Faculty of Computer Science and Information Technology

Adaptive Solar Tracking System Using Internet of Things (IoT)

Final Year Project

MOHAMAD ALIFF HAZWAN BIN OSMAN

(80063)

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Adaptive Solar Tracking System Using Internet of Things (IoT)

MOHAMAD ALIFF HAZWAN BIN OSMAN

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DECLARATION OF ORIGINALITY

I hereby declare that this research together with all its content is none other than that of my own work, with consideration of the exception of research-based information and relative materials that were adapted and extracted from other resources, which have evidently been quoted or stated respectively.

Signed,

……Aliff……

MOHAMAD ALIFF HAZWAN BIN OSMAN

Faculty of Computer Science and Information Technology 24th July 2025

University Malaysia Sarawak

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ABSTRACT

The growing demand for renewable energy necessitates innovative solutions to optimize energy capture and utilization. This project proposes an **Adaptive Solar Tracking System Using Internet of Things (IoT)** to enhance solar panel efficiency by dynamically adjusting their orientation to maximize sunlight exposure, while also having the capabilities to stay afloat in water. Using a prototyping methodology, the project developed a system integrating IoT-enabled sensors, microcontrollers, and adaptive algorithms. Key components include light-dependent resistors (LDRs), an Arduino Nano 33 IoT board, servo motors, and a ThingSpeak-based cloud platform for real-time monitoring and control. The development process employs the prototyping methodology, which encompasses requirements analysis, quick design, prototype building, user evaluation, and refinement, resulting in a cost-effective and scalable solution. The system demonstrated significant improvements in energy capture compared to fixed solar panels, highlighting its potential to bridge efficiency gaps while addressing environmental and economic challenges. This study contributes to the advancement of sustainable energy solutions, offering insights into the practical application of IoT for renewable energy optimization.

CHAPTER 1: INTRODUCTION

1.1 Introduction

As the world faces emerging environmental challenges, there is a growing imperative to change from fossil fuels toward renewable energy sources. The consequences of relying on conventional energy, such as greenhouse gas emissions, air and water pollution, and the depletion of natural resources, are becoming increasingly severe. Climate change, driven by these emissions, is affecting ecosystems and weather patterns globally, causing a ripple effect that impacts economies, biodiversity, and human well-being. To combat these environmental issues and reduce our carbon footprint, Novas et al. (2021) is placing a stronger emphasis on sustainable energy solutions, with solar power emerging as one of the most promising options.

Solar energy has captured global interest due to its ability to provide clean, renewable power without producing harmful emissions, according to Gong et al. (2019). Solar panels can harness the sun's energy, converting it into electricity to power homes, businesses, and infrastructure. With the sun as an abundant and renewable resource, solar energy has the potential to fulfil a significant portion of our energy needs, reducing dependency on environmentally harmful energy sources. As a result, both private and public sectors are investing heavily in research and development to enhance solar technology, making it more efficient, cost-effective, and accessible for consumers while also contributing to the Sustainable Development Goal.

One key area of focus in this development is improving the efficiency of solar panels to maximize energy capture. Although solar panels are widely deployed today, the fixed-position models commonly used have inherent limitations, as they can only collect sunlight optimally for part of the day. This static positioning restricts the amount of sunlight a panel can harness,

especially during times when the sun is low in the sky. To address this, engineers and researchers are developing innovative solar tracking systems that enable panels to follow the sun's movement, thereby capturing sunlight from optimal angles throughout the day.

Advancing solar tracking technology not only enhances the efficiency of solar energy systems but also accelerates the shift towards clean energy, as mentioned by Zhu et al. (2020). By improving the output and affordability of solar power, we can further encourage its adoption, supporting environmental goals and promoting sustainability. This project contributes to the ongoing efforts to refine solar technology, creating a smarter and more adaptable solar panel system that tracks the sun based on intensity. Such innovations in solar power systems are essential for achieving a cleaner and more sustainable future, offering an energy solution that meets modern needs while protecting the planet for generations to come.

1.2 Problem Statement

Fixed solar panels are widely used in solar energy systems due to their simplicity and lower installation costs. However, Hayat et al. (2018) states they are limited by their static positioning, which prevents them from following the sun's movement throughout the day all year round. As a result, fixed solar panels are unable to maximize their exposure to sunlight, leading to lower efficiency in energy capture. Studies by Islam et al. (2024) indicate that dynamic solar tracking panels can increase energy production about 20% depending on the system and conditions such as geographic location and season. This reduced efficiency impacts the overall energy output, making it challenging to meet higher energy demands in a sustainable way. Developing a solution to enhance solar panel efficiency is crucial for optimizing renewable energy utilization as this is in line with the goals of Sustainable Development Goal

11 (SDG 11) - "Make cities and human settlements inclusive, safe, resilient, and sustainable.", as mentioned by Obaideen et al. (2023).

1.3 Objectives

1. Design and Development of a Solar Tracking Mechanism: Create a mechanical design for a solar panel tracking system that can pivot based on sunlight intensity. This design will integrate sensors, control algorithms, and motorized components to optimize panel positioning.

2. Prototype Construction: Build a functional prototype of the solar tracking system, incorporating all necessary components such as light sensors, control boards, and motorized pivots to simulate real-world application.

3. Testing and Evaluation: Test the prototype under various environmental conditions to compare its performance with fixed solar panels. Measure the increase in energy output and assess the reliability and accuracy of the tracking mechanism.

1.4 Project Scope

The goal is to improve the energy capture of solar panels, ultimately increasing the output compared to fixed solar panels. The project will demonstrate the potential for dynamic solar tracking systems to improve solar energy efficiency, making them a more viable and sustainable option for meeting increasing energy demands.

Boundaries of the project:

- The tracking mechanism will be single-axis due to cost and complexity constraints
- The project will not include large-scale industrial implementation due to budget and production constraints.
- The solar panel used in this project will only be able to generate enough electricity to power certain components which are specifically chosen in the project environment.

Coverage of the project:

- In theory, the system is designed for small- to medium-scale applications, such as residential, commercial rooftops, and floating solar farms on calm water bodies.
- The IoT integration will primarily focus on real-time monitoring using ThingSpeak, an Internet of Things (IoT) platform to collect data from this project.
- The prototype will be tested under controlled conditions with simulated real-world scenarios to evaluate its efficiency.

Limitations of the project:

- The system is limited to areas with consistent sunlight exposure and may not perform optimally under extreme weather conditions (e.g., heavy rain, snow, or storms).
- Initial costs for implementation may still be a factor for some users despite efforts to keep components affordable.
- Battery life and power consumption of the tracking mechanism need to be optimized for extended autonomous operation.

1.5 Brief Methodology

The methodology that is chosen for this project is the Prototyping Model.

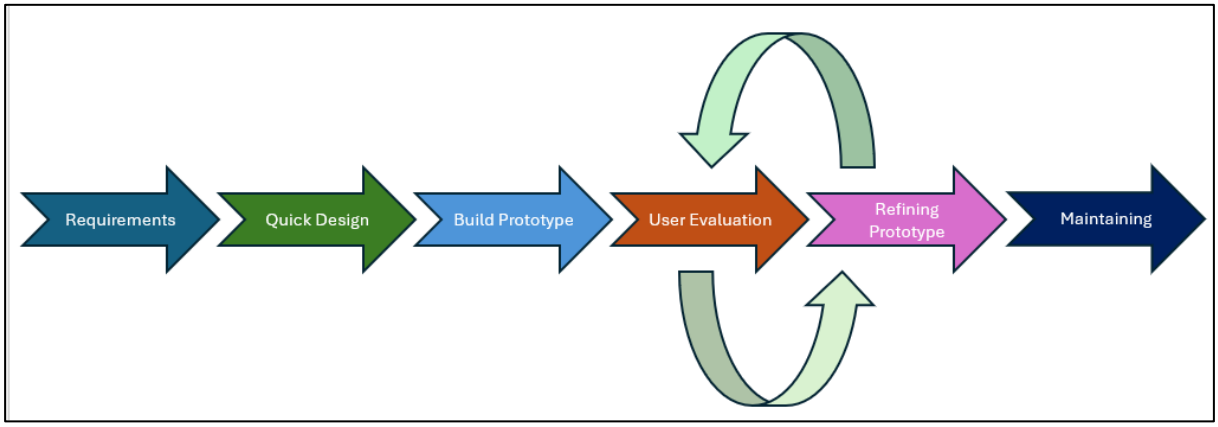


Figure 1 Prototyping Methodology

Choosing the prototyping model as the methodology for this project provides a dynamic, iterative approach that aligns well with the project's goals of innovation and optimization. The prototyping model enables us to develop, test, and refine a functional version of the solar tracking system in stages, allowing for continuous improvement and adaptation based on real-time feedback and performance. This model consists of 6 phases which are Requirements, Quick Design, Build Prototype, User Evaluation, Refining Prototype and Maintaining.

The following are the phases in the Prototyping Methodology:

- Phase 1: Requirements

In this initial phase, project requirements are gathered and analysed to understand the basic functionality, objectives, and user needs of the proposed system. Key requirements for

the solar tracking system, such as tracking accuracy, sensitivity to sunlight intensity, and energy efficiency, are identified.

- Phase 2: Quick Design

Based on the gathered requirements, a preliminary design for the prototype is created and it focuses on essential features and functionalities without diving into full-scale details, allowing for quick initial development.

- Phase 3: Build Prototype

In this phase, the initial prototype is built based on the quick design and this prototype is a working model of the system, albeit limited in features, that demonstrates core functionalities such as sunlight intensity detection and basic panel movement.

- Phase 4: User Evaluation

The prototype is tested in a real or simulated environment to evaluate its performance and functionality, and any feedback is collected on aspects such as tracking accuracy, response time, and energy efficiency. Issues and areas for improvement are identified, providing insights into how the prototype can be enhanced.

- Phase 5: Refining Prototype

This phase often involves multiple iterations, where the prototype is adjusted and improved repeatedly until it meets performance and functional requirements, based on the evaluation earlier.

- Phase 6: Maintaining

After deployment, periodic reviews and maintenance may be conducted to ensure continued efficiency and to address any long-term issues or performance adjustments.

1.6 Significance of the project

- Enhanced Energy Efficiency: By developing a solar tracking system that adjusts to sunlight intensity, this project significantly increases the amount of sunlight captured compared to fixed panels. This improvement in energy efficiency enables higher energy output, making solar power more effective and reliable.
- Contribution to Renewable Energy Advancements: As a step toward optimizing solar panel technology, this project adds valuable research and development to the field of renewable energy. Insights from this project may be applied to larger solar farms, urban settings, or even off-grid applications, helping drive innovation in renewable energy systems.

1.7 Project Schedule

Project schedule consists of a list of project's terminal elements with intended start and finish date. The development and maintenance of project schedule are important as a guide for developer or researchers to keep track on their tasks of project and make sure their project finish on time. This Gantt chart is to show all the activities during the development process in order to ensure that all the activities and events start and finish according to the date.

Figure 2 and 3 below is the Gantt chart for FY1 and FYP2 of the project:

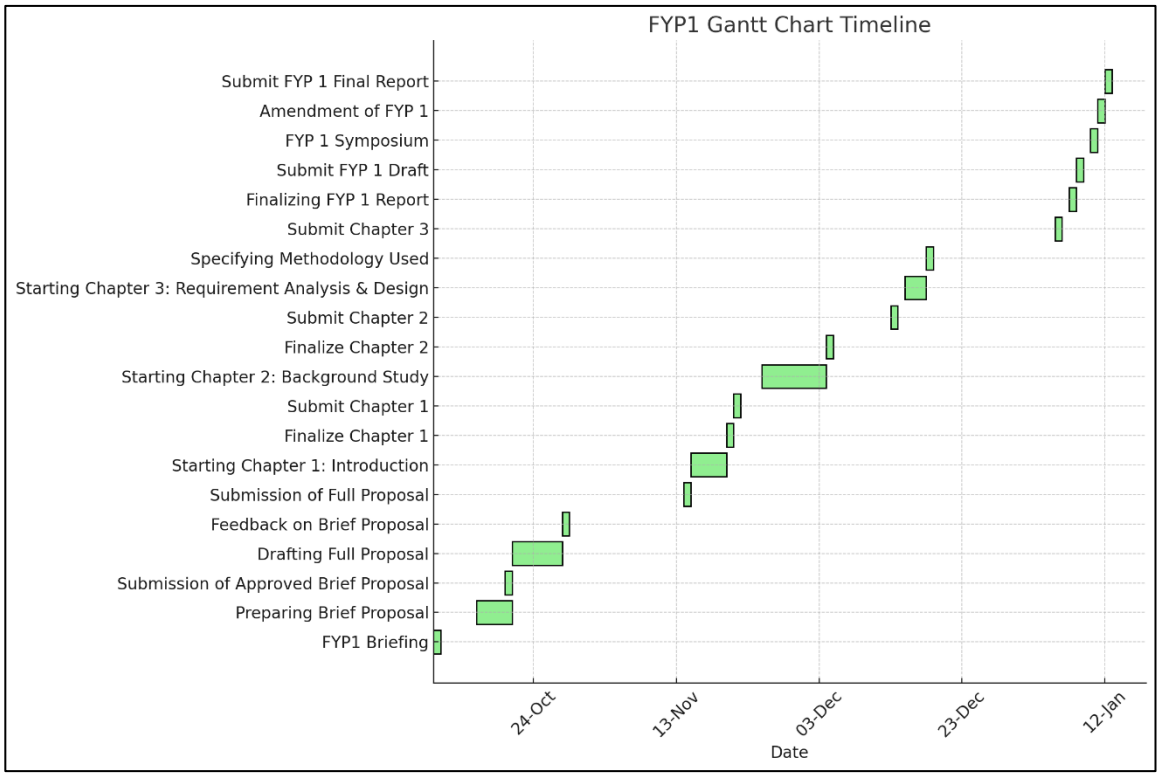


Figure 2 Gantt Chart for FYP1

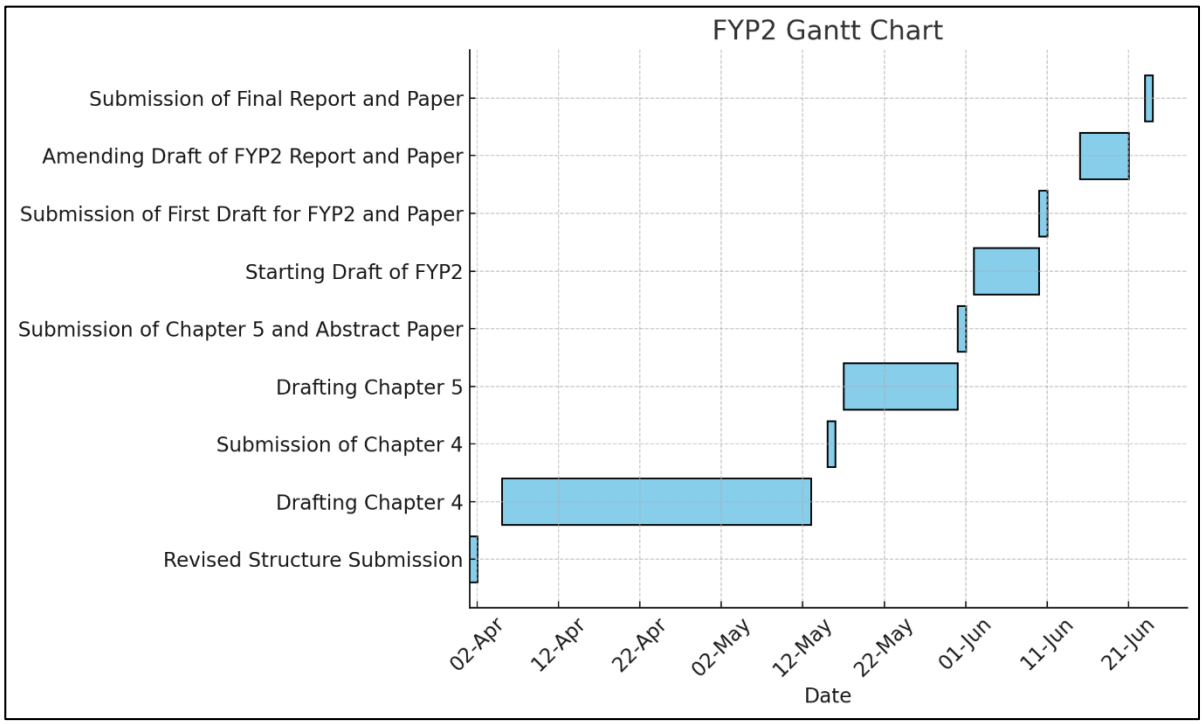


Figure 3 Gantt Chart for FYP2

1.8 Expected Outcome

1. Increased Solar Panel Efficiency: One of the most significant outcomes would be an observable increase in the energy output of solar panels equipped with the tracking system.

2. Data on Energy Gains: Testing and evaluating the prototype will yield quantifiable data on the improvements in energy capture with the tracking system. This data could demonstrate the percentage increase in efficiency, which could be used to support the adoption of solar tracking systems as a standard in the solar energy industry.

3. Increased Adoption of Solar Power: If the project successfully demonstrates the advantages of solar tracking in increasing efficiency and lowering energy costs, it could encourage wider adoption of solar energy.

1.9 Summary of Chapter 1

The goal of this proposed project is to overcome the drawbacks of fixed-position solar panels, which have a lower energy efficiency since they cannot maximise sunlight capture throughout the day. By utilising Internet of Things technology, the proposal suggests a dynamic solar tracking system that maximises energy capture and advances sustainability objectives by reorienting solar panels in reaction to sunshine intensity.

CHAPTER 2: BACKGROUND STUDY

2.1 Introduction

The goal of background study is to give a hindsight on **Adaptive Solar Tracking System Using Internet of Things (IoT).** This means that it will explore existing works to compare their features, advantages and limitations. Also, this will show that the proposed solution will try to improve upon certain aspects of these existing works.

The growing need for renewable energy solutions has made solar power a key focus in the transition to sustainable energy systems, as mentioned by Ray (2019). Solar energy offers significant potential due to its accessibility and environmental benefits, but the efficiency of conventional solar panels remains a crucial factor in optimizing energy generation. Traditional solar panels, which are typically fixed in position, often fail to capture the maximum amount of sunlight throughout the day due to the sun's changing position in the sky. Several studies have examined the efficiency rates of these fixed systems, reporting that they can be significantly lower compared to systems that actively track the sun’s movement.

To address this challenge, solar tracking systems have been developed, which adjust the orientation of solar panels to follow the sun’s trajectory, thereby maximizing sunlight exposure and improving energy generation. While traditional tracking systems offer improved efficiency over fixed panels, they still face limitations such as high costs, mechanical complexity, and limited adaptability, as said by Fkirin et al. (2025). In recent years, the integration of Internet of Things (IoT) technologies has introduced a new dimension to solar tracking systems. IoT-based adaptive tracking systems, which leverage sensors, real-time data, and automated controls, offer a more flexible, efficient, and cost-effective solution for optimizing solar panel performance.

2.2 Background Study

Today's solar technology has far improved than a decade ago thanks to innovation and sustainability efforts. Also, they are more accessible and easier to acquire for consumers nowadays, with variations that vary depending on each use case. These use cases involve many functions and ways to operate, but they all serve the same purpose, to generate renewable energy.

2.3 Reviews on Existing System

This section reviews existing systems that have existed in the solar panel industry and each unique spin on it. These systems have been chosen for their relevance to the original goals of the proposed title project. By comparing their features, strengths and weaknesses, this review established the foundation for comparison and highlights the differences between the proposed system and existing system.

2.3.1 Sun Tracking Technology in Solar photovoltaic (PV) System

This system explores advancements in solar energy harnessing through tracking systems that optimize the alignment of solar panels with the sun's trajectory. This focuses on a new concept, which is Solar PV systems and an overview of solar cells, their materials, and classifications of PV systems. Also, a new mechanism in introduced by Awasthi et al. (2020) to move the solar panel is introduced which is the Dual-Axis Tracking Systems, which allows more angle to rotate.

Advantages:

- Efficiency Improvements: Dual-axis solar tracking systems improve energy collection by dynamically adjusting the angle of solar panels, resulting in a significant increase in energy capture compared to fixed systems.
- Increased Solar Energy Output: Dual-axis systems show a 34% energy production improvement over fixed panels
- Flexibility: Designed to adapt to different environments and weather conditions, ensuring better utilization of available sunlight.

Disadvantages:

- Higher Costs: Dual-axis tracking systems are more expensive to install and maintain due to their complexity and the need for additional components, such as motors and sensors.
- Energy Consumption: These systems require energy to operate the tracking mechanisms, slightly offsetting the gains from increased energy production.
- Maintenance Demands: The presence of moving parts increases the likelihood of mechanical wear, requiring periodic maintenance.

2.3.2 Flexible Self-Charged Power Panel

This study is about a flexible self-charged power panel designed to harvest and store both solar and mechanical energy. The panel integrates amorphous silicon (a-Si) solar cells, triboelectric nanogenerators (TENGs), and lithium-ion batteries into a single, compact device. The study highlights the potential of hybrid energy solutions for sustainable, portable power generation, according to W et al. (2019).

Advantages:

- Dual Energy Harvesting: Simultaneous collection of solar and mechanical energy ensures reliable power generation, even in low-light or nighttime conditions.
- Energy Storage Integration: Direct storage of generated energy into lithium-ion batteries minimizes energy loss and enhances efficiency.
- Flexibility and Portability:The lightweight and bendable structure makes it suitable for wearable electronics and irregular surfaces like clothing, hats, or backpacks.

Disadvantages:

- Complexity: Combining solar cells, TENGs, and energy storage increases the design and fabrication complexity compared to standalone solutions.
- **Cost**: Advanced materials like amorphous silicon solar cells, ETFE films, and the integration process may raise production costs.
- **Energy Output Limitations**: While efficient, the energy output may not be sufficient for high-power applications or devices with high energy demands.

2.3.3 Automatic Sun Tracking for the Enhancement of Efficiency of Solar Energy System

This study discusses the development of a single-axis automatic sun tracking system to optimize solar energy collection. It also highlights the limitations of fixed solar panels and presents a tracking system that rotates solar panels to maintain perpendicular alignment with the sun throughout the day. The proposed system uses a gear train and simple electronic components to enhance energy efficiency, aiming to reduce complexity and mechanical failures compared to existing tracking solutions by P. Sahu et al. (2019).

Advantages:

- **Increased Efficiency**: The system captures up to 25-30% more energy compared to fixed solar panels.
- **Cost-Effectiveness**: Utilizes simple mechanical and electronic components, reducing overall complexity and manufacturing costs.
- **Reliability**: The design minimizes failure-prone parts, such as sensors and microcontrollers, present in more sophisticated systems.

Disadvantages:

- **Limited Tracking**: The single-axis design does not consider azimuth-altitude angles, leading to some energy loss compared to dual-axis systems.
- **Mechanical Wear**: Moving parts, such as gear trains and motors, require regular maintenance, potentially increasing long-term operational costs.
- **Initial Setup Complexity**: Retrofitting existing fixed panels requires modifications that may be challenging for some installations.

2.3.4 Simple Tracking System to Monitor Solar PV Panels

This system presents the design, testing, and optimization of a simple solar tracking system using light-dependent resistors (LDRs). The system focuses on enhancing photovoltaic panel efficiency by maintaining optimal alignment with the sun. According to Bentaher et al. (2014), it evaluates the performance of the tracking system through numerical and experimental approaches, emphasizing the influence of sensor alignment on precision.

Advantages:

- **Enhanced Efficiency**: Improves solar panel energy output by optimizing alignment with the sun, potentially increasing power generation by up to 50%.
- **Simplicity**: The use of basic components, such as LDRs and simple electrical circuits, reduces system complexity and cost.
- **Customizable Design**: The system allows for optimization based on the angle between photoresistors, enhancing accuracy in specific conditions.

Disadvantages:

- **Limited Accuracy**: The system's precision is affected by environmental factors like temperature, dust, and humidity, which can impact LDR performance.
- **Single-Axis Tracking**: The system does not account for altitude adjustments, limiting its effectiveness compared to dual-axis trackers.
- **Maintenance Needs**: The LDRs and motors require periodic maintenance to ensure consistent operation

2.3.5 Development and Testing of a Single-Axis Photovoltaic Sun Tracker through the Internet of Things

This research highlights how solar tracking systems can significantly enhance the efficiency of photovoltaic systems by continuously adjusting their position to follow the sun. By integrating these systems into buildings and homes, users can better meet their energy needs. The study introduces a unique "open loop" solar tracker that operates through the Firebase web service, showcasing the potential of modern technology in renewable energy solutions as mentioned Gutiérrez et al. (2020).

Advantages:

- **Real-Time Monitoring**: Allows for constant monitoring of the system's performance, which enables tracking the energy output in real-time through platforms like Firebase .
- **Automatic Operation**: The algorithm used in the control system allows the tracker to operate automatically anywhere in the world, enhancing its usability .
- **Suitability for Small Installations**: The inclined axis design makes it particularly suitable for small sun-tracking applications, which is useful for residential buildings.

Disadvantages:

- **Dependence on Wi-Fi**: The system requires a Wi-Fi connection for optimal operation, which could be a limitation for large-scale applications or in areas with poor connectivity, as a loss of signal would affect energy generation.
- **Structural Costs**: There is an identified need for improvement in the construction of the supporting structure for the photovoltaic modules, particularly in terms of cost reduction. This may require redesigning to maintain performance while reducing expenses, .

- **Measurement Uncertainty**: The study noted higher uncertainty in measurements during the early morning and late afternoon hours due to low irradiance levels and rapid changes in irradiance, which could affect performance assessments.

2.4 Comparison Between Existing Systems

The systems and study reviewed in section 2.3 highlights different approaches to improving solar panel's efficiency and increase the sustainability of it. It can be clearly seen that there are many strengths and weaknesses of each of them in their own perspective. This section however, comparers these systems across specific parameters such as tools used, cost, efficiency rate and practical applicability.

2.4.1 General Observation

After reviewing some articles, a general observation can be made for commonly used solar panels nowadays and while they are fit for the task, they may be improved for better efficiency and cost effective. Some of the observations that can be made are:

- **Environmental Impact**: Solar panels harness renewable energy, contributing to reduced greenhouse gas emissions and less reliance on fossil fuels. This makes them a sustainable energy solution compared to traditional non-renewable sources.
- **Efficiency Limitations**: Traditional fixed solar panels have limited efficiency because they are stationary and cannot always align with the sun's optimal angle. This reduces the amount of energy they can capture throughout the day and across seasons.
- **Cost and Accessibility**: The initial installation costs of solar panels, especially for larger setups, can be high. However, these costs have been decreasing, improving accessibility and long-term sustainability.

2.4.2 Comparative Analysis

Table 1 below shows the differences between existing systems and what makes them valuable to be a source of inspiration.

Table 1 Comparison between Existing Systems

System	Tools/Technologies	Advantages	Disadvantages	Usefulness
Sun Tracking Technology In Solar photovoltaic (PV) System	Actuators and Motors, Control Systems, Sensors, Image Processing Technology, Microcontrollers	Can adjust to the sun's position throughout the day and across seasons, maximizing solar energy capture	Increased operational costs and complexity in design and control mechanisms	Enhance the energy output of solar PV installations
Flexible Self-Charged Power Panel	Magnetron Sputtering, Plasma-Enhanced Chemical Vapor Deposition (PECVD), Thermal Evaporation Coating, Ethylene-Tetra-Fluoro-Ethylene (ETFE), Triboelectric Nanogenerator (TENG), Lithium-Ion Battery (Li-ion Battery)	Highly versatile, can harvest both solar and mechanical energy. Also allows for continuous power generation even in varying environmental conditions	Increased complexity in manufacturing. Potential challenges in maintaining the performance of each individual component	Useful for powering wearable electronic devices. Able to harvest energy from everyday activities, such as walking or exposure to sunlight

Automatic Sun Tracking for the Enhancement of Efficiency of Solar Energy System	Gear Train Mechanism, Stepper Motor, Light Dependent Resistor (LDR), Electrical Circuit Components, Helical Spring, Battery Storage, Mechanical Stoppers	Increase energy efficiency by ensuring the solar panel remains perpendicular to the sun's rays	Frequent maintenance due to its moving parts (such as gears and motors)	Enhancing solar energy collection in areas where fixed panels are inefficient.
Simple Tracking System To Monitor Solar PV Panels	Light-Dependent Resistors (LDRs), Electrical Circuit, DC Motors, Sensor Arrangement, Control System, Two-Axis Mechanism	Affordable, uses inexpensive components like light-dependent resistors (LDRs) and basic electrical circuits	Limited precision, environmental factors like dust, humidity, and temperature can affect the performance.	Increase the energy output of solar panels by optimizing their alignment with the sun throughout the day.
Development and Testing of a Single-Axis Photovoltaic Sun Tracker through the Internet of Things	Photovoltaic (PV) Modules, Microcontroller, Photosensors, Firebase, Development Environment	Affordable, increase energy production while also small in size.	Structural costs overall is high, Measurement uncertainty due to scale of project	Able to fit in smaller space while also improving electricity production.

2.4.3 Insights from Comparison

1. Sun Tracking is Crucial for Efficiency:

- All systems involving solar energy benefit significantly from sun tracking mechanisms.
- Tracking systems optimize energy capture by maximizing the surface area exposed to direct sunlight, leading to higher energy output.

2. IoT is a Key Enabler:

- The integration of IoT (Internet of Things) technologies is evident in many of the systems.
- IoT allows for remote monitoring, control, and data analysis, enhancing system efficiency and maintenance.

3. Trade-off Between Complexity and Efficiency:

- More complex systems (like adaptive tracking systems) generally offer higher efficiency but also increase operational costs and maintenance requirements.
- Simple systems, while less efficient, are often more cost-effective and easier to maintain.

4. Material Science Plays a Vital Role:

- Advancements in materials science are crucial for improving the performance of solar cells and flexible panels.
- Materials like ETFE, TENG, and various coating techniques contribute to increased efficiency and durability.

2.5 Comparison between the Proposed System and the Existing System

This section compares the proposed **Adaptive Solar Tracking System Using Internet of Things (IoT)** with the existing systems reviewed in Section 2.3. The comparison focuses on key factors such as cost, tools used, and efficiency rate, demonstrating how the proposed system bridges gaps in current solutions

2.5.1 Key Features of the Proposed System

The proposed system is designed to address the challenges of affordability, adaptability and efficiency in solar panels. Some of its key features include:

1) IoT Integration:

- Real-time monitoring of solar panel performance through IoT-enabled sensors and cloud platform.
- Remote control and adjustment of the solar tracking system via a mobile app or web interface.

2) Adaptive Tracking:

- Adaptive algorithms to adjust to weather changes (e.g., cloud cover) and maximize efficiency.

3) Energy Data Analytics:

- Collection and analysis of energy production data to optimize system performance over time.

4) Smart Sensors:

- Integration of light intensity sensors (LDRs) and environmental sensors (temperature, humidity, etc.) for enhanced tracking precision.

5) Automated Control:

- Use of microcontrollers (e.g., Arduino, Raspberry Pi, or ESP32) for controlling stepper motors and actuators.
- Automated reorientation of panels at the start and end of the day or during extreme weather conditions.

6) Environmental Adaptation:

- Adjustments for seasonal variations and geographic location based on sensor.
- Can stay afloat on water.

2.5.2 Comparative Analysis

The following table illustrates how the proposed system improves upon the limitations of existing solutions:

Table 2 Comparative Analysis

Criteria	Existing Systems	Proposed System
Cost	High-end systems (e.g, Sun Tracking Technology In Solar photovoltaic (PV) System) are expensive since the parts needed are expensive	Balances affordability and functionality with low-cost Arduino Board, sensors, solar panels and supported motors to be used
Tools Used	Light-Dependent Resistors (LDRs), Electrical Circuit, DC Motors, Sensor Arrangement, Control System, Two-Axis Mechanism	Arduino Board, Light Sensors, Servo or DC Motors, Motor Driver Module, Solar Panel, Power Supply/Battery Pack, Resistors and Capacitors, Breadboard and Jumper Wires
Efficiency Rate	Improve energy capture by 10–20% compared to fixed panels.	Improve energy capture by **25–40%** compared to fixed solar panels.

2.5.3 Enhanced Comparative Insights

- Cost: Compared to other tracking systems that may use complex or proprietary controllers, Arduino-based setups often deliver comparable performance at a fraction of the cost due to the price of microcontrollers such as Arduino being cheaper. The proposed system can be used for more people if it is cheaper to produce.

- Tools used: The tools used in the proposed system can be bought readily available from physical stores or online shops, with easy-to-use manual. For the existing system, it requires external tool such as a welder to weld the components together, and industrial grade solar panels which is not readily made available to consumers.

- Efficiency Rate: The efficiency rate between a solar tracking system with Arduino and other solar tracking systems is between 20% to 30% if compared with the tools cost, setup costs, installation and overall maintenance.

2.5.4 Advantages of Proposed System

- Affordability: The proposed system is designed with consumer grade materials and tools, which are made available at a cheaper cost than that of a an industrial grade materials.
- Scalability: The components within an Arduino setup such as the proposed system are interchangeable and easy to upgrade or swap with.
- Enhanced usage: The proposed system is also made to be used in a water of bed such as rivers or lakes. This is because all those spaces are empty real estate which can be used to generate electricity.

2.5.4 Addressing Key Challenges

- Cost Barriers**:** The expensive cost for consumers to implement a solar panel solution for their homes are the gap that needs to be bridged for sustainability.
- Geographical Location**:** Malaysia is located near the equator, receiving an average of 4-6 hours of direct sunlight daily, which is ideal for solar energy generation.
- Placement**:** The precise placement of solar panels must be considered for maximum efficiency

2.6 Tools and Technology Used In The Development Of The Proposed System

The proposed **Adaptive Solar Tracking System Using Internet of Things (IoT)** relies on a combination of hardware and software technologies to ensure affordability, scalability, and efficiency. This section details the tools and technologies used, along with their roles and justifications for inclusion in the system.

2.6.1 Hardware Components

1. Arduino Board

- Component: Arduino Uno or Arduino Nano
- Purpose: Serves as the microcontroller to process sensor data and control the motors based on sunlight intensity.

2. Light Sensors

- Component: LDRs (Light Dependent Resistors) or photodiodes
- Purpose: Measure sunlight intensity. You'll need at least two LDRs positioned on opposite sides of the solar panel to detect light direction and intensity differences for tracking the sun.

3. Servo Motors or DC Motors with Motor Driver

- Component: Servo motors (SG90 or MG996R for small to medium panels) or DC motors with an H-bridge motor driver (like L298N)

- Purpose: Rotate the solar panel to follow the sun's movement. Servos are ideal for smaller models as they allow precise angle control. For larger panels, DC motors with a motor driver are suitable.

4. Motor Driver Module (if using DC motors)

- Component: L298N or L293D Motor Driver Module
- Purpose: Controls the DC motors' direction and speed to adjust the solar panel's position according to sunlight direction.

5. Solar Panel

- Component: Small solar panel (for prototyping purposes)
- Purpose: Acts as the main energy-gathering component. You can use a small panel for prototyping to test the tracking system.

6. Power Supply/Battery Pack

- Component: 12V or 9V battery pack (depending on motor and Arduino requirements)
- Purpose: Provides power to the Arduino, motors, and other components. For portability, you may also consider a rechargeable battery pack.

7. Mounting Frame

- Component: Metal or wood frame (adjustable platform)
- Purpose: Holds the solar panel securely while allowing movement for tracking. This frame should support rotation based on motor movements and be sturdy enough to handle the prototype.

8. Resistors and Capacitors

- Component: Resistors (typically 10kΩ for LDRs) and capacitors (optional for signal stability)
- Purpose: Resistors help with LDR circuit stability, while capacitors can smooth signal noise if necessary.

9. Breadboard and Jumper Wires

- Component: Breadboard and jumper wires for prototyping
- Purpose: Allows for easy connections between the Arduino, sensors, and motors without soldering.

10. Voltage Regulator (if required)

- Component: LM7805 or similar (if power regulation is needed)

- Purpose: Ensures a stable 5V output for the Arduino if your main power source is higher than 5V.

2.6.2 Software Components

1. Arduino Code and Libraries

- Component: Arduino IDE (software environment) with Servo or Motor libraries (if using servo motors)
- Purpose: Programming environment to write and upload the code controlling sensor data reading and motor actions based on light intensity.

2.7 Summary of Chapter 2

This chapter provides a comprehensive literature review on solar tracking systems, focusing on their evolution and potential for optimization through IoT integration. It examines current solar tracking technologies, such as single-axis trackers, hybrid energy panels, and dual-axis systems, emphasising both their advantages in terms of efficiency and versatility as well as their drawbacks, such as cost and mechanical complexity. A comparative study highlights the ways in which these systems differ in terms of energy capture, usefulness, and technological sophistication, highlighting the contribution of IoT to improving functionality. By discussing efficiency constraints in fixed panels and contrasting current technologies, the chapter establishes the groundwork for the suggested Adaptive Solar Tracking System.

The chapter also assesses the innovations of the suggested system, including adaptive algorithms, real-time IoT monitoring, and affordable hardware integration (e.g., Arduino-based

controllers). These characteristics fill up the gaps in energy efficiency, cost, and adaptability, especially for areas with substantial solar potential. The chapter highlights the benefits of the suggested system, which strikes a balance between high performance, scalability, and affordability, hence representing a breakthrough in the solar panel sector, through the examination of tools, technologies, and efficiency measurements.

CHAPTER 3: REQUIREMENT ANALYSIS AND DESIGN

3.1 Introduction

This chapter will focus more on the development methodology, the requirement analysis and design implemented to develop the proposed system. The methodology adopted in this proposed system provide the fundamental guideline and direction to the development process. It consists of several subsections that describe in more detail about the chosen development methodology in the previous which is the introduction chapter. This chapter also will include the details on analysis and design on the hardware and software of this project.

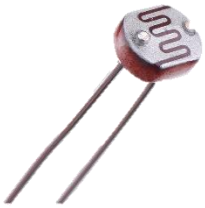
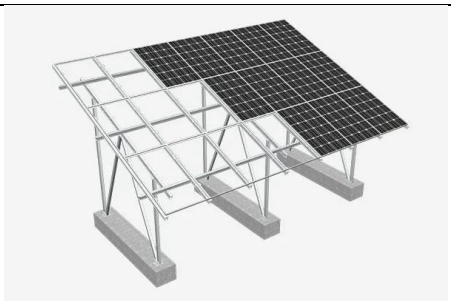
3.2 Requirement and System Analysis

This section outlines the hardware and software requirements for the Adaptive Solar Tracking System. A comprehensive analysis was performed to identify the necessary components and ensure the system's compatibility, efficiency, and scalability. The system requirements were divided into hardware and software components, as detailed below.

3.2.1 Hardware Component

Specifically, this section focuses on components that provide reliable and precise solar tracking while ensuring cost-efficiency and ease of integration with one another. Each component was carefully analysed based on its functionality and role within the system. Compatibility was kept in mind when choosing these components. Table 3 below shows the hardware that will be used for this project.

Table 3 Hardware Component

Hardware	Image	Quantity	Usage
Arduino Nano 33 IoT		1	Microcontroller for data processing and motor control
Light Dependent Resistors		6	Detect sunlight intensity and direction
SG90 Servo Motor		2	Rotates solar panel to optimize sunlight exposure
Solar Panel		1	Converts sunlight into electrical energy
Solar Mount		1	Provides structural support for panel rotation

CN3065 Mini Solar Charger Module		1	Regulates and stores solar energy. Also, distributes the energy efficiently and with the appropriate wattage.
Rechargeable Batteries		1	To store power generated from the solar panels. Also, powers the system when sunlight is unavailable
Jumper Cables		40	Connects all the components together.

The components listed in Table 3 are the essentials for this project to achieve completion. The 'Arduino Nano 33 IoT' is the brain of this project and the 'CN3065 Mini Solar Charger Module' will be in control of energy conversion from the solar panels to the batteries and other appliances. The Light Dependent Resistors detects sunlight intensity and from there, the G995 Servo Motor will move the Solar Mount towards the direction of sunlight that has the highest intensity.

3.2.2 Software Component

The software requirements focus on the implementation of algorithms, IoT connectivity, and the user interface for remote monitoring and control. The software system is designed to integrate seamlessly with the hardware to enable real-time solar tracking and data visualization. Below are the components to be used.

Table 4 Software Component

Software	Specification	Purpose
Integrated Development Environment (IDE)	Arduino IDE	Code development and deployment.
Programming Language	C++	Embedded system logic for solar tracking.
Operating System	Windows	A platform to run both coding and testing environment.
IoT/Cloud platform	ThingSpeak	Real-time monitoring and data visualization.

3.3 System Design

The Adaptive Solar Tracking System's structural and functional elements are the main emphasis of this section. It guarantees that every part functions as a whole to provide the best possible solar tracking and energy management. A system flowchart that describes the general functioning and user interface design is included in this section to guarantee a seamless connection with the IoT platform.

3.3.1 System Flowchart

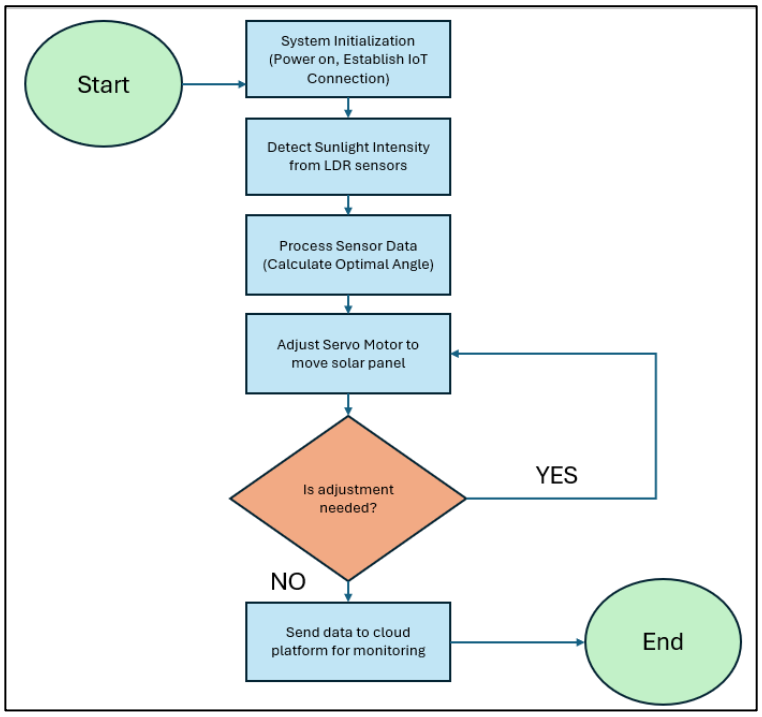


Figure 4 System Flowchart

Based on the flowchart above, the solar panel will move accordingly to sunlight's intensity. When the LDR sensors detects the highest sunlight intensity, the Arduino Nano 33 IoT will read that data and move the servo motors accordingly. Detailed descriptions are as below:

1) Initialize System:

- Power on the Arduino Nano 33 IoT.
- Connect to ThingSpeak for real-time monitoring.

2) Read LDR Sensor Data:

- Compare intensity readings from all LDRs.
- Identify the direction with the highest intensity.

3) Control Servo Motor Movement:

- Adjust the solar panel to align with the detected sunlight direction.
- Repeat periodically for continuous tracking.

4) Update IoT Dashboard:

- Send data (sunlight intensity, panel position) to ThingSpeak.
- Store historical performance logs for efficiency analysis.

5) Check status input of power:

- If input is low, rotate the solar to gain maximum sunlight.
- If input is optimal, maintain solar position.

6) End Process / Repeat:

- The loop continues throughout daylight hours for maximum efficiency.

3.3.2 User Interface Design

For the user interface design, the cloud IoT platform ThingSpeak will be used to monitor sunlight intensity and any additional readings. The figure below shows the general design of the interface for the proposed system.

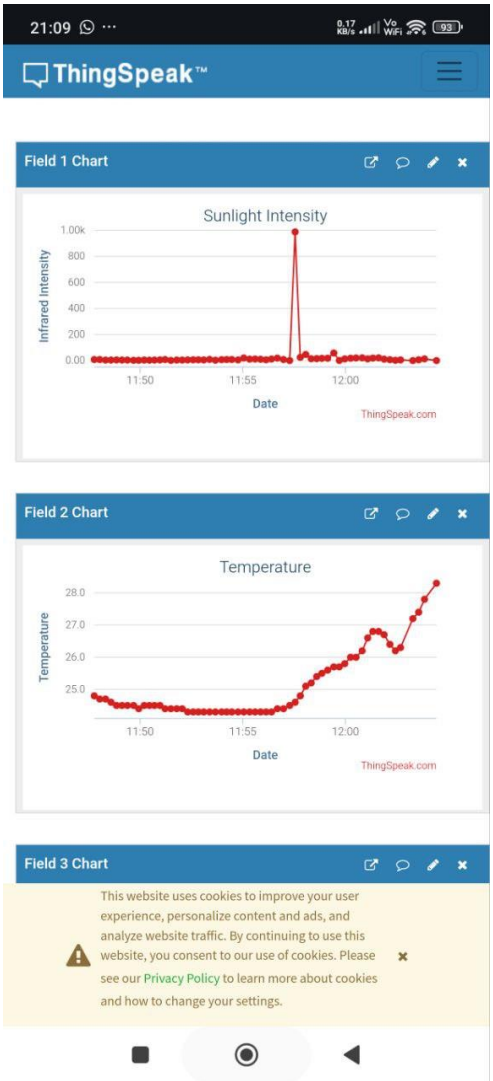


Figure 5 Screenshot of User Interface

Detailed description of the user interface are stated below:

1) Real-time data visualization

- Displays sunlight intensity readings from multiple LDRs.
- Shows current energy gain of solar panel.

2) Temperature status

- Shows whether the components are getting too hot or in normal temperature.

3) Historical energy tracking:

- Logs efficiency of solar panel over time.

3.4 Summary of Chapter 3

Based on this chapter's contents, Prototyping Model is considered as the most suitable methodology to develop the proposed system. There are six main phases in the Prototyping Model which are Requirements, Quick Design, Building a Prototype, User Evaluation, Refining Prototype and Maintaining

CHAPTER 4: IMPLEMENTATION AND TESTING

4.1 Introduction

System implementation is the process that describes how the system is developed and ensures that the system is fully operational according to the criteria set as well as meets the required quality standard. The testing process is essential to detect any error or defects in the system so that the correction can be done. If the testing is not donc, the developed system will be incomplete because the resulting project may not meet the conditions that are appropriate to satisfy the user.

The tools used in developing **Adaptive Solar Tracking System Using Internet of Things (IoT)** are a mix of hardware and software components, with hardware being the majority. The hardware used are:

1. Arduino Nano 33 IoT
2. Cn3065 Mini Solar Charger Module
3. Solar Cell 5V 250mA (1.25W)
4. Light Dependent Resistor
5. MG995 Metal 360 Continuous Servo
6. 18650 3.7v Rechargeable Battery
7. Jumper wires
8. USB Cables

On the other hand, the software components used are:

1. Open-source Arduino Software (IDE)

4.2 System Implementation

Arduino Nano IoT 33 IoT is a small, powerful microcontroller board with integrated Wi-Fi and Bluetooth connectivity which makes it ideal to be the brain or the main component of the system. In order for it to be able to run and control the components, the code must be uploaded from a source such as computers and laptops. The software 'Arduino IDE' is installed on a laptop and a Micro USB cable is used to connect the Arduino board to the laptop.

The Cn3065 Mini Solar Charger Module is a small electronic circuit board designed to charge a single-cell lithium-ion or lithium-polymer battery using a solar panel as its power source. This is to be connected to the solar panel and a power source such as the rechargeable battery.

The solar panel used is small in size that can generate up to 1.25 Watts of power, ideally providing an output of 5 volts and 250 milliamperes in bright sunlight. It's connected to the charger module so that the voltage can be regulated.

The Light Dependent Resistor (LDR) is a passive component that acts like a resistor that "sees" light. The brighter the light, the lower its resistance, and the dimmer the light, the higher its resistance. This light-sensitive resistance variation makes it useful for detecting and responding to changes in light intensity. Because of this, the LDR will be attached to two ends of the solar panel, representing sunrise and sunfall. Then, it is connected to the Arduino board via breadboard. This is to ensure the data received from the LDR can be transmitted to the servo motor.

The SG90 servo motor is a widely popular and very small (micro) servo motor, often used in hobby electronics, robotics, and educational projects. It's a type of motor that allows for precise control over its rotational position. Unlike a continuous rotation DC motor, a servo

can be commanded to move to and hold a specific angle. This will be attached to the solar panel so that the motor can move it accordingly to the data from LDR.

The 18650 3.7V rechargeable battery is a versatile and widely used lithium-ion cell known for its good energy density and standardized size, making it a popular power source for numerous portable applications. It is attached to the solar charger so that it may charge via the energy collected from the solar panel.

4.3 Prototype Development

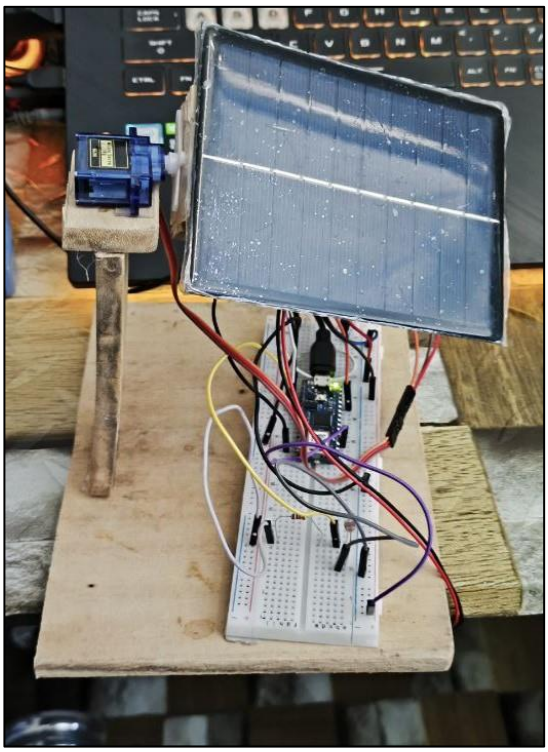


Figure 6 Prototype model

Figure 5 above shows the prototype of Adaptive Solar Tracking System Using Internet of Things (IoT). In this project, there are several phases of the development which are circuitry set-up and prototype modelling. The main components used in this project are the Arduino Nano 33 IoT, Servo Motor, Light Dependent Resistors and a solar panel.

4.4 Prototype Programming

Below is the pseudocode of the actual code used in the completion of this prototype.

```
BEGIN
  Initialize light sensor 1 on analog pin A0
```

```
Initialize light sensor 2 on analog pin A1
Initialize servo motor on digital pin 9
Set initial servo angle to 90 (center)

FUNCTION moveServoSmooth(targetAngle):
  IF targetAngle > currentAngle THEN
    FOR angle FROM currentAngle TO targetAngle STEP 1:
      Rotate servo to angle
      Delay for smooth movement
    END FOR
  ELSE IF targetAngle < currentAngle THEN
    FOR angle FROM currentAngle TO targetAngle STEP -1:
      Rotate servo to angle
      Delay for smooth movement
    END FOR
  END IF
  Set currentAngle to targetAngle
END FUNCTION

LOOP FOREVER:

  Read light level from sensor 1 (value1)
  Read light level from sensor 2 (value2)

  Display value1 and value2 on serial monitor

  IF value1 OR value2 > lightThreshold THEN
    Set lightPresent to TRUE
  ELSE
    Set lightPresent to FALSE
  END IF
```

```
    IF lightPresent is TRUE THEN
      Set leftAngle to 45 degrees
      Set rightAngle to 135 degrees
    ELSE
      Set leftAngle to 75 degrees
      Set rightAngle to 105 degrees
    END IF

    IF value1 > value2 + threshold THEN
      Set targetAngle to leftAngle
    ELSE IF value2 > value1 + threshold THEN
      Set targetAngle to rightAngle
    ELSE
      Set targetAngle to centerAngle (90)
    END IF
    Call moveServoSmooth(targetAngle)
    Wait 500 milliseconds
  END LOOP
END
```

4.5 Prototype Testing

For the testing, 2 setups are prepared, one with a static solar panel and one with a dynamic solar tracking panel. The static solar panel is simply placed on a stand while the dynamic solar panel is implementing IoT to move it according to the sun's intensity. Each of these setups are connected to the 'Cn3065 Mini Solar Charger Module' which regulates the voltage generated so that it can charge the '18650 3.7v Li-Ion Rechargeable Battery'. Below is the table with results obtained from the testing.

Table 5 Static Solar Panel Efficiency

Time	Battery Voltage (V)	Battery level % (~)
08:00	3.65	5
09:00	3.66	5
10:00	3.69	10
11:00	3.69	10
12:00	3.73	15
13:00	3.77	30
14:00	3.80	40
15:00	3.83	45
16:00	3.85	50
17:00	3.88	60

Table 6 Dynamic Solar Panel Efficiency

Time	Battery Voltage	Battery % (~)
08:00	3.64	5
09:00	3.64	5
10:00	3.68	5
11:00	3.71	15
12:00	3.77	30
13:00	3.84	50
14:00	3.89	60
15:00	3.93	70
16:00	3.97	75
17:00	4.02	85

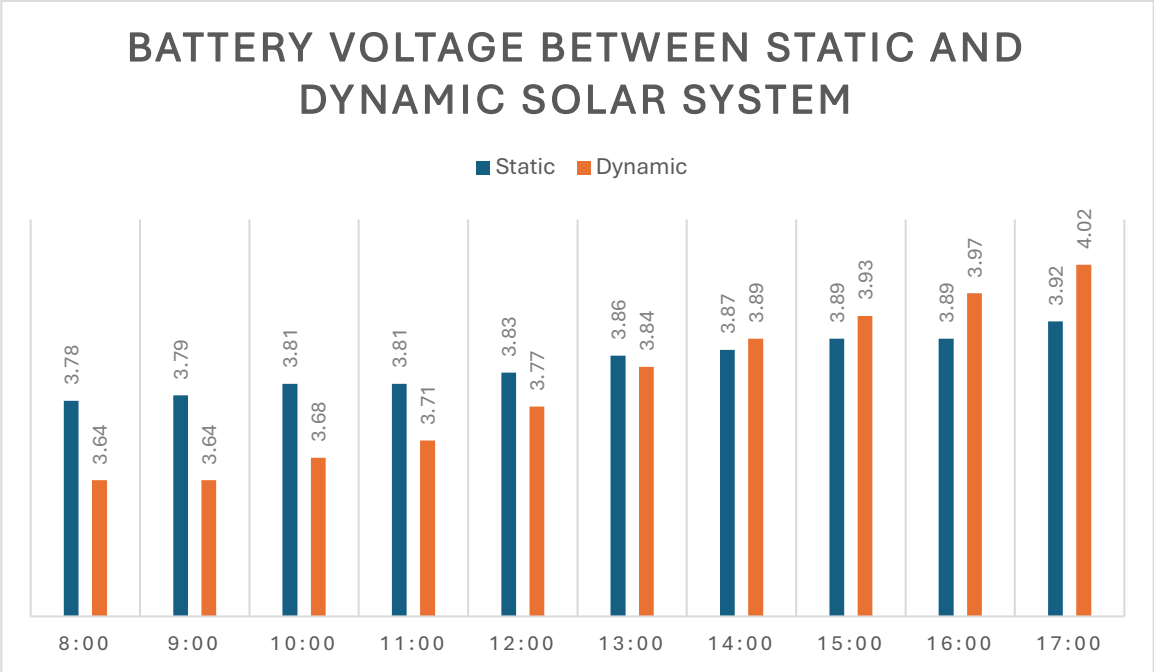


Figure 7 Graph of battery voltage in both setup

Figure 6 shows that the battery charged by the dynamic solar tracking system consistently reaches a higher voltage throughout the day compared to the static system. While the battery in the static setup is a bit higher since the start due to technical limitations, the tracking panel gradually outperforms the static panel as it follows the sun's position. By 5:00 PM, the dynamic setup achieves a noticeably higher voltage, indicating more efficient and consistent energy capture over time. This demonstrates the clear advantage of dynamic tracking in maximizing solar input.

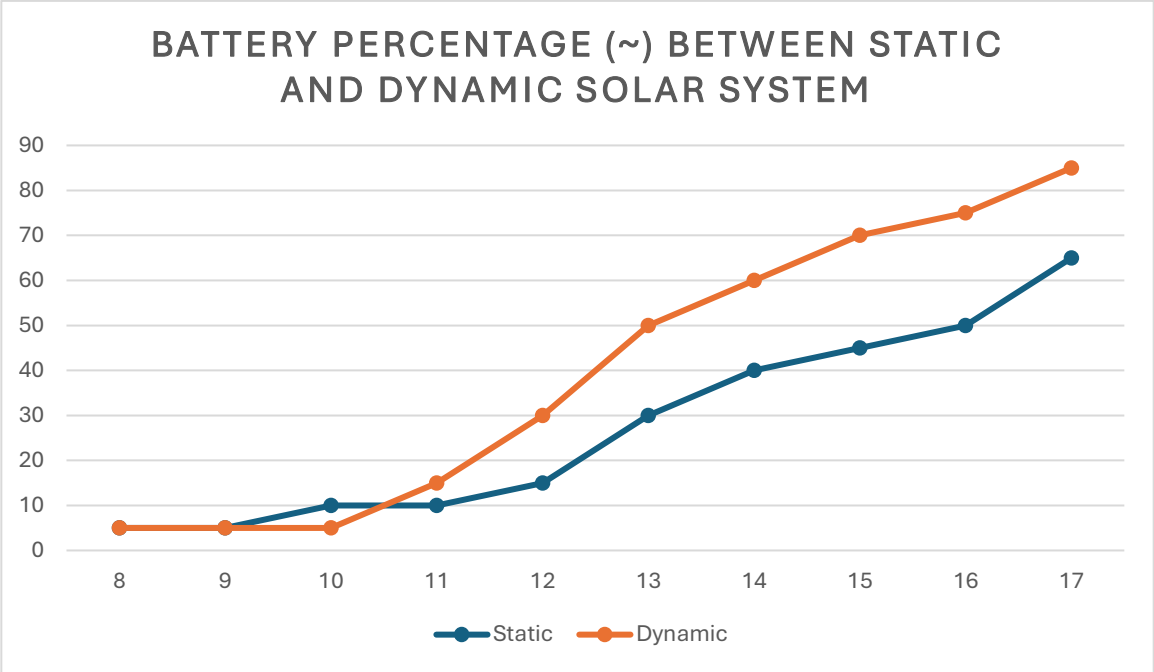


Figure 8 Graph of battery percentage difference

Figure 7 illustrates the estimated battery charge percentage over time. The dynamic solar system shows a steeper and more consistent increase in battery level throughout the day, while the static system progresses more slowly. By the end of the day, the dynamically tracked panel charges the battery to about 85%, compared to only 65% with the static setup. This highlights how tracking sunlight direction improves charging performance, making the dynamic system more effective for renewable energy applications.

4.6.1 Circuit Testing

For overall testing, all the device, sensor and modules need to be re-tested in order to ensure the functionality of the entire component are fully functioned. A set of test cases will be conducted to ensure the user is satisfied with the prototype, as mentioned in table 7 below.

Table 7 Circuit Testing

Test case name	Arduino Nano 33 IoT		
Test Case Description	To ensure Arduino Nano is functioning		
Pre-Condition	1. Arduino IDE needs to be installed on main device. 2. Arduino board needs to be connected via USB cable		
Step	Test Description	Expected Result	Result
1	Connect the Arduino board to any power source, such as laptop or powerbank	The Arduino board will power on, indicated by a light turning on or flashing.	Pass
2	Connect the Arduino board to a laptop via USB cable.	The connected board can be seen in the Arduino IDE	Pass

4.7 Summary

Based this chapter, the implementation is considered complete when the prototype meets the objectives mentioned in Chapter 1. The testing results of the prototype needs to be promising or positive to be considered as functional.

CHAPTER 5: CONCLUSION AND FUTURE NETWORK

5.1ntroduction

This chapter will describe the analysis of the project, limitation of the prototype system and the achievement of the project. There are some limitations during the development process of this project due to resource and the technical problems. Therefore, there are also suggestions on how to improve the prototype system in the near future.

5.2 Objective Achievement

The Adaptive Solar Tracking System Using Internet of Things (IoT) has been developed to achieve the objectives that has been stated in Chapter 1. Table 8 shows the objectives and achievements in this prototype system.

Table 8 Objectives Achieved

Objective	Achievement
Design and Development of a Solar Tracking Mechanism	The system has been created, one which follows the intensity of sunlight and rotates the solar panel accordingly.
Prototype Construction	The prototype has been constructed as plan.
Testing and Evaluation	The system prototype passed all testing and evaluation. It performed as expected and delivers results.

5.3 Future Work

As for the future development of this project, there are several aspects that needs to be improved due to the lack of technical and skill required to make this project perform better. Firstly, the custom-made solar mount could be improved so that it doesn't shake and therefore improving its stability altogether. This is a problem when using larger solar panels, as was done before.

After that, the delay between upload intervals to ThingSpeak could be reduced to improve efficiency and increase data accuracy. This is important to for data analysis and to track whether the solar is functioning at optimal efficiency.

Next, the limited battery capacity of the Li-Ion battery could be a limiting factor since there are many components running on it. Adding more cells or increasing the battery capacity of each cell could be a way to improve.

The last future works are the Wi-Fi reliability for the Arduino Nano 33 IoT to be able to connect to the Internet. Since solar panels are usually placed on higher elevation places or places with less people, the Wi-Fi coverage may be limited. A stronger antenna or specialized component dedicated to improving connection could be implemented to ensure the Arduino board has clear and stable connection.

5.4 Summary

This chapter discusses the review of the development process and the achievement of the Adaptive Solar Tracking System Using Internet of Things (IoT). Overall, the objectives mentioned in Chapter 1 has been achieved. In conclusion, the developed project can be further improved over time and can be a viable as a product in the future.

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