

Development of IoT Monitoring with Solar Tracking System for Multi-Purpose Building

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Abstract

This paper discusses the development of an Internet of Things (IoT)-based solar tracking and monitoring system designed to enhance energy efficiency in multipurpose buildings. To optimize solar energy absorption throughout the day, a photovoltaic panel is integrated with a dual-axis solar tracking system. Real-time data, such as voltage, current, and light intensity, is collected and transmitted by an ESP32 microcontroller to a cloud-based platform for remote monitoring and analysis. When compared to a fixed solar panel, a prototype system created and tested under various conditions demonstrated improved energy output. The findings indicate that the system facilitates sustainable energy management in building applications, enhances solar efficiency, and reduces the need for human monitoring.

1. Introduction

The use of renewable energy technologies, especially solar power, as an environmentally friendly option for building energy systems has increased due to the quick rise in energy demand and concerns about the environment (Fernandez et al., 2024). However, the angle of solar panels toward sunlight has a significant impact on their efficiency, which limits the performance of fixed-panel systems (AL-Rousan et al., 2018). Solar trackers have been developed to address this issue by aligning photovoltaic panels with the sun's position throughout the day (Imad Shakir et al., 2021). Furthermore, real-time monitoring and smart control of energy systems have been made possible by the development of Internet of Things (IoT) technology (Gunjal et al., 2003). To enhance solar energy capture and facilitate continuous monitoring for multipurpose building applications, this study focuses on developing an Internet of Things (IoT)-based dual-axis solar tracking system (Bamisile et al., 2025).

2. Solar Tracking System

Solar tracking is a device used to position photovoltaic panels, reflectors, lenses, or other optical devices toward the sun (Ponniran et al., 2011). Since the sun's position changes in the sky with the seasons and time of day, Malaysia is one of the many countries that has a lot of cloud, which causes solar inefficiency (Lau et al., 2015). Besides, for any solar tracker to work, it requires basic components which are a Photovoltaic (PV) solar panel, Light Dependent Resistor (LDR) sensors, a servo motor, a Peripheral Interface Controller (PIC) microcontroller, a voltage regulator, a battery, and a charge controller (Vaka et al., 2020). The Fig. 1 below shows an example of a solar tracker prototype that can be applied in a multi-purpose building.

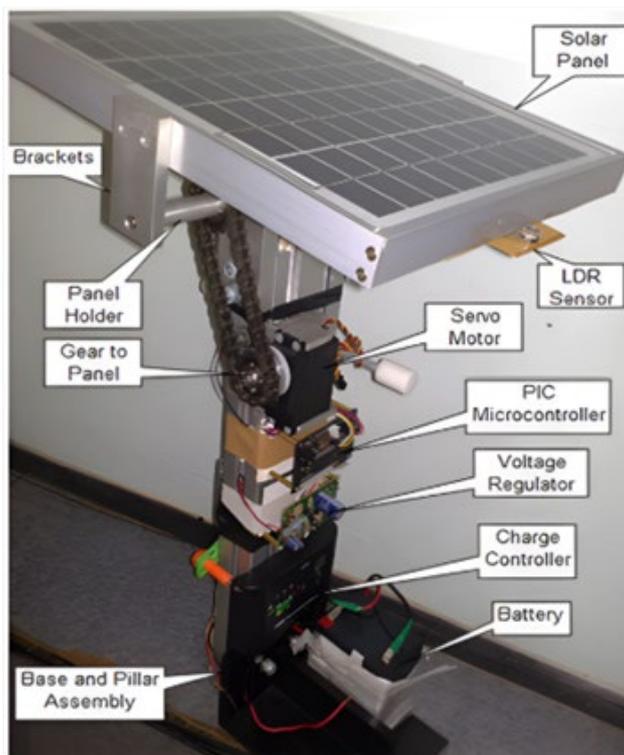


Fig. 1 Actual solar tracker design (Priyam, 2023)

2.1 Single Axis Tracker

Single-axis trackers have only one degree of freedom, which can be either North to South or East to West. This tracker is commonly used in many tracking systems and has been proven to be much more efficient than traditional static solar panels. Besides, the tracker will move to 3.75 degrees every 15 minutes. Because there are only two resistors used, the cost is reduced and the efficiency increases to about 20% (Priyam, 2023). Furthermore, the single-axis solar tracker can either have a horizontal, vertical or tilted single-axis tracker.

2.1.1 Horizontal Single Axis Tracker (HSAT)

It is used in tropical regions where the sun gets very high at noon, but the days are short (Nayak, 2012). Besides, Li et al. 2025 developed a mathematical procedure to estimate the daily collection of radiation by the system. He found that East-West sun tracking performed less efficiently (8% increased efficiency) and North-South sun tracking performed more efficiently (around 11-12% increased efficiency), which gained maximum efficiency (Priyam, 2023). Fig. 2 shows an example of a horizontal single-axis tracker (HSAT).

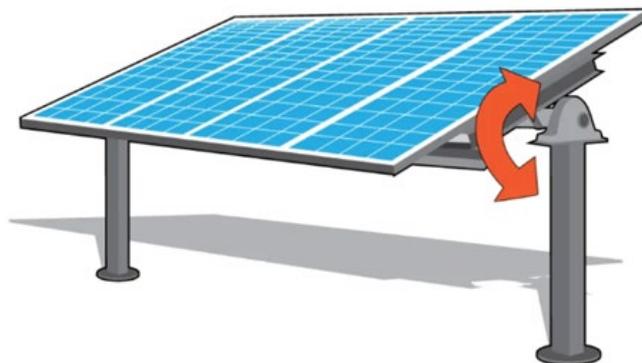


Fig. 2 Horizontal Single Axis Tracker (HSAT)

2.1.2 Vertical Single Axis Tracker (HSAT)

This type of tracking system can be directed either east-west or north-south, and it will move up/down. In the northern areas, where latitudes range from 40 to 50 degrees, they can be highly beneficial (Priyam, 2023). Fig. 3 shows the vertical single-axis tracker (VSAT).

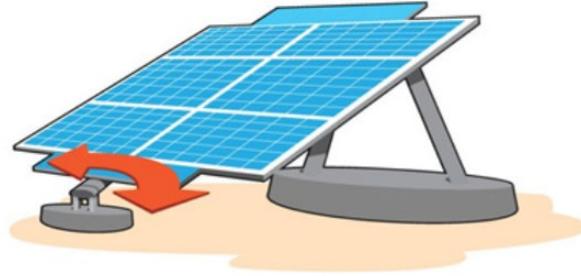


Fig. 3 Vertical Single Axis Tracker (VSAT)

2.2 Dual Axis Tracker

It has both a horizontal and a vertical axis and can track the sun's apparent motion or movement. Concentrated Solar Power (CSP), which requires a high degree of accuracy to ensure the sunlight is directed precisely at the focal point of the reflector or lens, was applied in this dual-axis tracker. Since the distances between the mirror and the central receiver in the tower construction are greater, dual-axis tracking is crucial in solar tower applications to reduce angle errors (Nayak, 2012). The figure below shows an example of the dual-axis tracker. Fig. 4 shows an example of a dual-axis tracker.



Fig. 4 Dual-axis tracker

2.2.1 Azimuth-Altitude Dual Axis Tracker (PADAT)

This first axis is the axis that is perpendicular to the ground, called the azimuth axis. The second axis is the altitude axis. When the collector turns toward the sun, the apparatus operates properly. As a result, the azimuth angle changes, and the ground is called the azimuth axis. Besides, when the system rotates around the altitude axis, there is a change in the altitude angle (Priyam, 2023).

2.2.2 Polar Aligned Dual Axis Tracker (PADAT)

The polar-aligned technique is a dual-axis tracking technique, also known as spinning-elevation tracking, which utilizes two axes. The figure below shows the polar-aligned tracker principle. Fig. 5 shows an example of the polar-aligned tracker principle

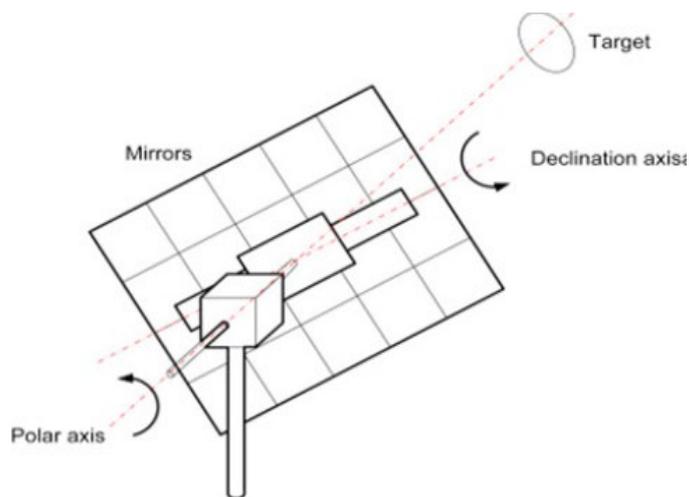


Fig. 5 Polar-aligned tracker principle (Priyam, 2023)

One axis points in the direction of the celestial north pole, while the other is parallel to the earth's rotational axis. It moves in the opposite direction but at the same speed as the earth's rotation (Priyam, 2023).

2.3 Internet of Things (IoT) Monitoring

Finding, analyzing, and controlling linked devices are all part of monitoring your Internet of Things (IoT) inventory. Being aware of potential problems or difficulties that could impact on the functionality of user services and business-critical software is crucial. This covers the initial identification and analysis of the model, ongoing monitoring of their performance and status, and timely problem-solving. Users can enhance consistency, protect critical operations that depend on IoT technology, and proactively manage connected devices by implementing an effective IoT monitoring system.

2.3.1 ESP WiFi

The ESP32 is a semiconductor that provides Bluetooth and Wi-Fi connectivity to integrated devices, often referred to as Internet of Things (IoT) devices. Although the ESP32 is just a chip, the company that manufactures it commonly refers to boards and modules that contain this chip as "ESP32." The ESP32 is mostly used in the creation of wearable mobile devices and Internet of Things applications such as Nabto Border. Additionally, the ESP32 has been the top semiconductor choice for IoT developers and followers since the framework's OS released the ESP32 IoT Starter Kit. It can be applied to the corporate Internet of Things (IoT), and over the past four years, its capabilities have grown significantly. The figure below shows an example of an ESP32 processor chip. Fig. 6 shows the processor chip.



Fig. 6 ESP32 processor chip

2.3.2 ESP WiFi

The Arduino software, sometimes known as the IDE or integrated development environment, is created by arduino and is freely accessible for Arduino board programming. Allow authorization for code to be uploaded and written to Arduino boards. Numerous tools and several small projects all utilising user-friendly Arduino software, are also included. It helps you develop devices that are interactive and get begin with technology for robotics,

electronics, and coding. The figure below shows an example of Arduino IDE software interface. Fig. 7 shows the arduino IDE software interface.

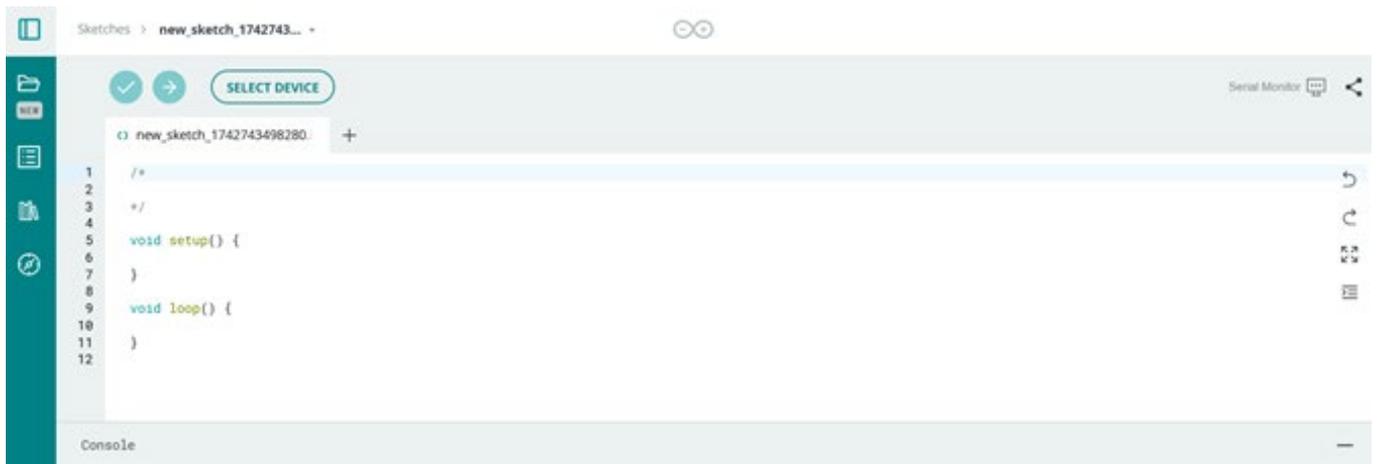


Fig. 7 Arduino IDE software interface

2.4 Integration of Arduino ESP32 with Solar Tracking System

By combining an Arduino ESP32 with a solar tracking system (supported by an Arduino UNO R3), it can enhance energy reliability and efficiency while reducing reliance on non-renewable energy sources, such as fossil fuels. By using a jumper wire from female to female for the model that connects to the Arduino ESP32 chip placed in the solar tracking system. The figure below shows the jumper female to female. Fig. 8 shows the jumper wire (Female to Female)



Fig. 8 Jumper wire (female to female)

Additionally, utilizing a solar dual-axis system (Azimuth-Altitude Dual Axis Tracker) with monocrystalline material for the panel is cost-effective in the long term and enables the panel to receive maximum sunlight by using LDR sensors to track the sunlight with the assistance of the Arduino UNO R3. Furthermore, the Internet of Things (IoT) enables monitoring and control of the model through the Blynk smartphone application or the Blynk platform, utilizing sensors (Mukhopadhyay et al., 2021). Energy storage in battery Lithium Iron Phosphate, LiFePO₄, is suitable due to its more efficient, reliable, and longer life cycle.

3. Planning Design

Planning design is an essential stage in developing the IoT-based solar tracking system because they provide a clear framework before the prototype is constructed. The system's goals can be turned into a workable model that combines IoT monitoring, and solar energy collection with careful design. The system layout, component placement, and connections are all optimized for cost-effectiveness, efficiency, and safety throughout the design process. This was accomplished by modeling the system using 3D visualization software (Blender), which decreased the possibility of implementation errors and enhanced knowledge of how it was installed in a multipurpose building. Fig. 9 shows the 3D model of the prototype design

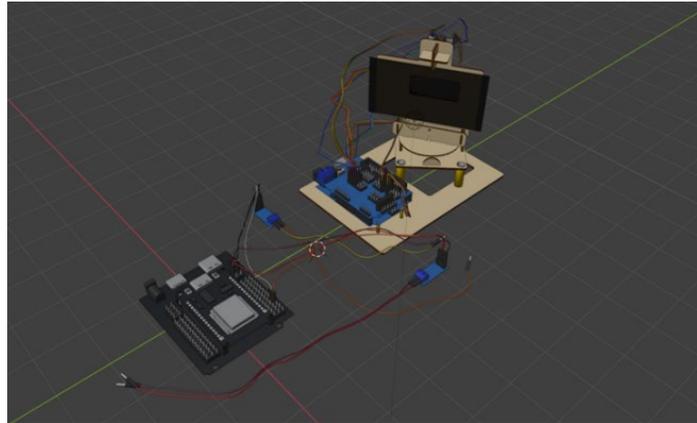


Fig. 9 Design model (prototype) that install in multi-purpose building

4. 5/12V Monocrystalline Solar Panel Quations

The solar panel collects solar radiation and transforms it into electrical energy that can be used in buildings and companies. Additionally, monocrystalline solar panels are composed of photovoltaic cells made from a single piece of silicon, containing a junction box and electrical cable, which enables them to capture energy from the sun and convert it into usable electricity. With the use of bypass diodes to reduce the impact of shadows, the monocrystalline solar panels ensure a high level of energy transfer efficiency. By using the formula below, the voltage and current can be codes inside the Arduino IDE for it to self-calculation within the system. Equation 1 shows the formula for the voltage (analog to digital converter), which explains how ESP32 reads signals as numbers (0 to 4095) and still not in volts yet. The first step is to convert that number back into a voltage that the sensor actually measured.

$$V_{ADC}(V) = Sensor\ Value \times \frac{V_{ref}}{ADC_{ref}} \tag{1}$$

$$V_{diff}(V) = V_{adc} - V_{offset} \tag{2}$$

$$V_{rms}(V) = \sqrt{\frac{1}{N} \sum_{i=1}^N (V_{diff,i})^2} \tag{3}$$

$$I(A) = \frac{V_{rms}}{sensitivity} \quad (\text{Using ACS712 sensitivity}) \tag{4}$$

$$I(A) = V_{adc} \times \frac{R1+R2}{R2} \tag{5}$$

$$P(W) = V_{sensor}(V) \times I(A) \tag{6}$$

$$\Delta Ewh = P(W) \times \frac{\Delta t}{3600} \tag{7}$$

$$\Delta Ewh = P(W) \times \frac{\Delta t}{3600000} \tag{8}$$

$$Ewh(k) = \sum_{n=1}^k \Delta Ewh(n) \tag{9}$$

5. Results & Discussion

When compared to the fixed solar panel system, the test results of the IoT-based solar tracking system show a clear increase in energy efficiency. Due to the solar tracking model's ability to continuously adjust itself with the

position of the sun using LDR sensors, it consistently produced greater energy values over the two-week testing period at UTHM Pagoh Block F with every second reading. During morning and late afternoon sessions, when sunlight angles are lower, this dynamic positioning increases light absorption and reduces reflection losses. Environmental factors that affected data accuracy and hardware performance included high temperatures on October 15, 2025, and heavy rains on October 14, 2025, underscoring the significance of temperature management and waterproofing for IoT components.

Despite these difficulties, the system was able to return to regular operation with a few minor adjustments to wiring and coding. Its reliability for continuous solar energy tracking applications was confirmed by the real-time data visualization and error identification made possible by the monitoring through the Blynk IoT platform (Navaneethan & Meenatchi, 2019). Furthermore, the performance graphs (Energy vs. Time) indicated that, compared to the fixed system, which exhibited irregular decreases in energy output, the solar tracking system maintained a steady energy output even under unpredictable weather conditions. The results confirm the effectiveness and potential of IoT-assisted solar technology for renewable energy optimization in multi-story structures, as previous research has shown that tracking systems can produce 15–25% more energy production than fixed systems (Vieira et al., 2016).

5.1 Result Correlation

This chapter shows how the data support the study's goals and presents the experimental results from the developed IoT-based solar tracking system. The analysis focuses on voltage, current, and energy generation data collected across several test dates, comparing the performance of the tracking system to that of a stationary solar panel. The table below shows the result correlation based of the dates that monitor the sunlight. The correlation values in Table 1 demonstrate the degree to which sunlight intensity affected the solar tracking system's energy output on each testing day.

Table 1 Result correlation based of the dates

Result correlation based on date	Result
13/10/2025	0.9097
14/10/2025	0.9976
15/10/2025	0.6251
21/10/2025	0.9638
23/10/2025	0.7616
28/10/2025	0.3684

On 13/10/2025 (0.9097), 14/10/2025 (0.9976), and 21/10/2025 (0.9638), there were higher correlations since the weather was often sunny and consistent. There is a strong linear relationship between sunlight and energy output under clear skies, as sunlight intensity increases gradually throughout the day, allowing the solar tracker to maintain constant alignment with the sun. On the other hand, moderate correlations on 15/10/2025 (0.6251) and 23/10/2025 (0.7616) indicate partially overcast situations, where production fluctuated due to abrupt dips in sunlight. On October 28, 2025, the lowest correlation (0.3684) indicates extremely cloudy or rainy weather with significantly variable sunshine intensity. These findings indicate that the primary causes of the differences in correlation values observed across multiple dates are environmental factors, primarily cloud cover and shade.

6. Conclusion

An IoT-based dual-axis solar tracking and monitoring system, which enhances solar panel efficiency and facilitates intelligent energy management for building applications, was successfully developed in this study. Real-time IoT monitoring, combined with tracking technology, demonstrated increased power output, improved system visibility, and reduced maintenance needs. The suggested approach supports green technology initiatives and provides a workable and scalable method for integrating sustainable energy into multipurpose buildings (Florez & Ghazali, 2020). Data analytics integration and system expansion for large-scale applications are possible future improvements.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Chew Cheng Wah, Nuramidah Hamidon; **data collection:** Chew Cheng Wah, Nuramidah Hamidon; **analysis and interpretation of results:** Chew Cheng Wah, Nuramidah Hamidon, Mohd Arif Rosli; **draft manuscript preparation:** Chew Cheng Wah, Nuramidah Hamidon, Mohd Arif Rosli, and Mariah Awang. All authors reviewed the results and approved the final version of the manuscript.

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