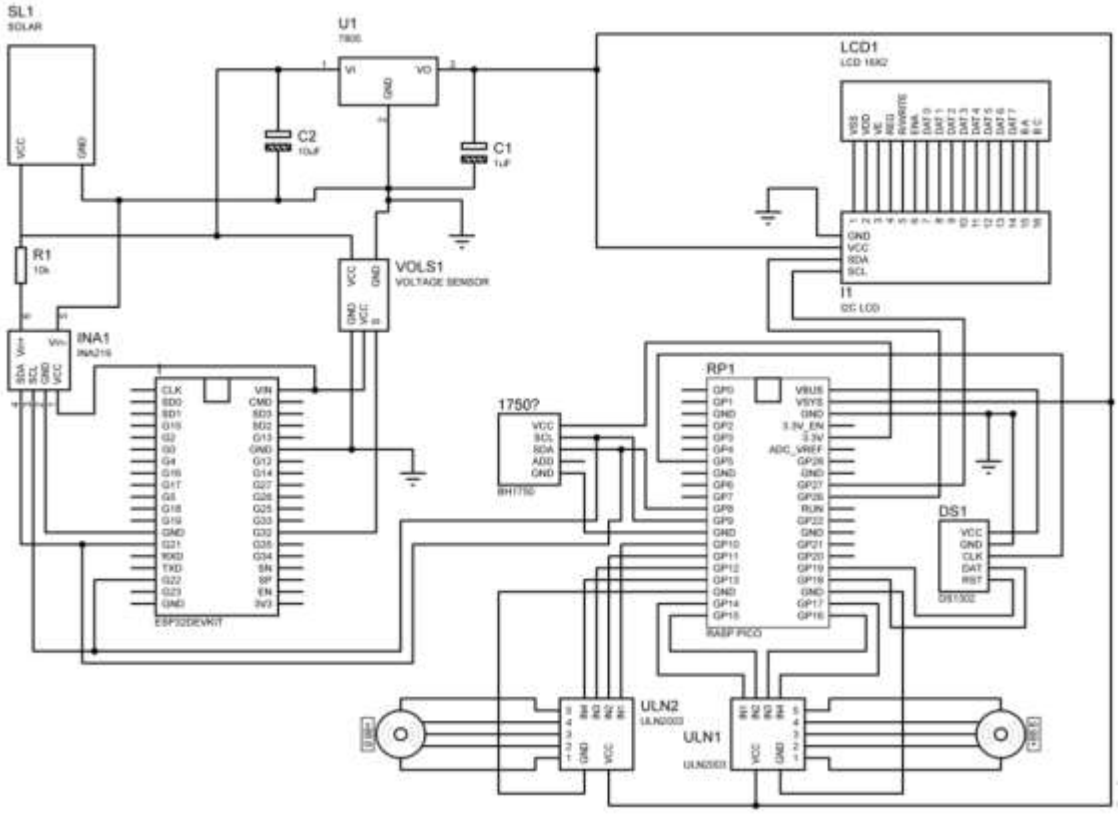

Figure 7. System Architecture Diagram.

Figure 7 illustrates the detailed schematic of the proposed system. The solar panel output is routed through a voltage regulator circuit built with the **L7805** IC to ensure a stable 5V supply for the entire system.

The sensor odule includes:

- **INA219 current sensor**
- **Voltage sensor**
- **BH1750 light intensity sensor**
- **DS1302 real-time clock module**

These sensors allow real-time monitoring of system performance and environmental conditions. An **LCD 16x2 display** is used to show the current date, time, and solar light intensity locally.

Tracking Mechanism:

The tracking mechanism is powered by **stepper motors**, selected for their precision and silent operation, which contributes to overall system stability. Stepper motors are controlled via the **ULN2003 driver module**, enabling accurate adjustments for both tilt (monthly) and horizontal orientation (hourly) of the solar panel.

Microcontroller Uits:

- **RP2040 (Raspberry Pi Pico)** – Handles solar tracking logic, real-time data processing, and stepper motor control.
- **ESP-WROOM-32 (ESP32)** – Manages sensor data acquisition and IoT communication with the mobile app.

Using two separate microcontrollers allows the system to divide responsibilities, enhancing fault tolerance and system reliability.

Key Component of the Control Circuit:

- **Power Regulation Module**:
  - IC **LM7805**: Regulates input voltage (7–12V) down to 5V DC.

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- ○ Decoupling capacitors (both high and low-frequency filters) are used for noise suppression.
- **Microcontrollers**:
- ○ **RP2040 30-pin MCU (Raspberry Pi Pico)**
- ○ **ESP-WROOM-32 (ESP32)**
- **Display Unit**:
- ○ **16x2 LCD** for compact visual feedback on environmental and system conditions.
- **Motor Driver Module**:
- ○ **ULN2003** module for driving stepper motors responsible for mechanical adjustment.
- **Sensor Suite**:
- ○ **BH1750** light intensity sensor
- ○ **INA219** current sensor
- ○ **Voltage sensor** (analog-based or divider network)
- ○ **DS1302** real-time clock module

3. Mobile Monitoring Application Development

The mobile monitoring interface for the system is developed using the **Blynk application**, which allows users to remotely supervise key system parameters including **current, power output, voltage, and ambient light intensity**. Based on the real-time data displayed on the application, users can manually or automatically adjust the solar panel orientation to optimize solar energy harvesting for specific times of the day and months of the year. All system parameters are transmitted to the smartphone via a wireless Internet connection.

Figure 8 shows the mobile interface developed in Blynk, enabling intuitive interaction and visualization of real-time solar energy performance metrics.

Figure 8. Development of the Mobile Monitoring Application.

IV. EXPERIMENTAL RESULTS

To evaluate the effectiveness of the proposed tracking system, two solar panel systems were deployed: one with a **fixed position (non-tracking)** and the other with an **automated tracking mechanism**. Both systems operated under identical environmental conditions throughout the same day to ensure a fair performance comparison.

1. Non-Tracking System

The performance data of the non-tracking system, measured hourly, is summarized in **Table 2**:

Table 2: Experimental Results – Non-Tracking Solar Panel

Time (h)	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Voltage (V)	2.43	4.50	5.24	6.01	6.02	6.30	6.43	6.43	6.20	5.76	5.12
Current (A)	0.01	0.02	0.04	0.05	0.07	0.10	0.15	0.15	0.13	0.10	0.07
Power (W)	0.024	0.10	0.20	0.30	0.40	0.60	1.00	1.00	0.81	0.60	0.35

Total daily energy harvested: **5.39 W**

2. Tracking System

The performance data of the tracking-enabled system is shown in **Table 3**:

Table 3: Experimental Results – Solar Panel with Tracking System

Time (h)	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Voltage (V)	3.97	5.01	5.90	6.30	6.60	6.84	6.98	6.92	6.80	6.40	5.50
Current (A)	0.04	0.04	0.05	0.06	0.07	0.12	0.16	0.15	0.12	0.11	0.08
Power (W)	0.16	0.20	0.29	0.37	0.46	0.82	1.12	1.04	0.82	0.70	0.44

Total daily energy harvested: 6.42 W

3. Improvement Comparison

The performance improvement (%) of the tracking system compared to the non-tracking system across each time interval is presented in **Table 4**:

Table 4: Improvement Percentage of Tracking System Over Non-Tracking System

Time (h)	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Voltage Improvement (%)	163	111	113	105	110	109	109	108	110	111	107
Current Improvement (%)	400	200	125	120	100	120	107	100	92	110	114
Power Improvement (%)	667	200	145	123	115	137	112	104	101	117	126

The data clearly show that the tracking system significantly outperforms the non-tracking counterpart in terms of voltage, current, and overall power output at almost every hour of the day. The greatest improvements were observed during early morning and late afternoon, when the sun's angle is not optimal for fixed-panel configurations. These results are consistent with the theoretical understanding of solar energy efficiency with respect to panel orientation.

It can be concluded that the tracking-enabled system provides a noticeable enhancement in energy harvesting, validating the effectiveness of the proposed method.

V. CONCLUSION

This paper presents a cost-effective and efficient **IoT-based solar tracking system** that enhances the energy harvesting efficiency of solar panels. The proposed system allows real-time remote monitoring of key parameters such as voltage, current, power, and light intensity via a smartphone application.

Experimental comparisons between tracking and non-tracking systems demonstrated that the proposed system significantly improves performance, particularly during off-peak solar hours. The integration of dual microcontrollers (Raspberry Pi Pico and ESP32) provides a reliable and modular architecture for simultaneous control and data transmission.

The findings confirm that **a solar tracking system with IoT integration not only improves power output but also offers greater flexibility, cost efficiency, and remote monitoring capabilities**, making it suitable for small- to medium-scale solar energy applications.

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REFERENCES

[1]. M. Waseem, A. F. Sherwani, and M. Suhaib, “Some Studies of Navigation System for Solar Powered Autonomous Vehicle,” in Proc. Natl. Conf. Trends and Advances in Mech. Eng., 2017, pp. 58–64.

[2]. S. Devaraj and P. C. Patel, “Taxicab Tipping and Sunlight,” PLOS One, vol. 12, no. 2, e0171996, 2017.

[3]. D. Wettergreen, B. Shamah, P. Tompkins, and W. Whittaker, “Robotic Planetary Exploration by Sun-Synchronous Navigation,” The Robotics Institute, Carnegie Mellon University, 2016.

[4]. M. Azam, T. Kumar, and M. Singh, “Sun Tracking Solar Panel System,” Int. J. Comput. Electr. Eng., vol. 6, no. 5, pp. 1–4, 2014.

[5]. W. Liu, “Sun Tracker: Design, Build and Test,” in IEEE 81st Vehicular Technology Conference (VTC Spring), 2015, pp. 1–5.

[6]. F. M. Al-Naima, R. S. Ali, and A. J. Abid, “Solar Tracking System - Design Based on GPS and Astronomical Equations,” in Proc. IT-DREPS Conf. & Exhibition, 2013, pp. 23–28.

[7]. P. Pokhra, Rajeshwari, and R. K. Yadav, “A Project Report on Automatic Sun Tracking Solar Panel Based on Open Loop Concept,” Int. J. Eng. Appl. Sci. (IJEAS), vol. 7, no. 2, pp. 12–15, 2020.

[8]. P. Singh, R. Pahuja, M. Karwasra, S. Beniwal, M. Bansal, and A. Dadhich, “Dual Axis Solar Tracking System for

Solar Panel," Bull. Electr. Eng. Informatics, vol. 5, no. 3, pp. 403–411, 2016.

[9]. A.A. Okandeji, M. B. Olajide, G. O. Olasunkanmi, and Z. O. Jagun, "Analysis and Implementation of a Solar Tracking Rack System," Niger. J. Technol. (NIJOTECH), vol. 39, no. 3, pp. 871–886, 2020.

[10]. Andrew Marsh, "3D Sun Path Diagram Tool," [Online]. Available: http://andrewmarsh.com/apps/staging/sunpath3d.html