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The Development of IoT Automatic Solar Tracking System for Oriented Solar Cell Applications

Muhamad Faris Hamidin[1], **Amirul Syafiq Sadun**[1]*

[1]Department of Electrical Engineering Technology, Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, Educational Hub Pagoh, 84600 Muar, Johor Malaysia

*Corresponding Author Designation

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Abstract: Creating a solar tracking system that will allow solar panels to constantly be pointed in the direction of the strongest radiation is the aim of this project. The quantity of sunlight absorbed in the morning, noon, and afternoon are not equal since the amount fluctuates during the course of a day. In Malaysia, there is also a significant amount of cloud cover, which causes the amount of solar output to vary greatly. The project's primary purpose is to develop a solar tracking system that can detect the light intensity, auto movement of the solar tracking system, monitor the output from solar panel, and discuss the output data. During operation, a solar tracking system is controlled using the ESP32 because it is ideal for achieving IoT. ESP32, as a microcontroller will connect to KY-018 photoresistor module, also known as light dependent resistor. This photoresistor function is to detect the light intensity and auto directed the tracking system the point, where is light outmost. Two servo motors will act to control the horizontal and vertical axis from the output from the photoresistor. The mechanical design and output from the solar are the type of testing that was done. Therefore, based on the output values, the movement tests have shown that this system can work properly. At the end of the study, the solar panel is approximately taking 13.51 hours to fully charge an 18650-lithium battery with a capacity of 3600 mAh using a constant current of 0.26 Amps.

Keywords: Solar Panel, Solar Tracker, IoT, ESP32, Photoresistor

1. Introduction

The burning of fossil fuels, such as coal and oil, to produce electricity is a significant contributor to global warming and climate change [1, 2]. Many countries heavily rely on fossil fuels, particularly for their industrial sectors, to support sustainable socio-economic development. As energy demand continues to rise, it is expected that fossil fuel consumption will increase, leading to a further rise in CO_2 emissions [3]. To address this issue, governments worldwide have been initiating measures to

*Corresponding author: amirul@uthm.edu.my

promote the adoption of renewable energy (RE) through national programs. RE is generated from naturally abundant sources like the sun, wind, biomass, etc. [3]. It is considered an eco-friendly energy form with minimal to zero CO_2 emissions [1]. Despite its potential to replace fossil fuels, the integration of renewable energy into the mainstream has been slow in many developing countries, including Malaysia. Malaysia introduced various measures in its 8th Malaysia Plan in 2001 to facilitate the rapid integration of RE into the national grid. However, transitioning to RE in Malaysia has encountered challenges, such as difficulties in securing funding, unattractive tariffs and incentives for utilities, and a lack of awareness among key decision-makers in the industry [4]. Presently, only 8% of Malaysia's energy is generated from RE, while the country has set a target of achieving 20% by 2025. According to the Malaysian Investment Development Authority (MIDA), thriving RE technologies in Malaysia include solar energy, hydroelectric power, and biomass [5]. Among these technologies, solar photovoltaic (PV) systems have witnessed remarkable growth in Malaysia and other countries due to recent advancements [4, 5]. Malaysia's hot and humid climate, coupled with abundant rainfall throughout the year, creates favorable conditions for solar energy generation [6]. The country receives a substantial amount of solar radiation year-round, with most regions experiencing a daily solar radiation mean of 4.7-6.5 kWh/m² [4].

A study conducted that the majority of the respondents are highly interested in solar energy in Malaysia with approximately 60% of the respondents are willing to choose solar energy if the cost related to solar energy usage is only as much as the current price of fossil fuel-generated electricity [4]. From the result, in the near future, social acceptance of solar energy in Malaysia from Malaysian perspective will be high. Hence, Malaysian recognized that it can convert solar energy into electrical energy by absorbing the light of the sun in a day [7, 8]. However, the conventional solar cells are suffered from the non-oriented solar panels [9, 10], where the intensity of sunlight that is harnessed will always change in a day, due to the intensity of the sunlight absorption between the time morning, noon, and afternoon is not the same [11, 12]. Consequently, there are such a waste for the solar panels that do not harnessing the sunlight in a day [10, 13]. In addition, Malaysia also has very high cloud cover and this results in high intermittency of solar output, resulting the fluctuation of sunlight absorptions [12].

The conventional way of data acquisitions to measure the voltage, current, and power of the solar panel are vital since it is required to use human power [14, 15]. This conventional way leads to the time-consuming and inaccuracy since there will be presented the human error due to the measurement using traditional instrument, specifically multi-meter [15]. The data measurements are recorded and facing a problem which is unable to record for long periods of time, where the recorded data may be lost, redundant, or damaged paper-based data records [15]. Therefore, these problems can be sought by benefitting the IoT based devices for the solar cells.

From this deportment, the concept of this study apportioned with development of a real-time solar tracking system that is capable for monitoring the changes in solar intensity based on sunlight transition, to identify the system performance in term of detection capabilities and real-time data collection, and to analyse the performance of the system in term of functionality and reliability. Ultimately, the system developed promises environmental oriented solar panel with benefitting completely of solar radiation for a whole day without any waste of non-absorbed sunlight.

2. Materials and Methods

A comprehensive analysis of the critical components is necessary to ensure that the project utilises the most suitable components and meticulously method. This study conducted with numerous noteworthy components, some imperative software, prototype development, and functionality testing parts which to ensure proper operation and performance of the prototype.

2.1 Materials

In this study, several vital components were used which have their respective functionalities

- NodeMCU ESP32
- KY-018 Photoresistor Module
- MAX471 Voltage Current Sensor
- SG90 Servo Motor
- Dual 18650 Lithium Battery Power Shield

Table 1 to 4 listed the detail specifications on these components, respectively.

The NodeMCU ESP32 commonly found in low-power chips, such as fine-grained clock gating, multiple power modes, and dynamic power scaling. With approximately 20 external components, it provides a highly-integrated solution for Wi-Fi and Bluetooth IoT applications.

Table 1: NodeMCU ESP32 technical specifications

Characteristics	Specification
Microprocessor	Xtensa Dual-Core 32-bit LX6 con 600 DMIPS
Wi-Fi (980.11 b/g/n)	HT40
Bluetooth	Bluetooth 4.2 y BLE
Operating Frequency	160 MHz
ADC	12-bit resolution
PWM (Hardware)	Not Available
PWM (Software)	16 channels
Interface MAC Ethernet	Yes
Work Temperature	–40 ºC to 125 ºC

The main feature KY-018 Photoresistor Module is the photoresistor, which is a passive component that exhibits a change in resistance based on the intensity of light it receives. When exposed to light, the resistance of the photoresistor decreases, whereas in darkness, the resistance increases. The module comprises a photoresistor, a 10 kΩ in-line resistor, and three male header pins.

Table 2: KY-018 Photoresistor technical specifications

Parameter Name	Technical Condition/Parameter
Type	Analog
Module	Light Sensor
Operating Voltage	DC 3.3V – 5V
Operating Temperature Range	–30
Dark Resistance	500 kΩ
Light Sensing Responses	30 μS
Spectrum Peak Value	540
Board Dimension ($L \times W \times H$)	30 mm × 15 mm × 6 mm
Weight	2 gm

A servo motor is a precise rotational motor that typically includes a control circuit providing feedback on the current position of the motor shaft. This feedback enables servo motors to rotate with exceptional accuracy.

Table 3: Servo Motor specifications

Microcontroller	Specifications of a small servo motor
Size	32 × 11.5 × 24 mm
Weight	8.5 g
Speed	0.12 – 0.10 sec/60º
Torque	1.5 – 2.0 kgf-cm
Voltage	4.8 – 6.0 V

The MAX471 is an integrated circuit designed to measure both voltage and current within an electrical circuit. It is specifically known as a high-side current-sense amplifier. The MAX471 offers a convenient and accurate solution for monitoring voltage and current levels in various electronic systems, including voltage sensing and current sensing applications. It measures the voltage across a shunt resistor that is placed in series with the load or power source. The IC amplifies the small voltage drop across the shunt resistor, facilitating easier measurement and processing

Table 4: MAX471 voltage current sensor

Parameter	Symbol	Conditions	Min	Type	Max	Unit
Supply Voltage	V_{RS+}	–	3		36	V
Supply Current	I_{RS+}	I_{LOAD} = 0 A, excludes I_{SIGN}		50	113	μA
Sense Current	I_{LOAD}	–			±3	A_{rms}
Sense Resistor	R_{SENSE}	–		35	70	mΩ

A Dual 18650 Lithium Battery Power Shield is an electronic module designed to provide power management and charging capabilities for two 18650 lithium-ion batteries. The power shield is equipped with a charging circuit that facilitates recharging of the connected 18650 batteries. The power shield incorporates various protection features to ensure safe and reliable operation. These may include overcharging protection, over-discharging protection, and short circuit protection, which help prevent damage to the batteries and connected devices.

Table 5: 18650 Lithium Battery Power Shield specifications

Parameter Name	Technical Condition/Parameter
Output Voltage	3 V/5 V
Micro USB Charging Current	600 mA – 800 mA
Output Port	USB type
Input Port	Micro-USB
Conversion Efficiency	96%
Board Dimension ($L \times W \times H$)	100 mm × 50 mm × 20 mm
Weight	38 gm

2.2 Methods

This part will describe the block diagram, flowchart, and the layout of the solar tracking system. The block diagram for this project on how the solar tracking function as depicted in Figure 1.

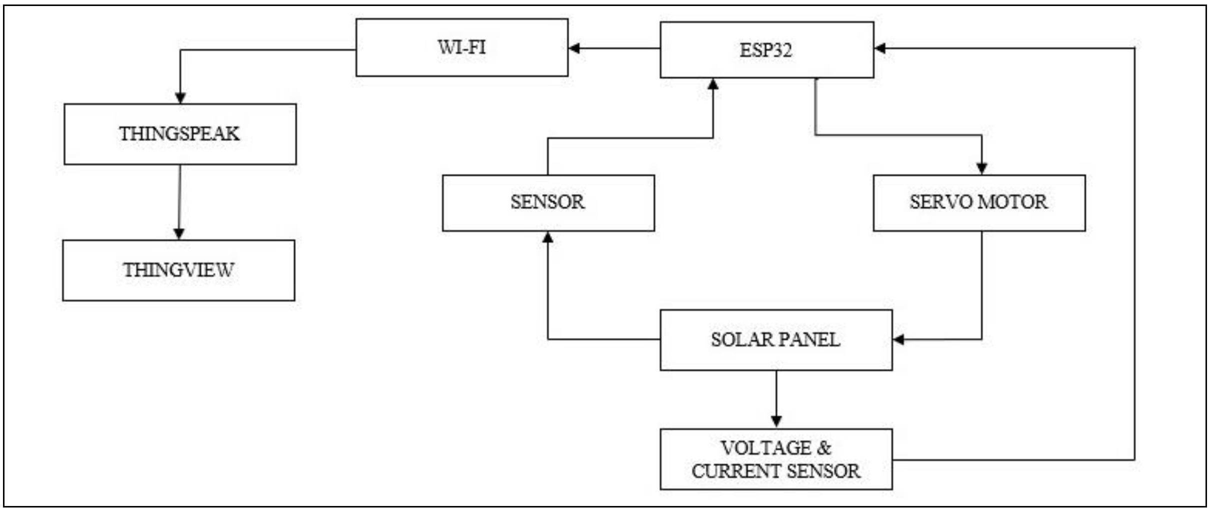

Figure 1: Block diagram of solar tracking system

According to the block diagram, during the tracking operation, the ESP32 is autonomously activated, leveraging its Internet of Things (IoT) capabilities. It is tasked with detecting the light intensity through sensor inputs and controlling the servo motor to adjust the position of the solar panel accordingly. Simultaneously, the sensor detects the light intensity in the new solar panel direction, and the resulting data is relayed back to the ESP32. Moreover, the voltage and current sensor outputs are seamlessly transmitted back to the ESP32. Additionally, the ESP32 establishes a connection with ThingSpeak, enabling the processing and operation of the output data through ThingView. The flowchart for this project on how the solar tracking function as illustrated in Figure 2.

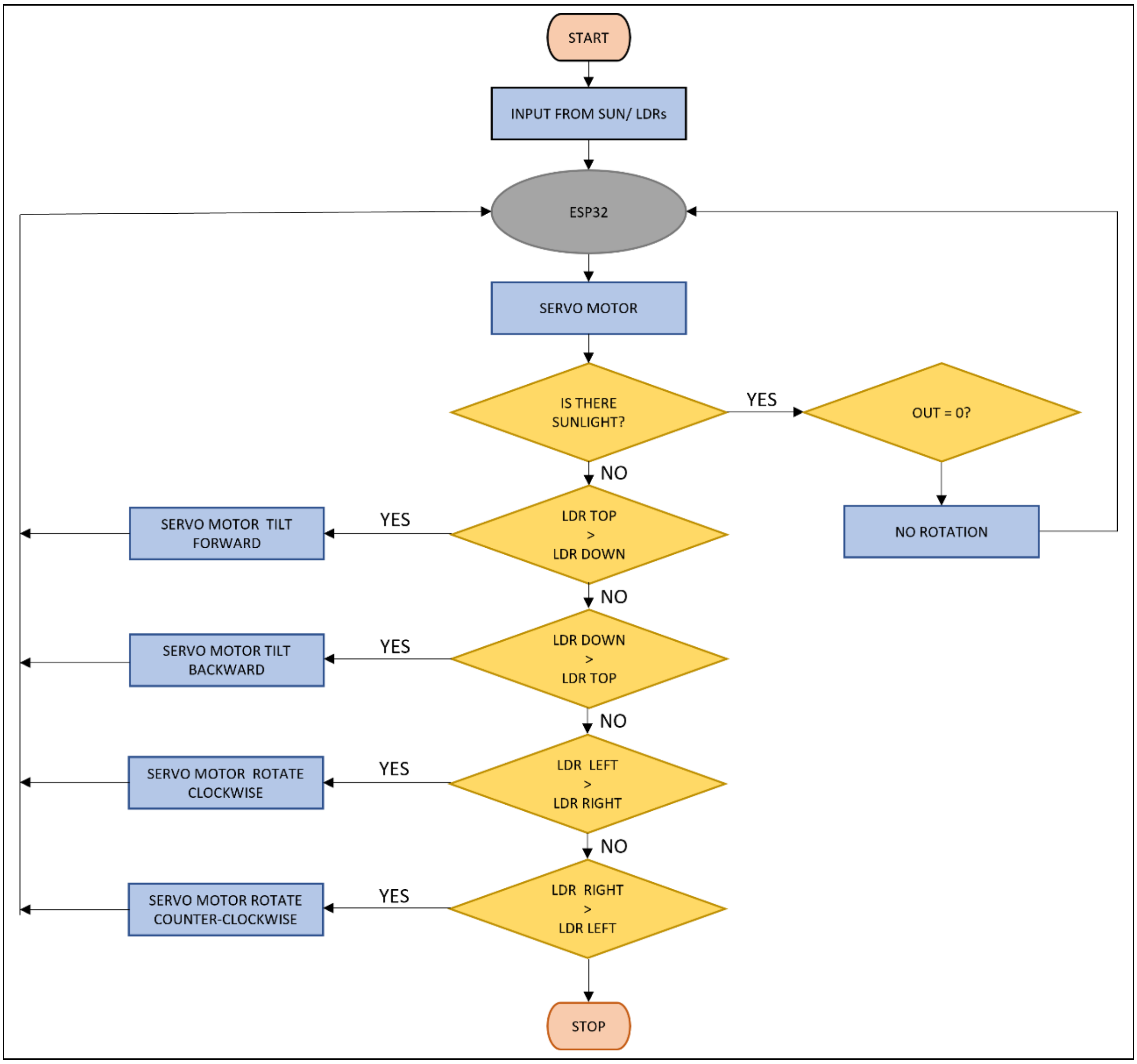

Figure 2: Flowchart of the functionality of solar tracking system

The solar tracking system is an intelligent method for harnessing solar energy. This system employs four sensors to detect the position of the sun. Light power is estimated using LDR sensors placed in the "top, down, right, left" configuration.

In this system, if the top LDR reading is higher than the down LDR reading, the servo motor will tilt the solar panel forward. Conversely, if the down LDR reading is higher than the top LDR reading, the servo motor will tilt the solar panel backward. Similarly, if the left LDR reading is greater than the right LDR reading, the servo motor will rotate clockwise. Conversely, if the right LDR reading is greater than the left LDR reading, the servo motor will rotate counterclockwise.

Figure 3 presented the design of circuit diagram of solar tracking system which illustrates the wiring connections between the various components. The central component of the project is the ESP-32 microcontroller, which features integrated Wi-Fi and dual-mode Bluetooth capabilities. The ESP-32 requires a supply voltage from the 18650 batteries to power on.

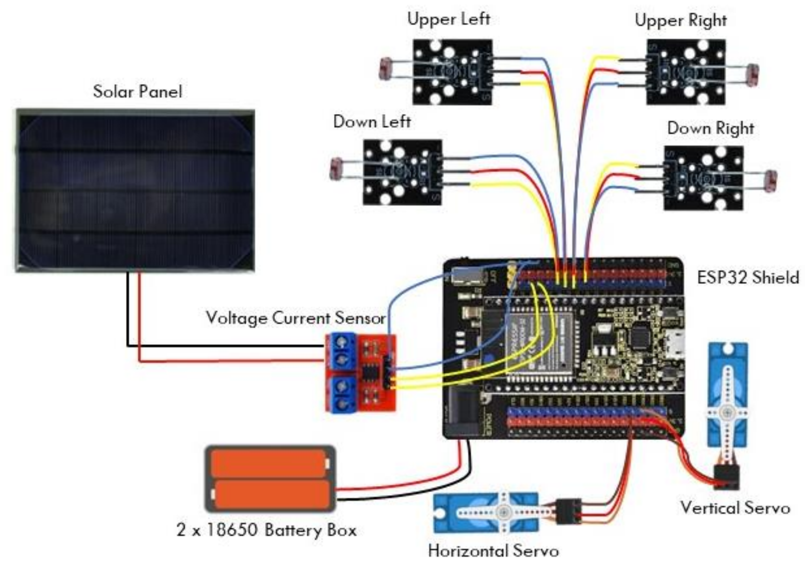

Figure 3: Layout of solar tracking system

The servo motor, responsible for controlling the horizontal and vertical movements, responds to input from the KY-018 photoresistor module, which consists of four light-dependent resistors positioned in the upper left, upper right, lower left, and lower right directions. These resistors sense the incoming light and transmit the data to the ESP-32, which instructs the servo motor to adjust its position accordingly. Lastly, the connection between the solar panel and the ESP-32 is established using a voltage current sensor called the MAX471. This device detects and converts the current from the solar panel into a measurable output voltage for the ESP-32.

2.3 Software

Two software were utilised in this study, Arduino IDE, ThinkSpeak and ThinkView. Arduino IDE is an open-source software, designed by Arduino.cc and mainly used for writing, compiling & uploading code to almost all Arduino Modules. The IDE environment mainly contains two basic parts: Editor and Compiler where former is used for writing the required code and later is used for compiling and uploading the code into the given Arduino Module.

ThingSpeak is an IoT (Internet of Things) platform that allows for the collection and storage of sensor data. By connecting solar panels to ThingSpeak, real-time data can be gathered, including solar panel output such as voltage, current, and power. The solar panel is positioned to directly face the sun, and its response is transmitted to an ESP32 device. The ESP32 device sends the collected data to ThingSpeak using IoT technology, allowing the user to monitor the gathered data. ThingSpeak enables remote monitoring of solar panel performance. This is particularly useful for installations that are not easily accessible or when continuous monitoring is required. It allows the prototype for real-time tracking of energy generation and detection of any issues or deviations from expected performance. It also can access the data collected by ThingSpeak from anywhere, enabling user to monitor the performance of the solar panels in real-time. ThingSpeak can be utilised for research and development purposes related to solar energy which its data will be collected through ThingSpeak can be used for these experiments.

The data collected from ThingSpeak can be transferred to ThingView through an integration or data sharing mechanism. ThingView is a separate platform or application that allows users to visualize and analyze data from various IoT sources, including ThingSpeak. To transfer the data from ThingSpeak to ThingView, you would typically set up a data transfer or integration process between the two platforms. This process may involve using APIs or other data sharing methods provided by ThingSpeak and compatible with ThingView. In ThingView, users can then analyze the solar panel performance, generate visualizations such as graphs or charts, and derive insights from the collected data. This integration allows for a unified view and analysis of data from various IoT sources, enhancing the monitoring and analysis capabilities for solar energy systems.

3. Results and Discussion

The system of solar tracking and prototype were completed successfully designed and functioned, where Figure 4 parades the complete prototype.

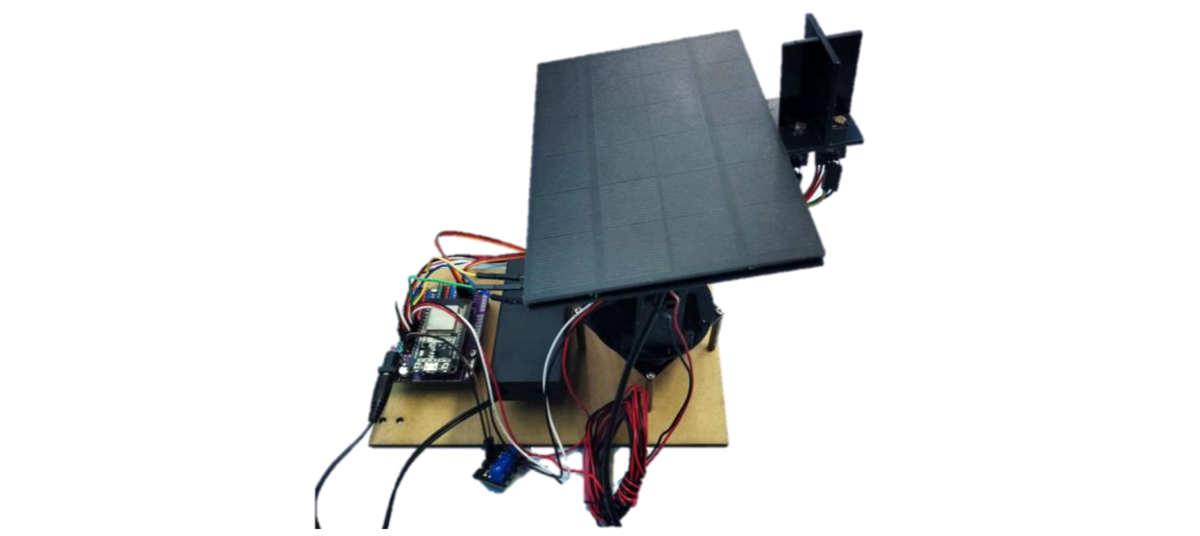

Figure 4: Prototype of solar tracking system

The data collected from ThingSpeak can be exported to Microsoft Excel, providing a convenient way to store the information. Since the data collected from ThingSpeak is generated for only one hour, users would need to collect data hourly to ensure it is not missed. The collected data from 10:00 a.m. to 12:00 p.m. can be transferred to Excel to generate charts for a clearer understanding. The *x*-axis represents the data collected, with 100 data points per hour (800 data points for 8 hours) as exhibited in Figure 5, 6 and 7 for voltage, electrical current, and power output, respectively, resulting in an average of 1.6 readings per minute. The *y*-axis represents the voltage, current, and power units.

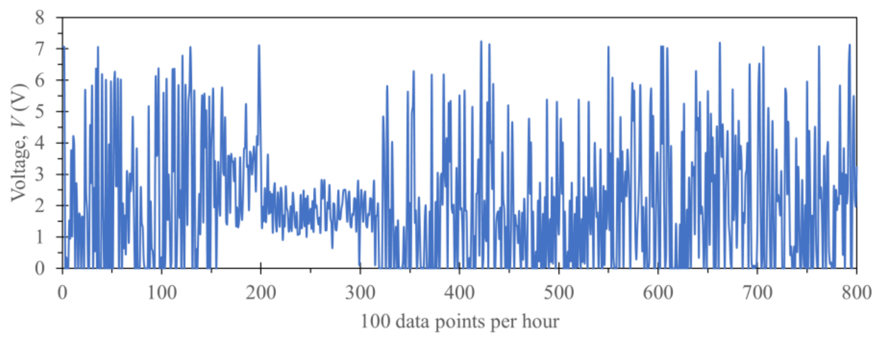

Figure 5: Voltage output by the solar panel in 8 hours

Figure 5 depicts the collected voltage which it can be observed that the majority of the voltage values are inverted. The highest voltage recorded was 7 V, occurring 13 times throughout the duration. On the other hand, the lowest voltage values, near 0 V, were prevalent for most of the hours, except during the peak hour from 12:00 to 1:00 p.m., where the voltage never approached the 0 V mark.

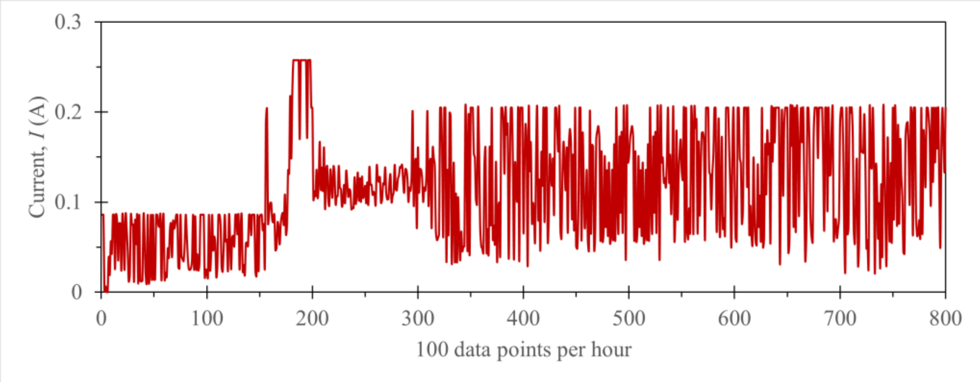

Figure 6: Current output by the solar panel in 8 hours

Figure 6 showcases the collected current data, where the highest recorded current was 0.26 A, which occurred during the peak hour from 12:00 to 12:20 p.m. The graph predominantly exhibits a consistent pattern, with the current remaining at 0.26 A for the majority of the data points after 290 data (around 12:50 p.m.). Prior to the peak hour, the lowest current values were approximately 0.1 A.

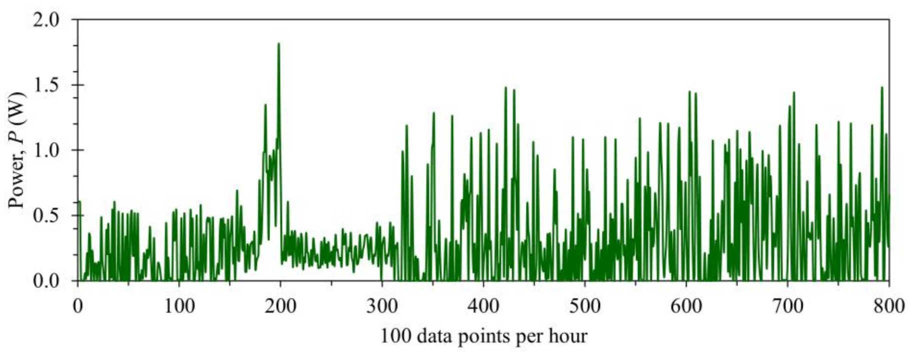

Figure 7: Power output by the solar panel in 8 hours

Figure 7 displays the power output data obtained that the highest recorded power was 1.8 W, which occurred around data point 197, close to 12:00 p.m. Following that, from data point 323 onwards (around 12:20 p.m.), the power remained within the range of 1.2 to 1.4 W, also exhibiting an inverted trend. The power output is influenced by the current and voltage measurements collected earlier.

From the graphs in Figure 5, 6 and 7, the fluctuated values of voltage, current, and power were influenced by some factors, which were changing of sunlight intensity during the measurements and temperature change of the solar panel. The intensity of sunlight is capable to diverge all over the daylight as a result of issues like cloud cover, shading, or the sunlight angle of incidence onto the solar cell [16]. Consequently, these factors resulting changing in sunlight intensity, thus, the fluctuating the voltage output of the solar cell [16, 17]. Another factor was the sensitivity of solar cells to temperature changes, in which, an increment of temperature onto the solar cell will burst to a downgraded in the voltage output of the solar cell [16]. The fluctuations in environmental temperature responsible to the fluctuations of voltage output of the solar cell [16, 17, 18].

When estimating the time required to fully charge a battery, it is important to consider factors such as battery capacity and charging current. In the case of an 18650-lithium battery with a capacity of 3600 mAh and a constant charging current of 0.26 Amps, the charging time can be determined. For it to calculate the charging time *T*, equal to the battery capacity *Q* over the charging current *I* as written in equation

$$T = \frac{Q}{I} = \frac{3.6\ \text{Ah}}{0.26\ \text{A}} = 13.51\ \text{h} \qquad \text{Eq. 1}$$

Therefore, it would take approximately 13.51 hours to fully charge an 18650-lithium battery with a capacity of 3600 mAh using a constant current of 0.26 Amps.

4. Conclusion

The objective of this project is to successfully develop a real-time solar tracking system that can effectively monitor the changes in solar intensity by accurately tracking the transition of sunlight. The success criteria will be based on three key aspects. Firstly, this project should demonstrate reliable and precise detection capabilities, ensuring that it accurately identifies and tracks the movement of sunlight. Secondly, the system should efficiently collect and record real-time data regarding solar intensity. By utilizing ThingSpeak and ThingView, the developed solar tracking system enables comprehensive analysis and evaluation. These platforms facilitate the recording of data over extended periods, ensuring long-term accuracy without the need for human intervention. Lastly, the performance of the system should be thoroughly assessed in terms of its functionality and reliability, ensuring that it operates seamlessly and consistently over extended periods. By achieving these objectives, the project aims to deliver a robust and effective solar tracking system that meets the requirements of real-time monitoring and analysis. The future direction of this study focused on use different types of solar panel and practice LabView to store data and log the output data from previous sessions. This feature enables users to access and review the historical data recorded by the system.

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