DESIGN AND IMPLEMENTATION OF A SMART SOLAR TRACKER USING ARDUINO FOR ENHANCED ENERGY EFFICIENCY

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DEDICATION

I dedicate this final year project report to all those who have played an integral role in my academic journey. To my family, whose unwavering support and encouragement have been my pillar of strength throughout my years of study. Your belief in my abilities and the sacrifices you have made are the foundation upon which I stand today. To my friends and classmates, for their camaraderie, motivation, and the countless hours spent together, navigating the challenges and triumphs of our academic pursuits. Your collective spirit has made this journey not only fulfilling but also enjoyable. To my professors and mentors, whose guidance and expertise have shaped my intellectual growth and expanded my horizons. Your dedication to teaching and willingness to go above and beyond in sharing knowledge have been invaluable to my development.

ABSTRACT

In the universe of solar energy systems, the quest for enhanced energy efficiency has led to the design and implementation of a Smart Solar Tracker using Arduino. This innovative solution leverages advanced control mechanisms to optimize solar panel orientation dynamically, addressing the inherent challenges posed by varying climatic conditions. Traditionally, solar trackers have faced limitations in adapting to changing weather patterns, impacting energy capture efficiency. The Smart Solar Tracker, outlined in this study, overcomes these challenges by integrating Arduino-based technology, demonstrating a robust and strong approach to solar tracking. The main result presented in this work showcases the superior performance of the Smart Solar Tracker, consistently delivering high and stable voltage outputs even in adverse weather conditions. In term of costing smart solar tracker is 3 times higher compared to traditional solar tracker whereas in terms of efficiency smart solar tracker using Arduino is 10 times which is 100 percentage more efficient compared to traditional solar tracker. The smart solar tracker using Arduino efficiency output was 68% which is the highest compared to both solar tracker which is 5% and 27% over 5 days of reading the Smart Solar Tracker. Here we show that the implementation of Arduino-based control systems in solar tracking significantly enhances energy efficiency, ensuring consistent power generation across diverse climatic scenarios. This advancement not only underscores the critical role of technology in optimizing renewable energy systems but also positions the Smart Solar Tracker as a promising solution for reliable and resilient solar energy harvesting. The findings presented specifically lead the way for the broader integration of advanced control mechanisms in renewable energy infrastructure, fostering sustainability in the face of environmental variability.

ABSTRAK

Dalam alam semesta sistem tenaga suria, usaha untuk kecekapan tenaga yang dipertingkatkan telah membawa kepada reka bentuk dan pelaksanaan Penjejak Suria Pintar menggunakan Arduino. Penyelesaian inovatif ini memanfaatkan mekanisme kawalan lanjutan untuk mengoptimumkan orientasi panel solar secara dinamik, menangani cabaran yang wujud yang ditimbulkan oleh keadaan iklim yang berbeza-beza. Secara tradisinya, penjejak suria telah menghadapi batasan dalam menyesuaikan diri dengan perubahan cuaca, memberi kesan kepada kecekapan penangkapan tenaga. Penjejak Solar Pintar, yang digariskan dalam kajian ini, mengatasi cabaran ini dengan menyepadukan teknologi berasaskan Arduino, menunjukkan pendekatan yang teguh dan kukuh untuk penjejakan solar. Hasil utama yang dibentangkan dalam kerja ini mempamerkan prestasi unggul Penjejak Solar Pintar, secara konsisten memberikan output voltan tinggi dan stabil walaupun dalam keadaan cuaca buruk. Dari segi kos penjejak solar pintar adalah 3 kali lebih tinggi berbanding penjejak solar tradisional manakala dari segi kecekapan penjejak solar pintar menggunakan Arduino adalah 10 kali ganda iaitu 100 peratus lebih cekap berbanding penjejak solar tradisional. Penjejak solar pintar menggunakan output kecekapan Arduino adalah 68% yang merupakan yang tertinggi berbanding kedua-dua penjejak solar iaitu 5% dan 27% sepanjang 5 hari membaca Penjejak Solar Pintar. Di sini kami menunjukkan bahawa pelaksanaan sistem kawalan berasaskan Arduino dalam penjejakan solar dengan ketara meningkatkan kecekapan tenaga, memastikan penjanaan kuasa yang konsisten merentas pelbagai senario iklim. Kemajuan ini bukan sahaja menekankan peranan penting teknologi dalam mengoptimumkan sistem tenaga boleh diperbaharui tetapi juga meletakkan Penjejak Solar Pintar sebagai penyelesaian yang menjanjikan untuk penuaian tenaga suria yang boleh dipercayai dan berdaya tahan. Penemuan yang dibentangkan secara khusus memimpin jalan untuk penyepaduan yang lebih luas bagi mekanisme kawalan lanjutan dalam infrastruktur tenaga boleh diperbaharui, memupuk kemampanan dalam menghadapi kebolehubahan alam sekitar.

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LIST OF SYMBOLS AND ABBREVIATIONS

m	-	Meter
PV	-	Photovoltaic
W	-	Watt
h	-	Hour
V	-	Voltage

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CHAPTER 1

INTRODUCTION

1.1 Background

Contemporary worldwide is experiencing rising needs for energy daily, despite the ongoing depletion of fossil fuel supplies and increased concern about environmental contamination. It goes without saying that this has spurred mankind to seek creative strategies for creating electricity from ecologically friendly renewable energies such as sunlight and wind energy.

Solar energy are major alternative sources sustainable energy source that has a high potential for conversion into electrical power. Solar energy is a energy which is obtained from the sunlight and transfered to electrical energy. Solar energy is absolutely obtained from sunlight and there will be no enviroment degradation. In this era of technology and disaster to the flora fauna, usage of solar are highyly encouraged. This is because we can save our hydro electric power which produce electricity via water, we can save our biomass energy which is produced using wood, plant and flora. To overcome this problem and save our nature solar electric energy is mostly recommended. Solar energy is obtanained which solar panel and using photovoltaic which is a converter.

1.2 Problem Statement

The current state of solar power generation faces several challenges that hinder its optimal efficiency and energy output. Firstly, traditional fixed solar panels are unable to dynamically adjust their orientation to track the sun's movement throughout the day. This static positioning limits their ability to capture the maximum available sunlight, resulting in inefficient power generation.

Secondly, manual tracking systems that require human intervention have limitations in terms of accuracy and consistency. They heavily rely on the operator's diligence and may not effectively adapt to changing weather conditions or variations in the sun's position. This manual approach is labour-intensive, time-consuming, and impractical for large-scale solar installations.

Furthermore, a lack of comprehensive efficiency analysis poses a challenge in accurately assessing the energy generation potential of solar panels. Without an automated system that continuously monitors and optimizes the panel's orientation, it becomes difficult to quantify the impact of suboptimal positioning on energy output. This deficiency hinders the ability to evaluate the effectiveness of existing fixed systems and identify areas for improvement.

To address these challenges, the project aims to design and implement a Smart Solar Tracker system using Arduino, a versatile microcontroller platform. The system will enable automatic and precise tracking of the sun's movement throughout the day, ensuring that solar panels maintain an optimal alignment for maximum sunlight exposure. By leveraging light-dependent resistors (LDRs) or other sensors, the system will accurately detect the sun's position and actuate motors to adjust the panel's orientation accordingly.

The implementation of the Smart Solar Tracker will eliminate the inefficiencies of fixed solar panels by dynamically adapting to the sun's position. The system will minimize energy loss caused by suboptimal alignment and maximize energy generation potential. Moreover, by automating the tracking process, the system eliminates the limitations of manual tracking systems, providing consistent and accurate positioning even in changing weather conditions.

Additionally, the Smart Solar Tracker will incorporate comprehensive efficiency analysis capabilities. By continuously monitoring energy generation and comparing it to the maximum potential output, the system will enable a thorough evaluation of the solar panel's performance. This analysis will allow users to identify any deviations from the optimal energy generation and make necessary adjustments or improvements to further enhance efficiency.

In summary, the Smart Solar Tracker project aims to overcome the limitations of traditional fixed solar panels and manual tracking systems by designing an automated solution using Arduino. By addressing the issues of inefficient power generation, manual tracking limitations, and the lack of comprehensive efficiency analysis, the project intends to enhance energy efficiency in solar power generation, contributing to the broader adoption of sustainable and renewable energy sources.

1.3 Research Objective

The main purpose of this project is to achieve infinite sunlight from morning until evening under 360 degree of rotation and compare which method is useful to obtain absolute sunlight. Specifically, the objectives are as follows:

a) To design and develope an automatic solar tracking system using Arduino.

b) To investigate the efficiency of the power output between solar trackers and without solar trackers.

1.4 Scope of project

The scope of this project is to get highest intensity of sunlight into the solar tracker which can gives a higher and expected outcome. Evaluate the sum of the amount of direct sunlight radiation that the solar tracker could absorb in a short time. This is because a normal solar tracker require an extensive duration of period to absorb sunlight radiation because a normal solar panel is in static form. Wiring shuld be done for connecting components such as light dependent resistor, light emiting diode, resistor, servo motor, rotary potentiometer, mini solar panel and push button switch. Then, codding process by C++ for programming Arduino UNO R3. Moreover, to compare the amount of sunlight radiation captured by pyranometer and the output energy stored in battery between shadow detection solar tracker and smart solar tracker using Arduino.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A system for tracking solar energy the main prosses where it directs then rotates the solar cell to face the direct sunlight. Sun's position changes throughout the day as it travels across their path. Solar energy may be generated at its peak utilizing this technique since it is aimed straight at the sun. By adjusting the output of the solar panels, these tracking devices increase the productivity of the solar energy system.

Photovoltaic panels, also known as the energy of solar, are the most important main sources of neat and tidy numerous, and limitless energy, not only providing substitute power supplies but also reducing the harm to the environment. The direct beam of sunshine transports around ninety percentage of the sun's energy, as the last sunshine fades.

This section will concentrate on the practical, technical, and theoretical aspects of this project. Which is solar tracking system, solar tracking technology, the solar cell principle and calculation and many more effects which is affecting the performance and outcome of the solar panel.

2.2 Solar Radiation

The sun’s radiation is the one and only unlimited renewable energy source. Electromagnetic radiation, produced by the sun, is generally referred to as solar radiation. The Earth’s elliptical orbit around the sun brings it closer to the sun for a portion of the year. When the sun is closer to Earth, sunlight is received more intensely on Earth’s surface. The presence of huge oceans moderates the hotter summers and colder winters that would be expected in the southern hemisphere as a result of this discrepancy.

The Earth's axis of rotation's 23.5° tilt is an increasingly important factor when calculating the quantity of sunlight impacting the Earth at a given point. Turning causes long days in the northern hemisphere from the vernal (spring) equinox to the autumn (the month of October) equinox, and shorter days in the southern hemisphere for the remaining 6 months. On the equinoxes, which occur on or around March 23 and September 22, both days and nights are precisely 12 hours long.[1]

Countries in the middle latitudes, especially the United States, get more solar radiation in summertime not just because the duration of the days are longer, but also because the sun's rays is almost high. During the shortest days of winter, the sun's beams are much more tilted. Cities like Denver, Colorado (around 40° latitude), receive roughly three times as much solar radiation in June as they do in December.[2]

On an hourly basis variations in sunlight are also affected by the Earth's rotation. The sunlight is dim in the sky in the early hours of the day and at sunset. The lights pass through the earth's atmosphere further than at the middle of the day when the sun is at its brightest. On a clear day, around the middle of the day the most solar energy reaches a collector that captures solar energy.

In Malaysia, the highest sun radiation spotted is in Kota Kinabalu which is in Sabah for 1900 kWh m^{-2} followed by Bayan Lepas and Georgetown which is in Penang for 1890 and 1785 kWh m^{-2} respectively.[3] The difference between kWh m^{-2} and W/m^2 is k is for Kilo, W is Watt, h is hour and m^2 is meter square per area. To convert kWh m^{-2} to W/m^2 we have to multiply by 1000 because 1Kilo is equal to 1000. In simple explanation, kWh/m^{-2} is in a month and W/m^2 is in a day.[39]

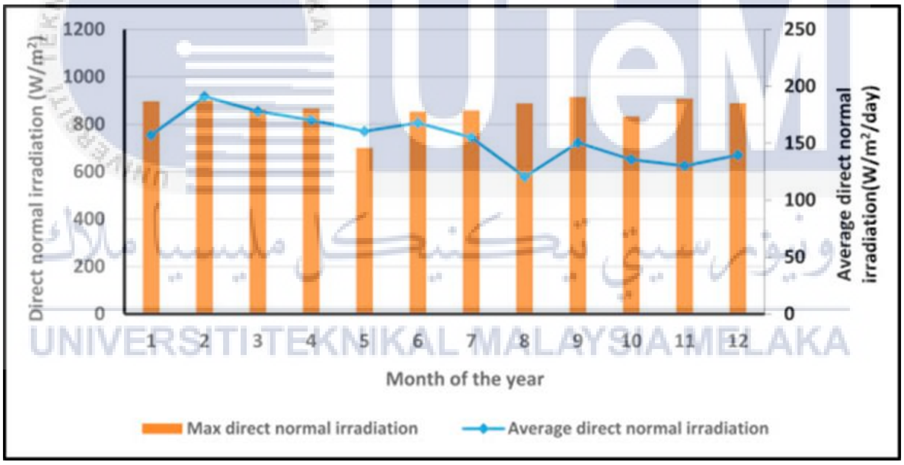

Figure 2.1 Shows Malaysia's solar radiance in monthly average.[4]

From the figure above can analise that the maximum average for a month of daily radiation was found on Febraury 2018 which is 282 W/m^2/day. Moreover the month of September had a record-breaking level of radiation from the sun which is 1068 W/m^2. The month of November had the least average per month peaking of radiation from the sun which is 209.2 W/m²/day. This is because Malaysia is located at equator which is Malaysia climate is catogarized as equatorial where being hot and humid throughout the year[5]. November until december its an raining season in Malaysia this why the solar radiation recorded in November is the least.

Without having to go through reflections and absorptions. Sunlight that has been reflecting by anything that reflects is referred as reflected solar radiation. Last but not least, scattered solar energy is radiation that penetrated the outermost layer of the earth but has been spread by atmospheric particles.

2.3 Relationship of pyranometer and voltage reading

A pyranometer is a device that measures solar irradiance, which is the power received per unit area from the Sun in the form of electromagnetic radiation with wavelengths ranging from 0.3 to 3 micrometres. The sun generates radiation over the range of wavelengths from 0.15 to 4.0 µm which is known as the solar spectrum[57]. Pyranometers typically function by turning incoming sun energy into an electrical signal, usually voltage.

The thermopile pyranometer is the most popular form of pyranometer. It is made up of a series of thermocouples that are exposed to sun radiation. When solar radiation is absorbed by the pyranometer's surface, heat is produced. This heat induces a temperature differential between the thermocouples, which generates a voltage output proportionate to the intensity of the solar radiation.

The relationship between solar radiation and pyranometer voltage output is normally linear, which means that an increase in solar radiation results in a corresponding rise in voltage output. Typically, the voltage output is calibrated to provide a precise measurement of solar irradiance in measures such as watts per square metre (W/m2).

In summary, a pyranometer influences voltage by turning incoming solar energy into a quantifiable electrical signal, generally in the form of voltage, which is then used to measure solar irradiance at a specific location.

2.4 Photovoltaic Effect

The photovoltaic cell are energy harvesting technology which transfers solar energy into useful electrical energy for variety of uses. This transformation is known as the PV, and it was Edmond Becquerel, a French chemist, discovered it in 1839.[6] In 1920's, Albert Einstein refered them as a 'grain of light'.[6] Photovoltaic panels weren't given widespread use in satellite technology till the years 1960. Rooftop solar panels built of PV cell modules started appearing around the end of the the year 1980. Since the beginning of the centuries, and photovoltaic capacity has steadily expanded, owing to the construction of massive solar farms.

Solar cells are made of semiconductor elements similar to those used in the microelectronics industry, for example silicon.[7] A small semiconductor wafer is specially treated to provide an electric field for solar cells that is positive on one side and negative on the other. When light energy strikes the solar cell, electrons are expelled from the atoms of the semiconductor material. Electrons can be captured as an electric current if electrical conductors are connected to the positive and negative sides of an electrical circuit. This electricity can then be used to power a load like a light or a tool.

Created the world's first rollable and completely printable solar cell out of perovskite, a significantly less expensive material to make than silicon. If we can also enhance their efficiency, we may be able to produce cheaper solar cells on a far larger scale than ever before.

The silicon solar cells that we are so familiar with have a fundamental drawback. We may run out of materials to create them by 2050 if enough are made to meet our requirements.[8] So we need new things, and plenty of them. Perovskite solar cells are emerging to fill the gap.

Universal Energy, based in nearby Redwood City, invented an apparent solar panel while San Jose has created a solar roofing system that is built identically to regular concrete roofing and catches radiation that comes from the unseen spectra.[9]

Certain researchers are even questioning silicon, the primary component of solar panels, and are experimenting with organic photovoltaics and perovskite solar cells, which replace silicon with a wider range of compounds for more economical production, as well as quantum solar cells, which are made of microscopic semiconductor particles and are capable of capturing the sun's energy more effectively.[10] Third-generation photovoltaic cells may be able to overcome the performance restrictions that currently plague solar, leading to a future in which energy is more cost-effective up front—and look nothing like the rigid blue panels we've become accustomed to.

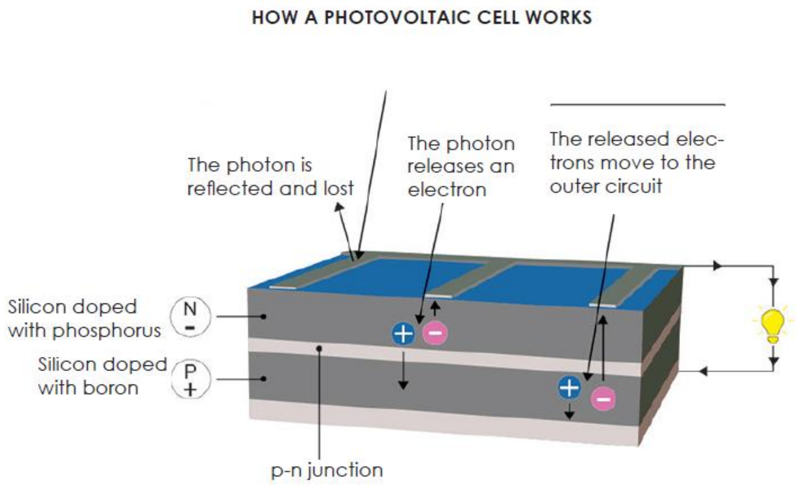

Figure 2.2 ; Ilustration on how a photovoltaic cell works.[11]

2.5 Efficiency of Solar Cell

The next subsection will go through the several varieties of solar energy cells obtainable through retail industry. In nowadays latest market the are many type type of solar cell such as momo-crystalline.

There's several forms as cell too such as amorphous silicon cells, silicon cells, polycrystalline silicon cells and many more. The very first generation was used crystalline silicon (c-Si) solar cells.[13] Amorphous silicon (a-Si), copper indium gallium diselenide (CIGS), cadmium telluride (CdTe), and organic semiconductors are included among the materials used in both the second and third generation solar cells. Below shows the maximum efficiency reached by types of solar.

Table 2.1: Types of solar cells get the highest efficiency.[12]

Solar cell type	**Maximal efficiency reached**	**Solar cell type**	**Maximal efficiency reached**
Multijunction Cells		*Thin-Film Technologies*	
• Three-junction	37.9-44.4%	• CIGS	22.6-23.3%
• Two-junction	31.6-34.2%	CdTe	22.10%
• Four-junction or more	38.8-46.0%	• Amorphous Si:H	14%
Single-Junction GaAs		*Emerging PV*	
Single crystal	27.5-29.3%	Dye-sensitized cells	11.90%
Thin-film crystal	28.80%	Perovskite cells	22.10%
Crystalline Si Cells		Organic cells(various)	11.50%
Single crystal	25.3-27.6%	Organic tandem cells	10.60%
Mylticrystaline	21.30%	Inorganic cells	12.60%
Silicon heterostucture	26.60%	Quantum dot cells	12.00%
Thin-film crystal	21.20%		

The Table 2.1 shows that multijunction solar cells has the highest efficiency campared to the emerging photovoltaic cell solar cell. The maximal efficiency reached is particularly essential variables used for deciding the best effective solar cell.

Outcome for panel and the total input of the sun is calculated and evaluated for the effectiveness. Light intensity, temperature of solar cell and also the incidence angle of the sunshine are most important factors and reason for the effectiveness of solar panel affected. Solar cell efficiency may alternatively be expressed as:

$$\eta = \frac{P_m}{EAc}$$

η = efficiency

P_m = maximum power point (W)

E = input of light irradiance (W/m^2) A_c = surface area of the solar cell (m^2)

A_c = surface area of the solar cell (m^2)

2.6 Factor that affect the efficiency of solar panel.

The effectiveness for solar energy panels total energy produced or generated by the solar energy. Efficiency of solar panel is also will affecting by temperature, light intensity, incidence angle of the plane and solar shading.

2.6.1 Temperature

Temperature is one such factor that affects photovoltaic cell effectiveness due to inherent properties in semiconductor materials used in their construction. The efficiency of solar panels increases at low temperatures but decreases as temperatures rise resulting in decreased voltage within cells.

Efficiency rating for solar panel modules are temperature-dependent with extreme temperatures having an unfavorable influence on their performance. Standard sunlight intensity measured indoor PV modules rated power at 25 °C but outdoor module thermostat settings are generally higher than this and have different heat dissipation requirements leading to lower output levels[40].

To better compare outdoor panel performance we must use Nominal Panel Operating Temperature (NMOT) concept which takes into account how temperature impacts typical values of efficiency.[41]

Solar panels perform best at cold temperatures although rising temperatures cause changes in semiconductor characteristics leading to a minor increase in current yet significantly larger fall in voltage thus harming both durability and lifespan if not managed properly since most sunlight striking panels converts into heat requiring good thermal management for enhanced efficiency and longevity.

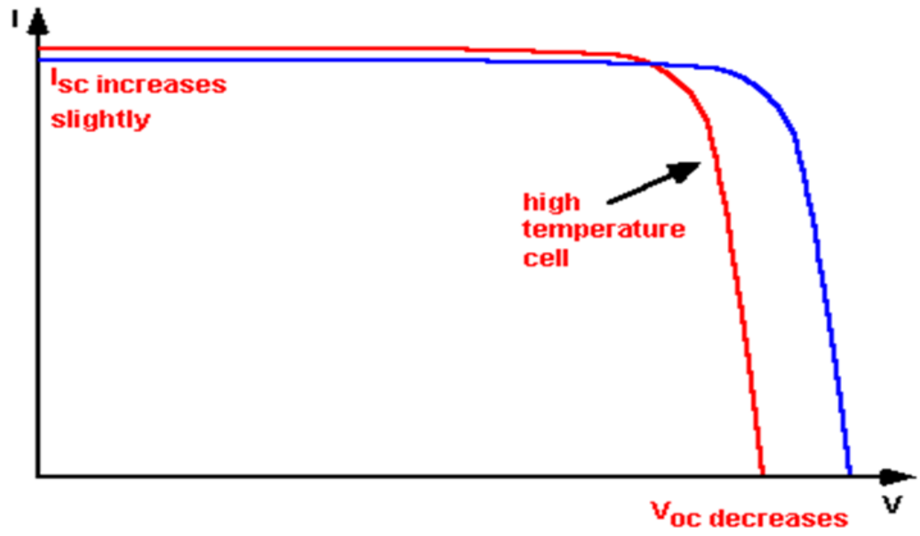

Figure 2.3; The effect of temperature on the IV characteristics of a solar cell.

2.6.2 Light Intensity

Intensity by sun radiation on solar panel affects its characteristics including efficiency, short circuit current, open circuit and series impact, and circuit resistances which ultimately impacts the amount of output power generated by the solar panel.

Direct sunlight photovoltaic cells are extremely vulnerable to sun shading with total or partial shade having a substantial influence on energy delivery capabilities causing poorer production and power losses. Solar cells linked in series produce greater voltage for adequate power but when shaded have several disadvantages since current is decided by the unit generating least current effectively shading entire series leading to bypass diodes being commonly used in installations to reduce energy loss.[14]

Light intensity plays an important role in solar panels along with temperature and incidence angle since it can be detected using pyranometer sensor technology. Solar cells endure daily changes in light intensity ranging from 0-1 kW/m² with shunt resistance influencing significantly at decreasing light levels leading to lower coefficients of bias and current through solar cell reducing equivalent resistance making total fraction going via shunt resistance increases resulting in fractional power loss from shunt resistance growing further.[42]

To overcome this problem researchers, analyze electrical performance parameters of photovoltaic cells using solar energy determining influencing factors while discarding weakly related ones designing targeted research programs based on studying impact of light intensity and temperature on battery temperature changes measuring maximum power point's output voltage/current for better optimization of system performance.[43]

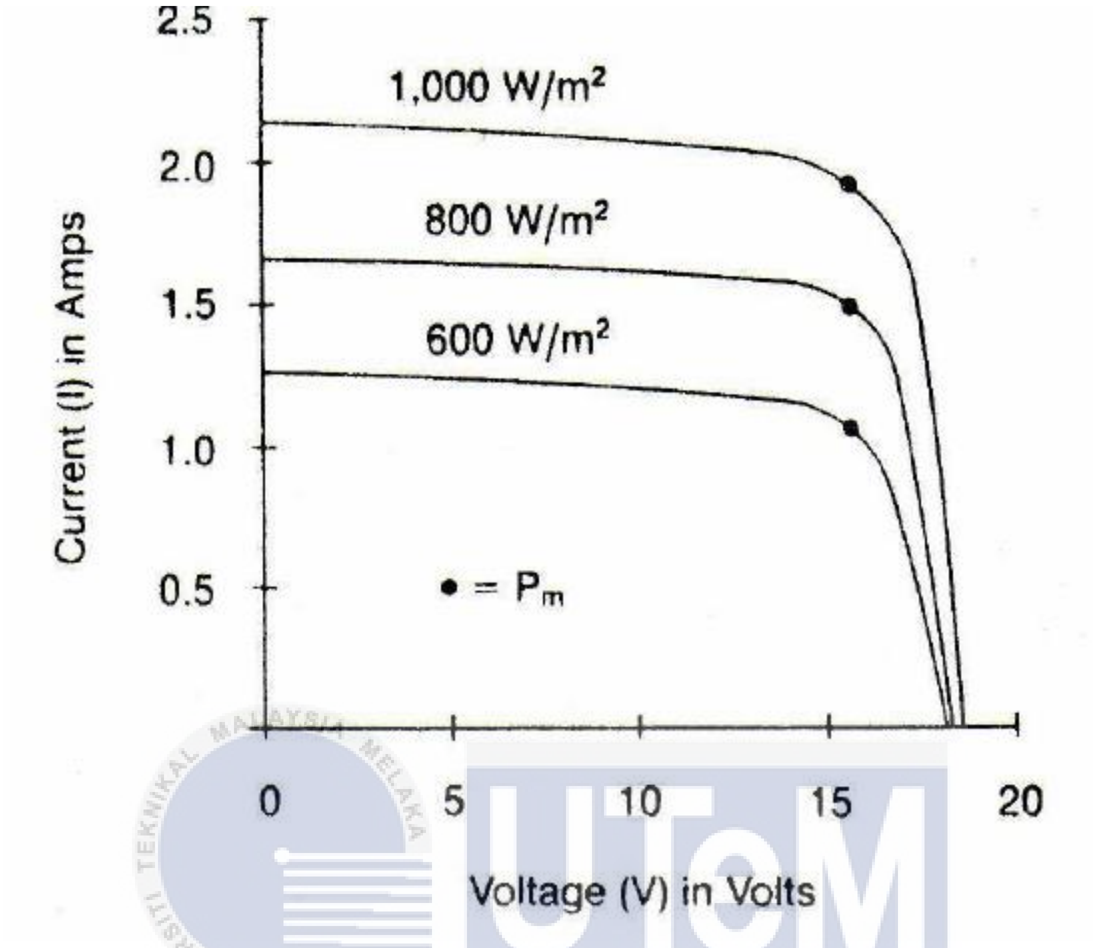

Figure 2.4; Effect of light intensity to the efficiency of solar panel.[15]

2.6.3 Incidence angle

The incidence angle is the angle which the sun reflects at the most and produces highest amount of energy cause incidine of angle plays the most important part in the outcome or result of the solar panel total amount of energy produced and total input from the sun. When the incidence of angle increases, the total quantity of sunlight observed will be decreasing which will cause the energy producting and generating become lesser and decrease. Incidence angle plays a crutial part in this project.

Sunlight strikes solar panels at changing angles throughout the day with a stationary installation. The angle of incidence controls how much of the incoming light is converted to electricity. With a smaller angle of incidence, a photovoltaic panel may produce more solar power. As a result, a solar panel perpendicular to the sun can create more electricity than one that is not.

Solar trackers are active trackers that completely alter photovoltaic systems to monitor the sun as it travels across the sky. This maintains the sun's beams perpendicular to the solar panels, allowing them to gather the most solar radiation and hence most energy. They're often utilised for ground-mounted solar panels as well as huge solar projects like solar trees.

PLCs, signal processing units, electromagnetic and mechanical motion control modules, and sensors are all part of the solar tracking system. To control the entire system, it is powered by an actuator. It also features photovoltaic equipment in addition to the sun tracking equipment. Inverters, racks and frames, and PV cells are included. The panel is activated by strong sun radiation, which is then sent to the sensors. The sensors send it to the PLC, which causes the machine's motor to turn on. This rotation causes the panel to face the sun.

This incidence angle which is affecting the power output of the solar tracker will be controlled by an arduino uno R3. This is because using a arduino we can controlled the servo motor and also the incidence angle according to the sunlight radiation which is observed by pyranometer sensor. Via this we can get the accurate result on where is the sunlight intensity is higher and get the highest ouput of our solar tracker. Morever, it will be automatically function system once the arduino uno R3 is connected.

The proper tilt angle of a PV panel is critical for its successful operation since incorrect alignment results in a loss of efficient solar energy. The optimal tilt angle calculations are based on increasing the solar irradiation falling on a slanted surface using various improvement techniques. Seasonal adjustments can produce up to 40% more solar energy than fixed slope panels. Malaysia's optimal tilt angle is 15^{o}. The PV panel's ideal tilt angles are changed annually. Collected yields climbed by 5.02, 5.03, 5.65, 6.13, and 7.96% in Johor Bahru, Kuala Lumpur, Ipoh, Alor Setar, and Kuching, respectively, while changing the ideal tilt angle monthly in the same locations increased by 4.58, 4.54,5.70, 5.85, and 4.11% significantly[44]. A solar panel's tilt angle should be suitable to obtain perfect sun irradiation while avoiding partial shadowing.

Shading solar panels affects the solar collector's efficiency " η" by lowering cell power " P MP " and modifying the short circuit-current " I SC ", open-circuit voltage " V OC ", and fill factor " FF ". As a result, the orientation and tilt angle of solar collectors are critical in minimising shade and, as a result, enhancing solar collector efficiency. The best tilt angles for solar collectors erected in Kuala Lumpur, Malaysia, were determined using a mathematical process that used Cooper's equation and Visual Basic Application (VBA) programming in Microsoft Excel [45]. The mathematical method was developed to discover the best layout in level fields, fields with stairs, and inclined fields. The results show that the worst shading effects occur in December, and the optimum flat distance between solar collector rows for a flat field is 2.66 m for a 2 m high collector, whereas for fields with steps and inclined fields, the arrangement of solar panels is determined by the slope or tilt angle ß.

This is why incidence angle plays a huge role in the power output of the solar tracker, so below Figure 2.5, shows the perfect and simple understanding of how incidence of angle would be affecting the total energy produced by the solar panel to understand.

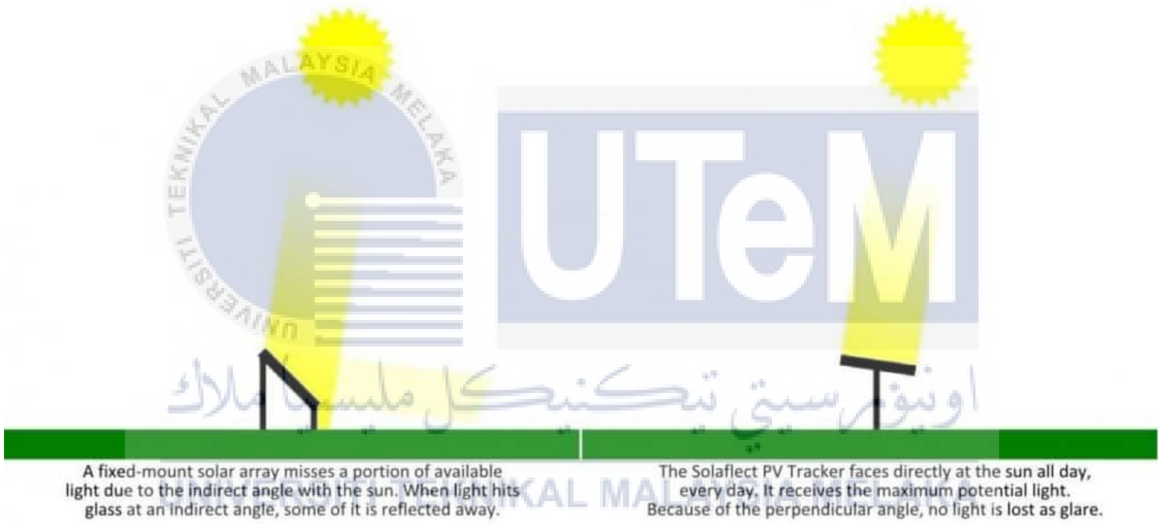

Figure 2.5; Effect of incidence angle to the efficiency of solar panel.[16]

2.7 Types of solar tracking system

Solar panels are installed above a moving frame in solar tracking systems to follow the transition of the sun throughout the day. Solar tracking systems are classified into three types:

I. Chronological solar trackers

II. Active solar trackers

III. Passive solar trackers

2.7.1 Chronological solar trackers

Chronological solar trackers use a timer-based measuring mechanism to move the structure at a constant rate throughout the day for chronology monitoring since the sun travels across the sky at a constant rate. While this type of tracker has low energy losses and minimal tracking error, its downside is that it consumes more power and has difficulty tracking on foggy days due to continuous rotation requirements making it an inefficient option compared to other types such as active or passive solar trackers [17].

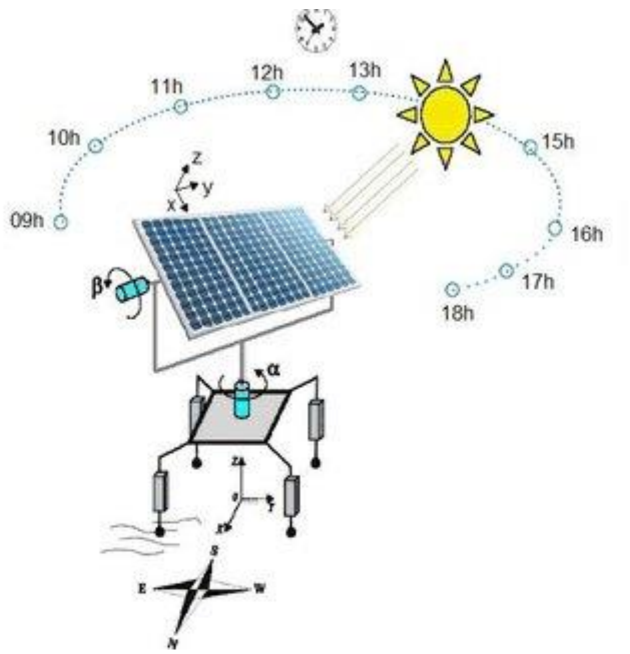

Figure 2.6; Shows how a chronological solar tracker works. [18]

2.7.2 Active solar trackers

Active solar trackers use sensors to continuously calculate the location of sun on daytime, transmitting a information to a motor and actuator for function accordingly. Results in solar panels regularly facing sun on daytime with high accuracy except on extremely foggy days where sensor identification of higher intensity light and location is required.

While active solar trackers are more accurate and efficient in tracking high sunlight intensity locations, they require additional electricity usage and may not be as accurate on overcast days due to low light intensity [19].

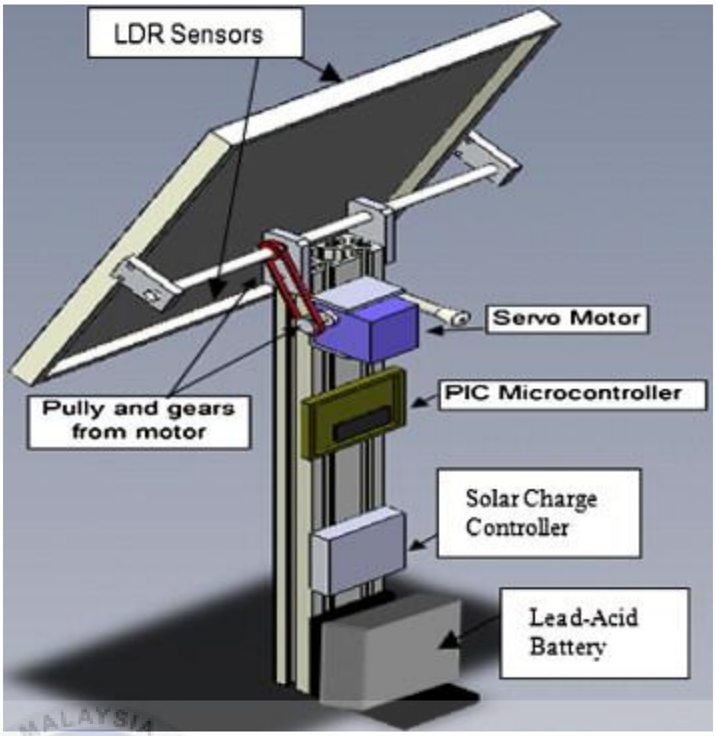

Figure 2.7; Shows a active solar tracker example.[20]

2.7.3 Passive solar trackers

Passive solar trackers operate by moving in response to a pressure imbalance between two sites at the tracker without requiring a controller, making them simple and quick to set up with minimal maintenance costs.[21] They also run automatically using motors or actuators, but are highly dependent on weather conditions and have low precision.

While there are passive sun monitoring devices available that use thermally active components such as liquid freon or similar volatile liquids to tilt the array towards the sun throughout the day based on changes in center of gravity due to sunlight exposure, these systems can be 25-30% more expensive than static systems, making them less cost-effective[22].

In summary, while passive solar trackers offer automatic operation and simplicity with minimum maintenance costs compared to other types of trackers that require controllers or sensors for precise tracking accuracy, their level of weather dependency and low precision make them less efficient options for solar panel installations compared to active or chronological solar trackers.

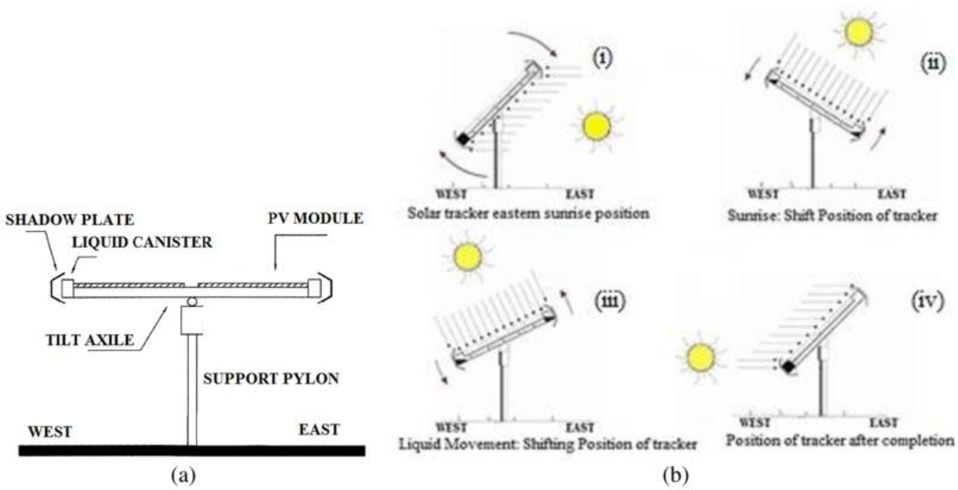

Figure 2.8; Shows how does a passive solar tracker works. [23]

2.8 Solar tracking system

Concept on solar trackers, which are

i. Single axis tracking system

ii. Dual axis tracking system

2.8.1 Single axis solar tracking system

Single-axis solar tracking systems rotate or tilt the photovoltaic surface around one axis to obtain the best possible sunlight angle, making them simple and cheap to set up with low running costs compared to other types of solar trackers.[24]

Advantages of using a single-axis solar tracking system include their reliability, longer lifespan than dual-axis trackers, ability to fit under areas with less sun exposure, and availability in different configurations such as horizontal single-axis solar tracker (HSAT), horizontal tilted single-axis solar tracker (HTSAT), vertical single-axis solar tracker (VSAT) and vertical tilted single-axis solar tracker (VTSAT).

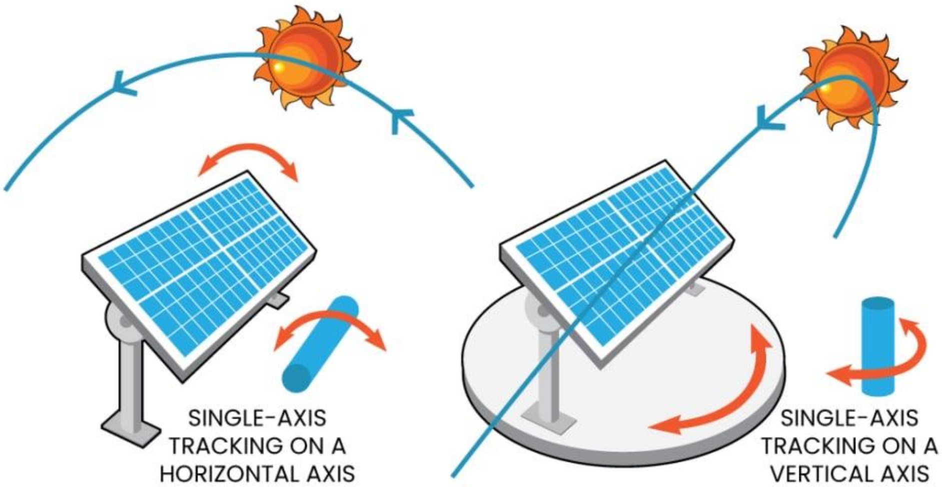

Figure 2.9; Single axis solar tracker [25]

2.8.2 Dual axis solar tracking system

Dual axis trackers capture solar energy from the East, West, North, and South orientations. They work on two axes: 'main' and'secondary'.

One of the axis will be moving its part horizontically which is from East to West and the other axis will moving vertically which from North to South.

It is also highly versatile due to its ability to move in all directions. The greatest feature about these trackers is that they can travel in all directions; they can provide more energy and work for longer periods of time by tracking the Sun's movement. They do not wait for the light to shine on the panels. Instead, the panels move with the Sun throughout the day.

The advantages of using dual axis solar tracking system is it provides more ouput energy compare to single axis solar tracking system. Moreover, dual axis solar tracking system does not need a larger area to accomodate while a limited space is enough for a dual axis solar tracking system to operate. The disadvantages of using dual axis solar tracking system compare to single axis solar tracking system is dual axis solar traking system is more expensive than single axis solar tracking system and its little complicated to fix and operates because of using many components.[26]

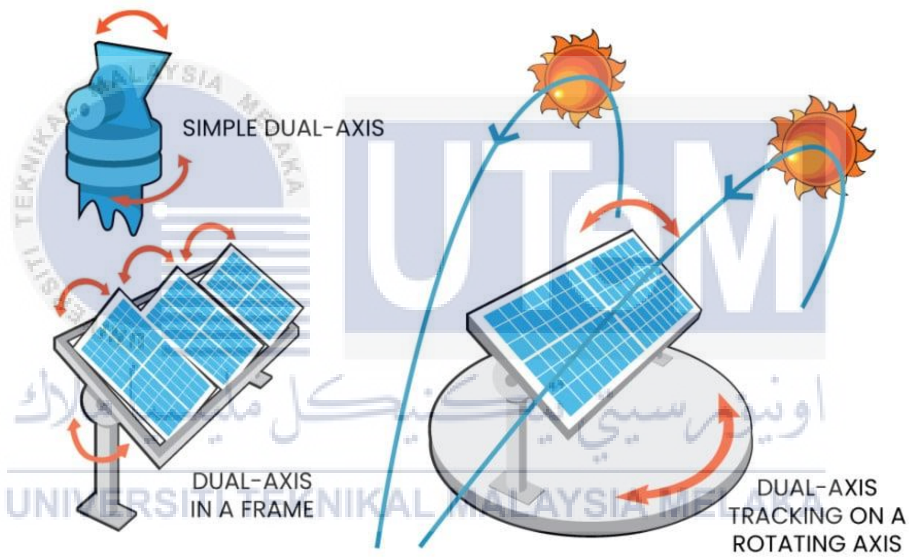

Figure 2.10; Dual axis solar tracker [27]

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will go through the technique that was used to overcome the problem that was mentioned in Chapter 2 in more detail. This chapter will also go into complexity regarding the project's flow, system design, software development, sensor, project testing, and the strategy that was used.

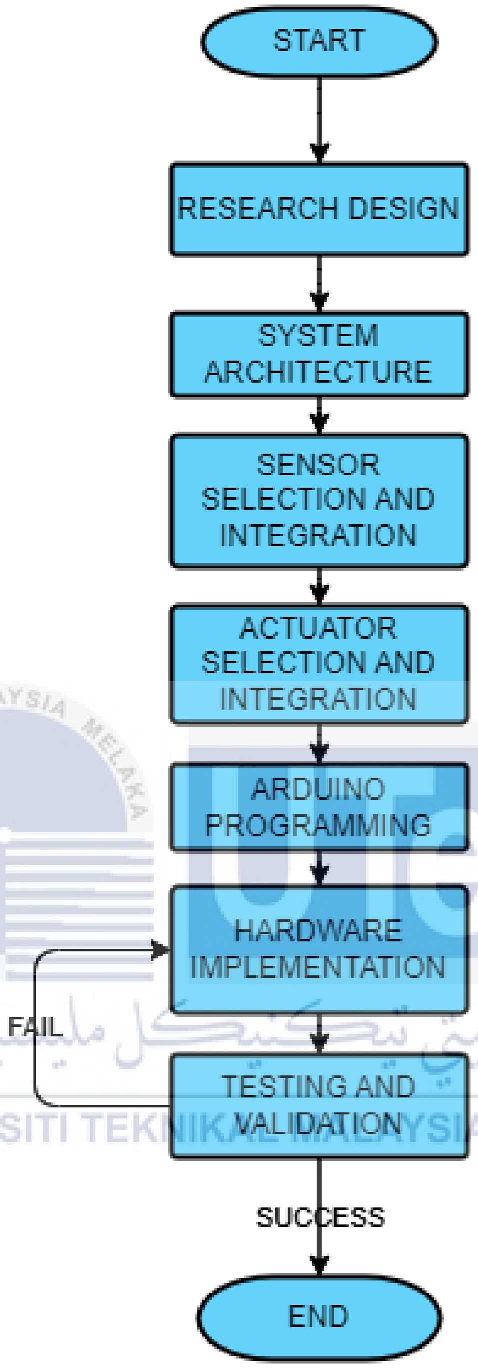

Figure 3.1; Shows the flow chart.

3.2 Research Design

The project includes using light sensors to gather data on sunshine intensity or direction, and the location of the solar panel or device will be modified using servo motors controlled by Arduino. Furthermore, data on the solar panel's position and the related sunshine intensity or direction will be gathered. The first step in creating an automatic solar tracker using Arduino is to connect the light sensors and servo motors to the solar panel support structure. Connect the light sensors and servo motors to the Arduino board after that. Then, calibrate the light sensors to accurately determine sunlight intensity or direction. Next, implement Arduino code to receive sensor data, identify the correct location, and operate the servo motors. In various lighting circumstances, test the solar tracker and gather data on the position of the solar panel and alongside sunlight intensity or direction. Finally, evaluate the collected data to determine the solar tracker's efficiency in tracking the sun.

Because Arduino boards are very adaptable and can be quickly programmed to interact with a wide range of sensors and actuators, the choice of Arduino as the platform for the solar tracker is justified. This adaptability enables the installation of numerous components required for an autonomous solar tracker. Next, in terms of cost and effectiveness, Arduino boards are very affordable when compared to other microcontroller platforms, making them ideal for prototyping and small-scale projects.

Furthermore, Arduino employs a simplified version of the C/C++ programming language, making it understandable even to beginners. The Arduino Integrated Development Environment (IDE) offers a simple interface for programming and uploading programmes to the board. Following that is expandability, with Arduino boards having numerous input and output pins, allowing for easy extension and attachment of extra sensors, motors, or other components that may be necessary for future solar tracker advancements.

In a word, Arduino's flexibility, low cost, plenty of online resources, ease of programming, and expandability make it an ideal platform for constructing an automatic solar tracker. Research design aligns with the project objectives because an automatic solar tracking system was developed and designed using Arduino.

3.3 System Architecture

The general architecture of an automatic solar tracker system consists of various components that work together to precisely position a solar panel or device within the direction of greatest sunlight. Here is an overview of the components and their connections:

3.3.1 Light Dependent Resistent

Light dependent resistors, also known as LDRs or photoresistors, are specialized electrical components used in electronic circuit designs to detect light's presence or amount.

LDRs differ from other types of resistors such as carbon film resistors, metal oxide film resistors, and metal film resistors typically utilized in other electronic systems because they are designed for light sensitivity and resistance changes resulting from it.

A photoresistor is a type of LDR that responds to changes in light intensity by changing its resistance value according to incident wavelength energy levels: with high resistance values ranging up into the megohm range when kept dark versus low ohmic values down into hundreds under intense lighting conditions [28].

These devices have simple layouts making them inexpensive compared to other sensors commonly employed as light detectors while being generally suitable for various applications including burglar alarm circuits, alarm clocks, light intensity meters among others.

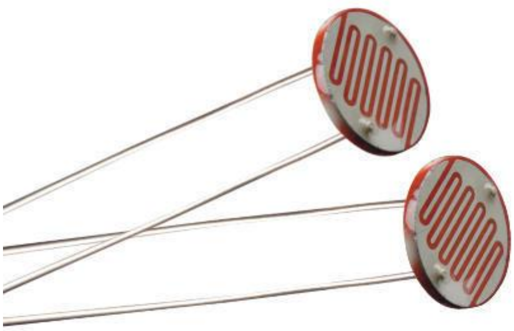

Figure 3.2; Light Dependent Resistor [29]

3.3.2 Arduino

The Arduino UNO is a standard Arduino board. In this example, UNO denotes 'one' in Italian. The original release of Arduino Software was labelled as UNO. It was also the first USB board made available by Arduino. It is regarded as a powerful board that is employed in a variety of tasks. The Arduino UNO board was created by Arduino.cc.

The Arduino UNO is built on the ATmega328P microprocessor[30]. In comparison to other boards, such as the Arduino Mega, it is simple to use. The board is made up of digital and analogue I/O pins, shields, and other circuitry.

The Arduino UNO has six analogue input pins, fourteen digital pins, a USB connection, a power jack, and an ICSP (In-Circuit Serial Programming) header. This arduino UNO is programmed based on IDE means Integrated Development Enviroment. This arduino UNO can be run on both platform which is online and offline.

The Arduino is a board that is based on an ATMEL AVR microprocessor. Microcontrollers are integrated circuits that can store instructions that you create using the programming language available in the Arduino IDE environment. These instructions allow you to write programmes that interact with the electronics on the board.

Because of their simplicity, the Atmega168, Atmega328, Atmega1280, and ATmega8 are the most often used microcontrollers on Arduino platforms, although it is being expanded to include Atmel microcontrollers with 32-bit ARM architecture, as well as Intel microcontrollers[31].

The Arduino microcontroller contains communication connectors as well as input/output ports, which allow us to attach a variety of devices to the board. The information from these connected devices will be sent to the microcontroller, which will be in charge of processing the data that comes via them.

On the other side, Arduino gives us with software that includes an IDE that implements the Arduino programming language, tools for transferring software to the microcontroller, and the bootloader that runs on the board. The software and programming language's key characteristic is its simplicity and ease of use.

The advantages of using arduino UNO is its very cheap and affordable price. It is also an easy to use with little or no programming knowledge. Moreover, arduino UNO has cross platform support such as Window, Linux and macOS.[32]

The disadvantages of using arduino UNO is lack of multitasking which is can run only a single program in a time. Other than that, arduino UNO has limited support for programming language which is it just supports C++ or C language only while does not support any famous and currently using language such as Python, Java and Javascript. Arduino UNO has another disadvantages which it has less memory storage capacity which 2kb of SRAM and 32kb of flash memory only.[33]

Figure 3.3; Arduino [34]

3.3.3 Pyranometer

A pyranometer is a sensor that turns the worldwide solar energy it receives into a measurable electrical output. Pyranometers are instruments that measure a section of the sun spectrum. The CMP21 Pyranometer, for example, measures wavelengths ranging from 0.285 to 2.8 m. Long-wave radiation has no effect on a pyranometer. A pyrgeometer is used instead to measure long-wave radiation (4 to 100 m).[35]

Pyranometer provide the silicon cell Pyranometer for total sunshine measurement and outdoor application. It is a popular and cost-effective sensor that is calibrated against a WMO Secondary Standard Thermopile. In watt.m-2, output is proportional to total solar energy.[36]

The Pyranometer is the primary light sensor on entirely weather stations, indicating the overall quantity of sunlight. It is also used by solar panel installers to test the output of the panels. These stations have surface temperature sensors for connecting to the solar panels, in addition to the Pyranometer and regular weather station sensors.

Pyranometers are not all created equal. The World Meteorological Organisation (WMO) and the International Organisation for Standardisation (ISO) have classified pyranometers into three types for various uses.

According to ISO 9060, a pyranometer can be classified as Class A, Class B, or Class C based on its specifications such as response time, thermal offsets, non-stability, non-linearity, directional response, spectral response, temperature response, and tilt response, as well as the calibration method.[37]

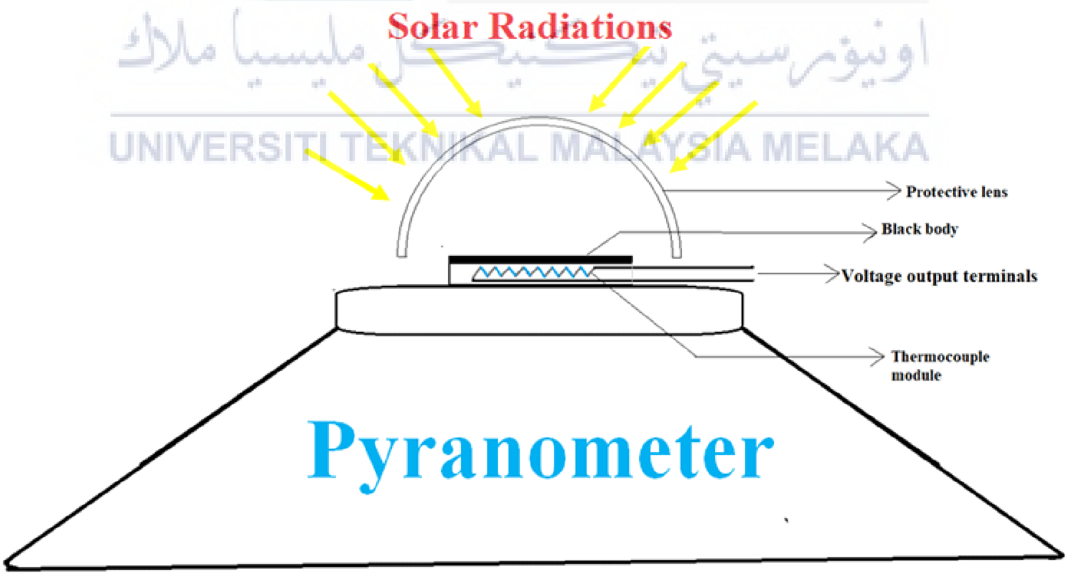

Figure 3.4; Pyranometer. [38]

3.3.4 Servo motor

A servo motor is a type of motor that can rotate with precise precision. This type of motor often includes a control circuit that offers an indication of the present position of the motor shaft. This feedback allows servo motors to rotate with amazing precision. A servo motor is used if one wish to rotate an object at a specified angle or distance. It is just a motor that is controlled by a servo system. If the motor is powered by a DC power source, it is referred to as a DC servo motor. If it is driven by an AC power supply, it is referred to as an AC servo motor. It will just covers the operation of a DC servo motor.

Besides of these basic categories, there are several different types of servo motors depending on gear arrangement and operational characteristics. A servo motor is often equipped with a gear arrangement which allows us to obtain a very high torque servo motor in tiny and lightweight designs. Because of these characteristics, they have been applied in a variety of applications like as toy cars, RC helicopters and aeroplanes, robotics, and so on.

A servo is made up of a motor (either DC or AC), a potentiometer, a gear assembly, and a control circuit. First and foremost, manufacturers apply gear combination to decrease RPM and increase motor torque. Consider that at the starting position of the servo motor shaft, the position of the knob that controls the potentiometer is such that no electrical signal is created at the potentiometer's output port. An electrical signal is now applied to the error detection amplifier's other input terminal. The difference between these two signals, one from the potentiometer and the other from other sources, is currently being processed in a process known as feedback, and the output will be in the form of an error signal.

This inaccurate signal serves as the motor's input, and the motor begins to rotate. The motor shaft has been connected to the potentiometer, and when the motor turns, so does the potentiometer, generating a signal. if a result, if the potentiometer's angular position changes, so does its output feedback signal. After a while, the position of the potentiometer reaches a point where the output of the potentiometer is the same as the external signal given[46]. There will be no output signal from the amplifier to the motor input since there is no difference between the external applied signal and the signal created at the potentiometer in this state, and the motor will stop moving.

Figure 3.5; Servo Motor [47]

3.3.5 Push button switch

A push button switch is a mechanical device that controls an electrical circuit by physically pressing a button to activate an internal switching mechanism. Depending on the design needs, they come in a range of forms, sizes, and combinations.

Push button switches are either usually open (NO) or normally closed (NC). When activated, typically open ("OFF") switches complete the circuit, whereas normally closed ("ON") switches break the circuit. Push button switches' functionality can be further defined within this group by the switching circuit they use.

Single pole, single throw (SPST), single pole, double throw (SPDT), double pole, single throw (DPST), or double pole, double throw (DPDT) are the most frequent. Because an SPST has just two terminals, it can only open and close one circuit. It might, for example, be used to switch on and off a motor. Because an SPDT has three terminals, it can control two separate circuits. As a result, it may be used to switch between powering two different LEDs or to switch an item of equipment from a sleep mode to an active state. The DPST and DPDT switch configurations allow for the control of two isolated circuits at the same time[48].

Push button switches, like all other forms of electrical switches, are used to reconfigure the electrical circuits to which they are connected. When an electrical circuit is open, electricity cannot continuously flow through it, stopping the operation of the electric equipment to which the circuit is attached. When a push button switch is used to shut an electric circuit, electricity may flow freely across the circuit, allowing the device to operate. Push button switches, depending on their design, can provide either persistent or temporary circuit shutdown. Push buttons may be equipped with springs that force the switch to retract when not depressed, keeping the circuits open.

Power can be transferred from one area to another by temporarily shutting down a circuit. Press buttons may maintain electrical flow in some cases such switches have on and off indications that are engaged or disengaged with each switch press operation. Push buttons, for no matter what purpose they are utilised for, are essential instruments in every location. Maybe may use these switches to manage the electrical current supply to the appliances. A switch's ability to conduct and stop electric current as instructed by the operator might be crucial. On many electric switches, breaking the circuit entails creating an air gap between two contacts. The contacts must be opened fast in order to perform the required activity.[49]

Figure 3.6; Push Button Switch [50]

3.3.6 Light Emitting Diode

LEDs are a kind of semiconductor that stands for "Light Emitting Diode." White LEDs, which have reached practical realisation through the usage of high-brightness blue LEDs based on Gallium Nitride invented in 1993, are gaining popularity as a fourth form of light source[51].

LED's (Light Emitting Diodes) are semiconductor light sources that combine a P-type (higher hole concentration) and an N-type (higher electron concentration). Applying a significant forward voltage causes the electrons and holes at the P-N junction to recombine, releasing energy in the form of light.

Unlike traditional light sources, which convert electrical energy into heat and subsequently into light, LEDs (Light Emitting Diodes) convert electrical energy directly into light, resulting in efficient light creation with minimal electricity waste.

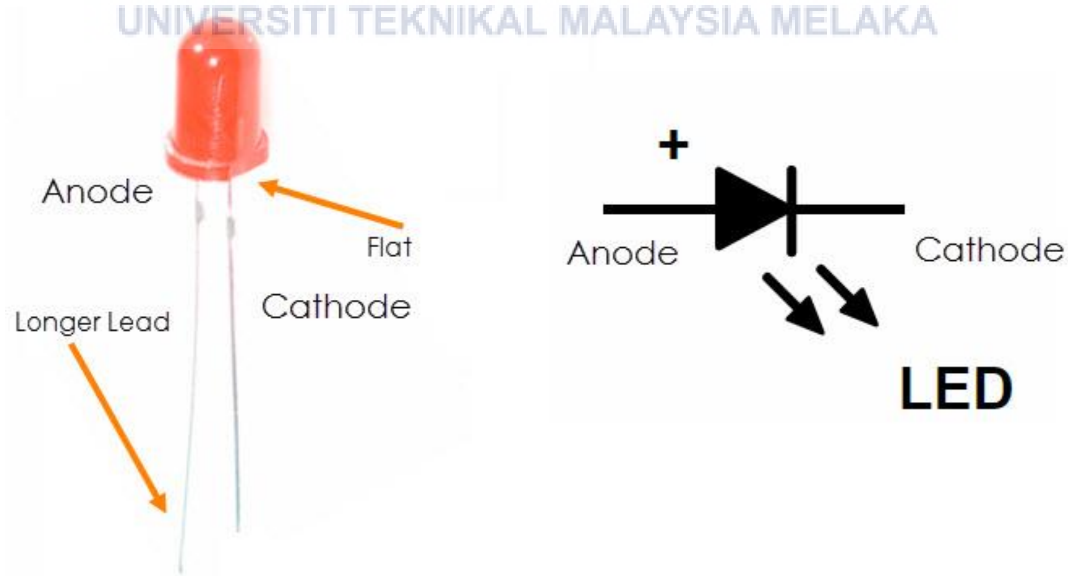

Figure 3.7; Ilustrate Light Emitting Diode[52]

3.3.7 Transistor

A transistor is a semiconductor device that conducts and insulates electric current or voltage. A transistor serves as both a switch and an amplifier. In layman's terms, a transistor is a small device used to control or regulate the flow of electrical impulses.

Transistors are essential components in the majority of electrical gadgets used today. The transistor, invented in 1947 by three American scientists, John Bardeen, Walter Brattain, and William Shockley, is regarded as one of the most important innovations in the history of science[55].

A transistor is made up of only one circuit element. Transistors are used in tiny quantities to make rudimentary electronic switches. They are the fundamental building blocks of integrated circuits (ICs), which are made up of a large number of transistors combined by circuits and formed on a single silicon microchip.

Transistors are used in huge numbers to construct microprocessors, with millions of transistors contained in a single integrated circuit (IC). They also power computer memory chips and memory storage devices used in MP3 players, cellphones, cameras, and video games. Transistors are firmly ingrained in virtually all integrated circuits (ICs), which are found in every electronic gadget.

Transistors are also utilised in low-frequency, high-power applications like power supply inverters, which convert alternating current to direct current. Transistors are also utilised in high-frequency applications, such as oscillator circuits that create radio waves.

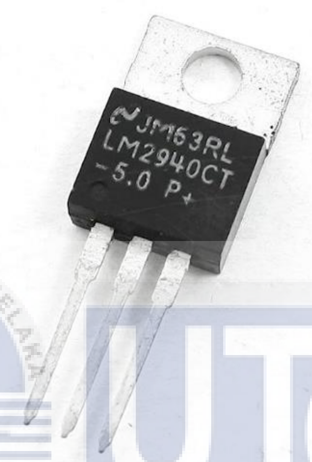

Figure 3.8; Transistor [56]

3.3.8 Interconnection and communications between component

Arduino board's analogue input ports. The servo motors are then linked to the Arduino board's appropriate digital output pins, which create the necessary control signals to modify their locations. The push button switch, LED, and rotary potentiometer may be linked to the Arduino board's digital input and output pins to allow for user interaction and system setup. The power source is then linked to the Arduino board's power input ports, sensors, and actuators to deliver electrical power. The Arduino board uses suitable methods or signals to interact with the sensors and actuators via its digital and analogue inputs and outputs. The Arduino board's programme code determines sensor data, finds the best location, and sends suitable signals to the servo motors to follow the sun. Overall, the components of the automatic solar tracker system are linked to allow data collecting, processing, and actuation, allowing the solar panel or device to follow the sun's position precisely.

3.4 Sensor selection and integration

The first step in choosing appropriate sensors for sun position tracking is to do research and establish sensor needs, which includes defining the characteristics needed for sun position tracking, such as sunlight intensity, direction, or total solar radiation. The operating circumstances and environmental elements that may impact sensor performance, such as temperature, humidity, and ambient light levels, are then evaluated. Then, examine the sensors' intended accuracy, reliability, reaction time, and range.

LDR are commonly used for sunlight intensity measurements. They are cost-effective and provide a voltage or resistance output that can be easily read by the Arduino's analog input pins. Moreover, LDRs have moderate accuracy and response time but may require calibration. They are also suitable for basic sun tracking applications.

Following, pyranometers are specialized sensors designed for measuring total solar radiation. They provide accurate and reliable data on solar irradiance. Moreover, pyranometers are available in various models with different measurement ranges and sensitivities. They typically have analog voltage outputs that can be read by the Arduino's analog input pins. Pyranometers also offer high accuracy and are ideal for precise sun tracking applications.

LDR's are often used to measure the intensity of sunlight. They are affordable and give a voltage or resistance output that the Arduino's analogue input pins can easily read. Furthermore, although LDR's have decent precision and reaction time, they may require calibration. They are also appropriate for simple sun monitoring applications.

Pyranometers are specialised sensors used to measure total sun radiation. They give precise and dependable sun radiation data. Furthermore, pyranometers are available in a variety of types that have different measurement ranges and sensitivities. They often feature analogue voltage outputs that may be read by the analogue input pins on the Arduino. Pyranometers are also quite accurate and are suitable for sun tracking applications.

For justification reasons, both LDRs and pyranometers may produce accurate readings, although pyranometers normally offer greater precision due to their specialised design and calibration capabilities. Pyranometers are preferred for precise tracking of the sun's location. That follows which, LDR's are typically reliable sensors with a long lifespan. Pyranometers, being specialised instruments, are built for long-term usage in sun tracking applications because to their excellent durability and stability. Both LDRs and pyranometers may be easily interfaced with the Arduino board for connectivity. LDR produce an analogue voltage or resistance output that may be read by the analogue input pins on the Arduino. Pyranometers, on the other hand, have analogue voltage outputs that may be attached to the Arduino's analogue input ports. The analog-to-digital converter (ADC) included into Arduino enables for precise measurement of sensor outputs.

3.5 Actuator selection and integration

The range of motion considered while selecting actuators for adjusting solar panel orientation is the required range of motion for the solar panel to follow the sun properly throughout the day. To accurately position the screen, actuators should be capable of both horizontal and vertical movement. The torque and speed requirements are then evaluated depending on the size and weight of the solar panel. The actuators must be able to apply enough torque to overcome any resistance or wind load while just maintaining smooth and accurate movement.

Then, power consumption is evaluated in order to ensure that the actuator's power consumption is suitable with the power source provided for the solar tracker system. To maximise energy usage, it is critical to evaluate total power requirements as well as efficiency. The primary objective is durability and dependability, and we select actuators that are both strong and reliability, able to tolerate external circumstances such as temperature fluctuations, humidity, and exposure to sunshine. Long-lasting actuators with minimum maintenance needs are important.

Because of its capacity to provide fine angular control, servo motors have frequently been used as actuators for solar panel placement. Servo motors offer accurate movement and may be easily controlled using PWM signals, making them suitable for use with the Arduino board.

Hardware integration involves connecting the servo motor control wires to the Arduino board's digital output pins. To ensure accurate wiring and connections while taking into consideration power needs and signal levels. To control the servo motors, code in the Arduino programming language must be written for software integration. To control servo motors, use the Arduino Servo library. In the code, define the servo objects and specify the associated pin numbers for the servo motor connections.

3.6 Arduino programming

To develop a solar tracking system using Arduino, consider note of the programming features of interfacing with sensors and actuators, as well as the algorithms used for sun position tracking and panel adjustment. The first step is to connect the appropriate sensors, which include a light-dependent resistor (LDR) or photodiode for sensing light intensity and, optionally, a compass module for calculating direction. The actuators for servo motors are then connected to control the movement of solar panels. Then, proceed to Arduino library installation, where you will install the Arduino libraries necessary for sensor and actuator connection. For example, the Servo library is used to control servo motors.

The next stage is sensor calibration, which involves calibrating the light sensor in order to receive correct light intensity data. This stage involves collecting sensor data at various light levels and converting them to suitable values. The final stage is to generate the snippets or pseudocode that will be used to demonstrate the implementation.

3.7 Hardware implementation

Designing the mechanical construction, assembling the components, establishing proper wiring and connections, and perhaps making modifications or adjustments during hardware implementation are all part of the physical implementation of an autonomous solar tracker system. The initial stage is to create a mechanical structure. A solar tracker system's mechanical construction generally consists of a base or frame that supports the solar panels, a support mechanism for panel movement, and a bracket for mounting the sensors. The base must be strong enough to hold the weight of the panels while also withstand wind forces. It might be constructed of metal or durable plastic. Depending on the dual-axis tracking, the support mechanism can be a mix of gears, pulleys, belts, or linear actuators. The sensor mount should be positioned to get the most sunshine exposure while reducing shadow influence.

The following phase is assembly, which involves assembling the mechanical components according with the design. Secure the solar panels to the frame or base, making sure they are properly positioned. Connect the support mechanism to the panels to ensure smooth and consistent movement. Install the sensors on their brackets, making sure they have a clear view of the sky and are appropriately positioned. Following that, the cabling and connectors link the Arduino board to the power supply, which is a solar panel. Connect the LDR and pyranometer sensors to the relevant analogue or digital pins on the Arduino board. Then, connect the servo motors or other actuators to the Arduino board's needed digital pins, being ensure to include power and ground connections. Make sure it double-check the pin connections and voltage levels for each component. To make reliable and safe connections, use jumper wires or suitable connectors.

Then there are changes and modifications. During the hardware implementation, it may face difficulties or identify opportunities for improvement. Modifications or adjustments might include modifying the size or position of sensor and actuator mounts to increase solar exposure and decrease problems. Fine-tuning the mechanical support system to guarantee the solar panels move smoothly and accurately. Aside from that, providing extra support or reinforcement to improve the stability and durability of the system. Weatherproofing techniques are being implemented to protect the components from environmental conditions. Consider installing emergency stop switches or limit switches to prevent over-rotation or damage.

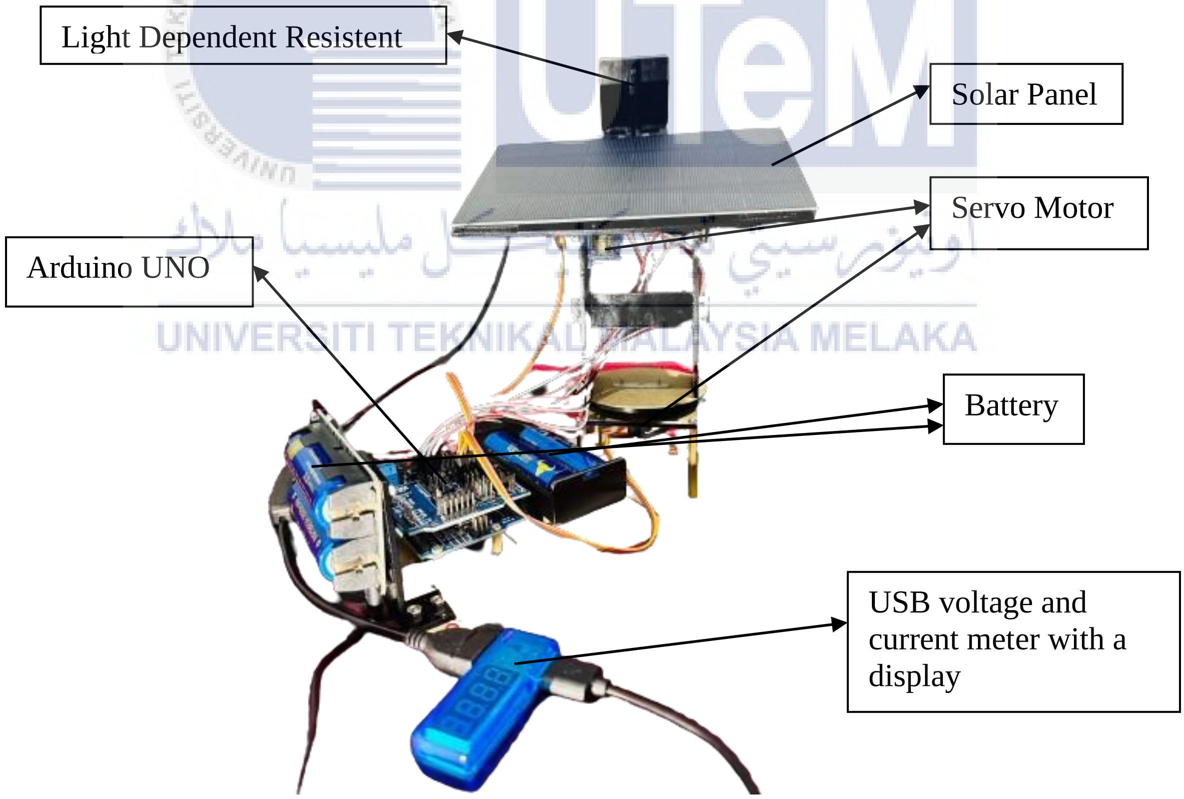

Figure 3.9; Ilustrate component of smart solar tracker using Arduino

3.8 Testing and validation

It is important to test the solar tracker system to confirm its proper operation and affirm its performance. First and foremost, power up the system and ensure that all components are receiving electricity. Align the solar panels manually to a known location and record the initial sensor data. Then, watch the solar panels move as the tracker changes their location based on sensor data. To check tracking performance, measure and record sensor data at regular intervals. Then, compare the estimated sun position with known sun position data for the test time to assess the system's accuracy and responsiveness. To evaluate the system's efficiency, measure the power output of the solar panels under various situations.

The testing is then carried out in an open outdoor environment that receives a multitude of sunshine throughout the day. Make sure the solar panels have a clear view of the sky. Position the system such that any possible shadows or interference from nearby objects is prevented. Create a data recording mechanism to keep track of sensor readings, servo motions, and power output statistics. The factors measured and methods used to calculate the position of the sun are light intensity or voltage readings from light sensors such as LDR and pyranometer. Servo angles or position measurements to confirm solar panel movement. Data from the solar panels' power production is used to calculate the energy capture efficiency. Validation is carried out by comparing the calculated sun position based on sensor readings to known sun positioning data. Then, evaluate the predicted performance of the solar tracker system using mathematical models or simulation tools.

The following are some of the difficulties and constraints. Inaccurate sensor readings because of light from the surroundings disruption or sensor calibration difficulties are two potential challenges during testing. Mechanical difficulties include opposition in the support system, motor stopping, and component misalignment. Environmental elements such as wind and extreme temperatures have an impact on the system's stability and performance. Aside from that, the system's limits could originate from tracking accuracy. Due to mechanical restrictions or sensor imperfections, the system may not achieve precise alignment. The tracking device itself may consume some electricity, perhaps avoiding the benefits of enhanced solar panel alignment. Furthermore, advanced tracking systems with dual-axis movement may have higher prices and complexity.

Overcoming these obstacles and challenge may need system troubleshooting and fine-tuning, improved sensor calibration, mechanical structure optimised performance, or consideration of new control algorithms. Maintain that testing should include a variety of weather conditions and time periods to confirm the system's dependability and efficacy in various circumstances. Furthermore, detailed documentation of the testing procedure, including data obtained and observed performance, will assist in future study and development of the solar tracker system.

The technical troubleshooting involved in addressing the low sensitivity of the Light Dependent Resistor (LDR) in the Arduino project comprises several key concepts. Firstly, the LDR operates based on photoconductivity, where its resistance changes in response to incident light. The sensitivity issue arises when the LDR fails to exhibit a proportional response to variations in light intensity. To resolve this, adjustments were made in the Arduino code, specifically within the mapping function responsible for translating analog voltage readings from the LDR into a meaningful range. Fine-tuning the threshold values in this mapping function and potentially calibrating the LDR were critical steps in enhancing its sensitivity. Calibration involves adjusting the system to ensure accurate readings, accounting for inherent variations and environmental conditions. Additionally, the code or physical setup may have been modified to mitigate the impact of ambient light, which could interfere with the LDR's readings. Through these technical interventions, the Arduino project successfully optimized the LDR's sensitivity, enabling it to reliably and accurately respond to changes in light conditions.

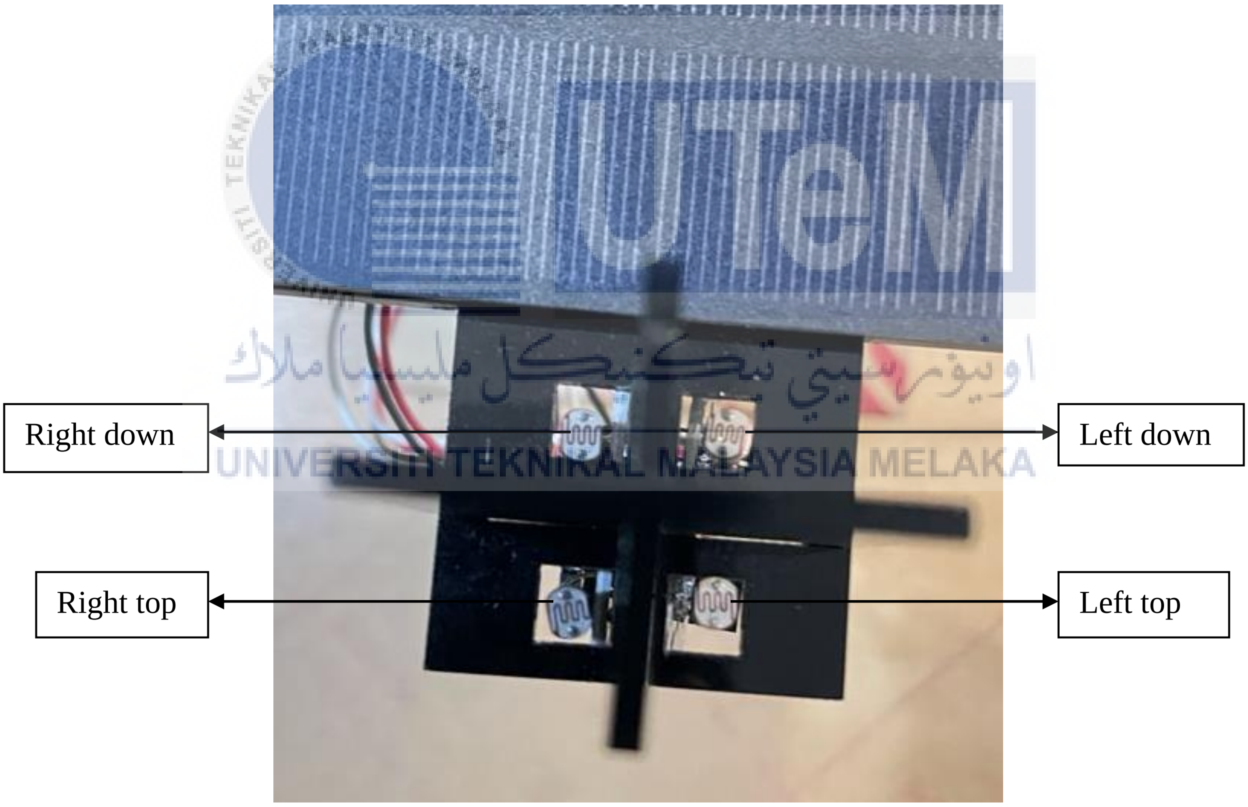

Figure 3.10; Light Dependent Resistor troubleshooted.

3.9 Experimental Setup

The calibration process of the smart solar tracker began with meticulous attention to the multimeter, an essential tool for measuring electrical parameters. To ensure accurate readings, the multimeter was calibrated by checking and adjusting its settings, such as voltage and current ranges. This involved using known voltage or current sources to verify that the multimeter displayed accurate measurements. The goal was to establish a reliable baseline for subsequent measurements during the calibration of other components in the system.

Moving on to the calibration of the Arduino components, special focus was placed on the sensors responsible for detecting light intensity and guiding the solar tracker's movement. These sensors, likely Light Dependent Resistors (LDRs) or photodiodes, were adjusted to respond optimally to varying light conditions. The Arduino programming code, regulating the behaviour of the solar tracker, underwent investigation to ensure precise control over the connected motors and the solar panel's positioning. Fine-tuning parameters in the code, such as sensor thresholds and motor control algorithms, was crucial to achieving accurate solar tracking.

With the multimeter calibrated and the Arduino components adjusted, the next step involved physically setting up the solar tracker in an open and sun-exposed location. This strategic placement aimed to maximize solar exposure and ensure unobstructed tracking of the sun's movement throughout the day. The solar panel, sensors, and motorized components were carefully installed to optimize the efficiency of the solar tracking system.

Once the physical setup was complete, the Arduino code was executed to activate the solar tracker. The dynamic tracking process began, with the sensors continuously feeding information to the Arduino controller. After allowing the system to run for a few minutes, a USB voltage and current meter with a display provided real-time feedback on the electrical output generated by the solar panel. This step was crucial for monitoring the system's performance and assessing its ability to harness solar energy effectively.

During the experimental phase conducted between December 15, 2023, to December 19, 2023, a systematic data collection approach was applied, with results recorded at 15-minutes intervals from 9 a.m. to 6 p.m. each day. This extended timeframe allowed for a comprehensive analysis of the smart solar tracker's performance over varied solar conditions throughout the daylight hours. By capturing data at regular intervals, the study aimed to provide a detailed understanding of the solar tracker's effectiveness in adapting to changing light intensities and solar positions during the specified days. The collected results, encompassing voltage and current outputs from the solar panel, were crucial in assessing the system's efficiency and its ability to dynamically track the sun, thereby optimizing energy absorption. This periodic data collection strategy served to capture the specifics of the solar tracker's performance throughout the specified timeframe, enabling a thorough evaluation of its operational reliability and effectiveness over an extended duration.

Finally, to evaluate the smart solar tracker's efficiency, a comparative analysis was performed by referencing the results obtained with a low-cost solar tracker using shadow detection. This alternative method likely employed sensors or algorithms to detect shadows on the solar panel and adjust its orientation accordingly. The comparison allowed for a nuanced understanding of the strengths and weaknesses of the smart solar tracker in optimizing solar energy absorption in real-world conditions. The entire step-by-step process showcases the comprehensive calibration and deployment of the solar tracking system, merging both technical precision and practical considerations.

In the comparative analysis between the smart solar tracker using Arduino and the low-cost solar tracker employing shadow detection, the latter's design is characterized by its cost-effective approach to optimizing solar panel orientation. In technical and engineering terms, the low-cost solar tracker integrates a shadow detection mechanism comprising sensors or algorithms capable of discerning shadows cast on the solar panel surface. These sensors, often photodiodes or phototransistors, detect variations in light intensity caused by shadows, triggering a response from the embedded controller. An actuation mechanism, such as motors or servos, is employed to dynamically align the solar panel with incident sunlight, minimizing the impact of shadows and enhancing energy absorption efficiency. The low-cost designation emphasizes the use of affordable components and a simplified design, making the system accessible for a broader range of applications. The effectiveness and efficiency of this will be lesser compared to smart solar tracker which is using Arduino.

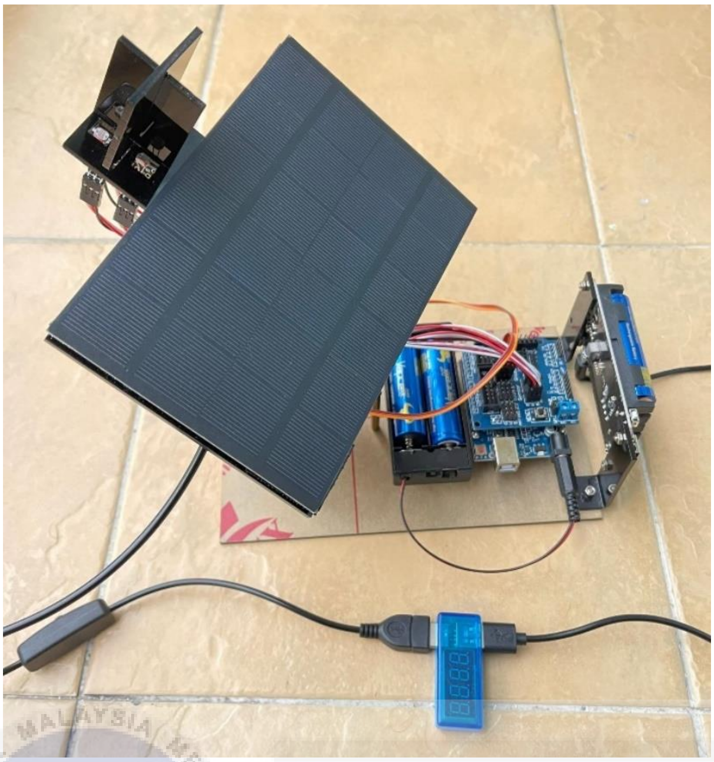

Figure 3.11; Smart solar tracker using Arduino

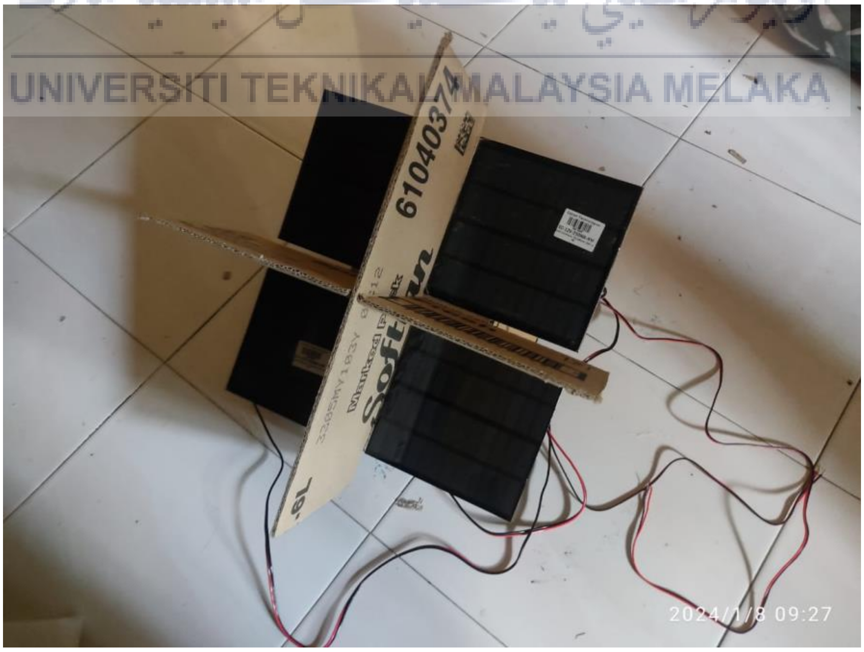

Figure 3.12; Low cost solar tracker using shadow detection.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will be showing the power and battery capacity reading of both traditional solar tracker and smart solar tracker using Arduino. The results were taken between few hours for 5 days which is 15 December 2023, 16 December 2023, 17 December 2023, 18 December 2023, and 19 December 2023. Results taken on different days show the different in efficiency between the traditional solar tracker and smart solar tracker using Arduino on different climates and situations.

4.2 Result Analysis

Result will be shown based on climate of the day and taken at 9 A.M till 6 P.M for every 15 minutes daily for continues 5 days.

4.2.1 Result on 15 December 2023 Sunny and Rainy Day

Table 4.1: Result on 15 December 2023

TIME	TRADITIONAL SOLAR TRACKER (V)	LOW COST SOLAR TRACKER USING SHADOW DETECTION (V)	SMART SOLAR TRACKER USING ARDUINO (V)
9.00 A.M	0	1.32	3.40
9.15 A.M	0	1.50	3.84
9.30 A.M	0	1.53	3.92
9.45 A.M	0	1.62	4.19
10.00 A.M	0	1.70	4.45
10.15 A.M	0	1.54	3.77
10.30 A.M	0	1.58	3.83
10.45 A.M	0	1.60	3.96
11.00 A.M	0	1.75	4.30
11.15 A.M	0	1.89	4.58
11.30 A.M	0.08	1.75	4.27
11.45 A.M	0.50	1.83	4.41
12.00 P.M	1.17	2.0	4.78
12.15 P.M	1.31	2.49	5.43
12.30 P.M	1.59	2.53	5.50
12.45 P.M	1.75	2.62	5.76
1.00 P.M	1.91	2.56	5.64
1.15 P.M	1.84	2.78	5.89
1.30 P.M	1.47	2.81	6.06
1.45 P.M	1.40	2.79	5.90
2.00 P.M	1.01	2.86	6.11
2.15 P.M	0.58	2.81	5.92
2.30 P.M	0.74	2.53	5.39
2.45 P.M	0.45	2.72	5.50
3.00 P.M	0.32	2.67	5.47
3.15 P.M	0.16	2.61	5.32
3.30 P.M	0.08	2.05	4.75
3.45 P.M	0.05	1.94	4.53
4.00 P.M	0	1.87	4.38
4.15 P.M	0	1.83	4.29
4.30 P.M	0	1.05	3.77
4.45 P.M	0	0.32	3.02
5.00 P.M	0	0.31	2.99
5.15 P.M	0	0.31	2.96
5.30 P.M	0	0.17	2.65
5.45 P.M	0	0.15	2.61
6.00 P.M	0	0.14	2.59

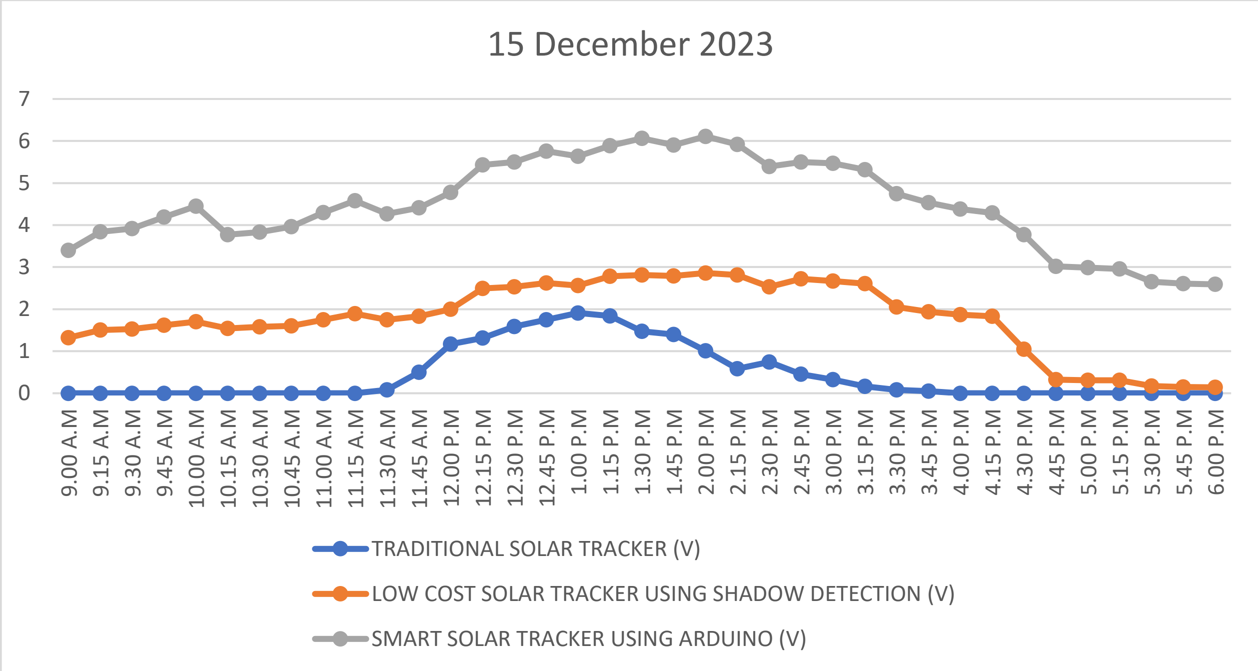

Figure 4.1; Comparison graph of 15 December 2023

The graph above represents the voltage outputs from three solar trackers on December 15, 2023, encompassing both sunny and rainy conditions. In analysing the graph, notable differences emerge between the Traditional Solar Tracker, the Low-Cost Solar Tracker using Shadow Detection, and the Smart Solar Tracker using Arduino.

Firstly, the Traditional Solar Tracker consistently maintains zero voltage, indicating a lack of effective sun tracking throughout the day. The Low-Cost Solar Tracker, incorporating shadow detection, displays a progressive increase in voltage, reaching its highest peak of 2.86 V at 2:00 PM. This peak signifies the tracker's ability to optimize solar panel orientation, although it still falls short of the peaks achieved by the Smart Solar Tracker using Arduino.

The Smart Solar Tracker consistently outperforms its counterparts, showcasing the highest peaks throughout the day. At 2:00 PM, it reaches the maximum peak of 6.11 V, demonstrating superior efficiency in adapting to changing sunlight angles. The Arduino-based control system enables precise solar tracking, resulting in optimal energy production.

In summary, while the Traditional Solar Tracker remains consistently inefficient, both the Low-Cost Solar Tracker and the Smart Solar Tracker using Arduino exhibit peak performance at 2:00 PM. Low-Cost Solar Tracker achieves 2.86 V while Smart Solar Tracker achieves 6.11 V at the peak which is the highest and efficient value compare to both Traditional Solar Tracker and Low-Cost Solar Tracker using Shadow Detention.

4.2.2 Result on 16 December 2023 Sunny, Cloudy and Rainy Day

Table 4.2: Result on 16 December 2023

TIME	TRADITIONAL SOLAR TRACKER(V)	LOW COST SOLAR TRACKER USING SHADOW DETECTION (V)	SMART SOLAR TRACKER USING ARDUINO(V)
9.00 A.M	0	0.08	1.57
9.15 A.M	0	0.18	2.42
9.30 A.M	0	0.11	2.30
9.45 A.M	0	0.06	1.51
10.00 A.M	0	1.00	2.99
10.15 A.M	0	0.06	1.48
10.30 A.M	0	0.07	1.50
10.45 A.M	0	0.06	1.49
11.00 A.M	0	0.06	1.48
11.15 A.M	0	0.03	1.37
11.30 A.M	0.01	0.06	1.46
11.45 A.M	0.03	0.09	1.74
12.00 P.M	0.06	0.07	1.52
12.15 P.M	0.07	0.09	1.69
12.30 P.M	0.09	0.10	1.83
12.45 P.M	0.06	0.11	1.87
1.00 P.M	0.02	0.12	1.90
1.15 P.M	0.01	0.12	1.89
1.30 P.M	0	0.11	1.86
1.45 P.M	0	0.10	1.82
2.00 P.M	0	0.10	1.81
2.15 P.M	0	0.10	1.82
2.30 P.M	0	1.00	2.74
2.45 P.M	0	0.09	1.57
3.00 P.M	0	0.03	1.01
3.15 P.M	0	0.02	0.99
3.30 P.M	0	0.02	1.00
3.45 P.M	0	0.03	1.18
4.00 P.M	0	0.04	1.25
4.15 P.M	0	0.03	1.16
4.30 P.M	0	0.05	1.49
4.45 P.M	0	0.01	0.76
5.00 P.M	0	0.06	1.83
5.15 P.M	0	0.07	1.91
5.30 P.M	0	0.06	1.75
5.45 P.M	0	0.05	1.59
6.00 P.M	0	0.06	1.77

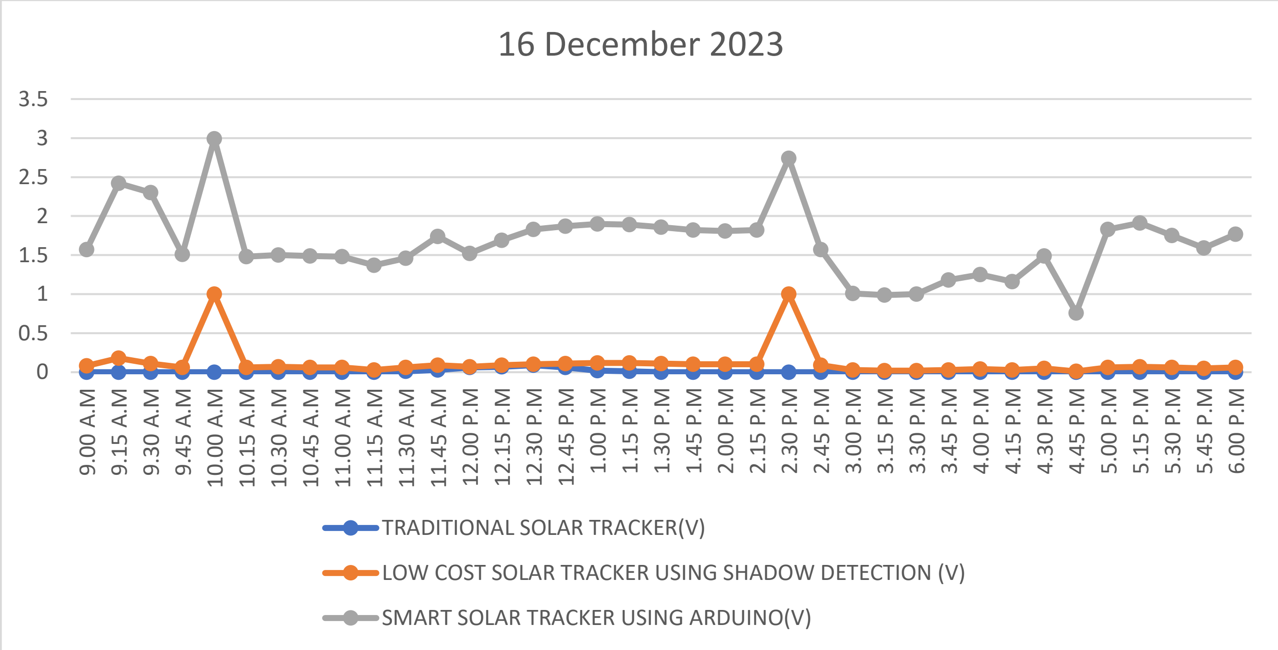

Figure 4.2; Comparison graph of 16 December 2023

The graph above shows the comparison of the voltage outputs from the three solar trackers on December 16, 2023, under varying weather conditions of sunny, cloudy, and rainy reveals interesting insights. Throughout the day, the Traditional Solar Tracker consistently registers zero voltage and the highest value is 0.09V at 12:30 PM, indicating its inability to effectively track the sun regardless of weather conditions. The Low-Cost Solar Tracker using Shadow Detection showcases some adaptability, achieving a peak of 1.00 V at 2:30 PM during a sunny interval. However, it still faces limitations in achieving higher peaks during cloudy or rainy periods.

The Smart Solar Tracker using Arduino stands out with superior performance under diverse weather conditions. It attains its highest peak of 2.99 V at 10:00 AM and 2.74V at 2:30 PM demonstrating its efficiency in optimizing solar panel orientation even on a sunny day. Importantly, it maintains relatively high peaks during cloudy and rainy periods, showcasing its adaptability. While the Low-Cost Solar Tracker achieves a notable peak during sunny intervals, it struggles to maintain efficiency in less favourable weather.

In summary, the graph illustrates that the Smart Solar Tracker using Arduino consistently outperforms both the Traditional and Low-Cost Solar Trackers, achieving higher peaks and maintaining better efficiency under varying weather conditions. The traditional tracker consistently lags, and the Low-Cost Tracker, while showing improvement, still faces challenges in adverse weather conditions compared to the advanced Arduino-based system.

4.2.3 Result on 17 December 2023 Sunny Day

Table 4.3: Result on 17 December 2023

TIME	TRADITIONAL SOLAR TRACKER(V)	LOW COST SOLAR TRACKER USING SHADOW DETECTION (V)	SMART SOLAR TRACKER USING ARDUINO(V)
9.00 A.M	0	1.35	3.51
9.15 A.M	0	1.36	3.54
9.30 A.M	0	1.71	3.89
9.45 A.M	0	1.73	3.95
10.00 A.M	0	1.31	3.43
10.15 A.M	0	1.34	3.48
10.30 A.M	0	1.85	3.94
10.45 A.M	0	1.97	4.06
11.00 A.M	0.13	1.65	3.77
11.15 A.M	0.38	1.86	3.98
11.30 A.M	0.64	2.12	4.32
11.45 A.M	0.79	2.11	4.29
12.00 P.M	1.37	2.22	4.40
12.15 P.M	1.43	2.30	4.46
12.30 P.M	1.45	2.36	4.54
12.45 P.M	1.49	2.50	4.71
1.00 P.M	1.46	2.45	4.63
1.15 P.M	1.39	2.78	4.89
1.30 P.M	1.17	2.86	5.26
1.45 P.M	0.74	2.83	5.21
2.00 P.M	0.40	2.82	5.17
2.15 P.M	0.17	2.75	5.03
2.30 P.M	0.07	2.66	4.84
2.45 P.M	0.01	2.55	4.78
3.00 P.M	0	2.62	4.89
3.15 P.M	0	2.47	4.63
3.30 P.M	0	2.53	4.76
3.45 P.M	0	2.60	4.85
4.00 P.M	0	2.37	4.57
4.15 P.M	0	2.39	4.62
4.30 P.M	0	2.36	4.59
4.45 P.M	0	2.30	4.41
5.00 P.M	0	2.10	4.24
5.15 P.M	0	2.12	4.28
5.30 P.M	0	2.23	4.39
5.45 P.M	0	1.62	3.76
6.00 P.M	0	1.51	3.63

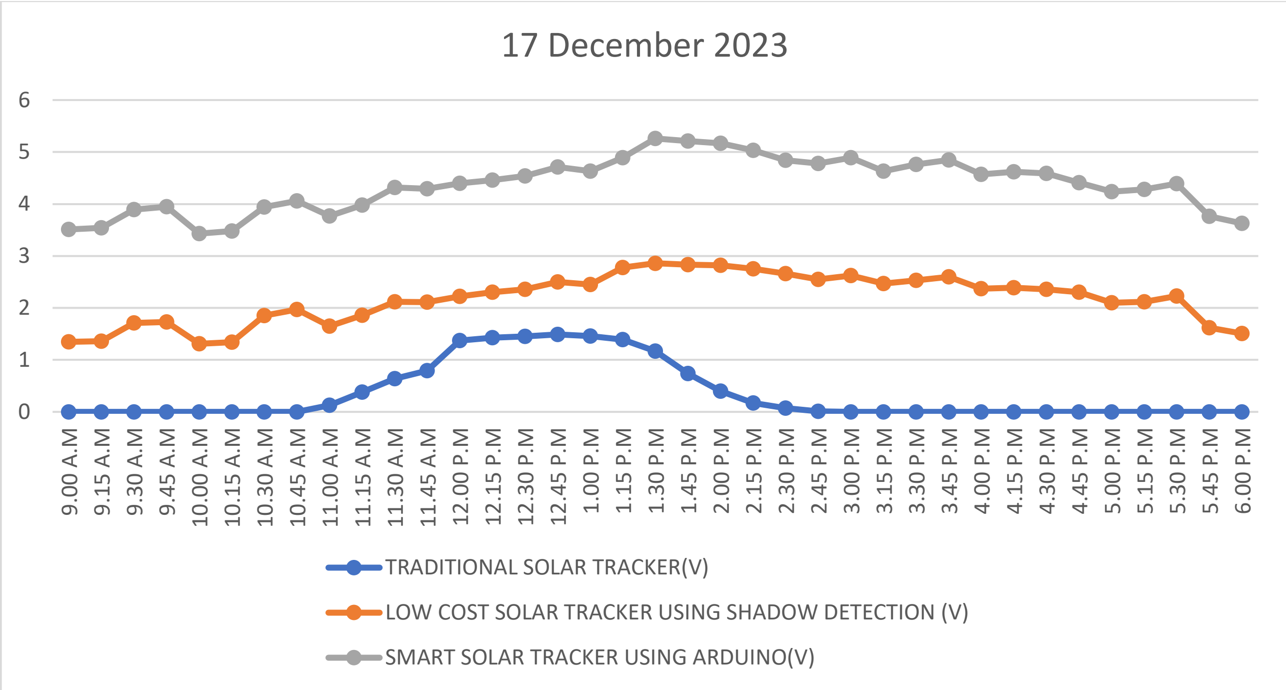

Figure 4.3; Comparison graph of 17 December 2023

The voltage outputs from three solar trackers on a sunny day, December 17, 2023, exhibit notable differences in their performance. The Traditional Solar Tracker consistently maintains zero voltage and the highest peak is 1.49V at 12:45 PM, indicating its limited efficiency in capturing solar energy. The Low-Cost Solar Tracker, incorporating shadow detection, shows improved performance, reaching a peak of 2.86 V at 1:30 PM. However, it is outperformed by the Smart Solar Tracker using Arduino, which consistently achieves higher peaks. The Arduino-based system demonstrates its technological superiority, reaching the highest peak of 5.26 V at 1:30 PM.

Analysing the peaks and lows, the Traditional Solar Tracker consistently lags, while the Low-Cost Tracker achieves moderate efficiency. The highest peak for the Low-Cost Tracker occurs at 2:00 PM, demonstrating its ability to adapt to changing sunlight angles. In contrast, the Smart Solar Tracker using Arduino showcases superior adaptability and precision in solar tracking, achieving its highest peak earlier in the day at 1:30 PM.

The detailed analysis of the peaks reveals that the Traditional Solar Tracker consistently fails to harness solar energy effectively, whereas the Smart Solar Tracker using Arduino emerges as the most efficient, achieving the highest peak among the three. This comparison highlights the significance of advanced technologies, such as Arduino-based control, in optimizing solar tracking for maximum energy production.

4.2.4 Result on 18 December 2023 Sunny Day

Table 4.4: Result on 18 December 2023

TIME	TRADITIONAL SOLAR TRACKER(V)	LOW COST SOLAR TRACKER USING SHADOW DETECTION (V)	SMART SOLAR TRACKER USING ARDUINO(V)
9.00 A.M	0	1.37	3.63
9.15 A.M	0	1.33	3.51
9.30 A.M	0	1.46	3.79
9.45 A.M	0	1.48	3.86
10.00 A.M	0	1.31	3.60
10.15 A.M	0	1.67	3.98
10.30 A.M	0	1.85	4.27
10.45 A.M	0	1.92	4.41
11.00 A.M	0	1.65	3.94
11.15 A.M	0	1.61	3.89
11.30 A.M	0.21	1.85	4.18
11.45 A.M	0.49	2.14	4.62
12.00 P.M	0.45	2.12	4.59
12.15 P.M	0.47	2.25	4.76
12.30 P.M	0.58	2.36	4.95
12.45 P.M	0.76	2.52	5.24
1.00 P.M	0.94	2.70	5.62
1.15 P.M	1.15	2.79	5.77
1.30 P.M	1.23	2.94	5.99
1.45 P.M	1.27	2.98	6.13
2.00 P.M	1.03	2.97	6.08
2.15 P.M	0.71	2.82	5.81
2.30 P.M	0.46	2.83	5.88
2.45 P.M	0.23	2.55	5.46
3.00 P.M	0.04	2.37	5.32
3.15 P.M	0	2.46	5.44
3.30 P.M	0	2.54	5.61
3.45 P.M	0	2.59	5.75
4.00 P.M	0	2.38	5.43
4.15 P.M	0	2.37	5.39
4.30 P.M	0	2.26	5.17
4.45 P.M	0	2.33	5.38
5.00 P.M	0	1.82	4.94
5.15 P.M	0	1.78	4.79
5.30 P.M	0	1.83	4.90
5.45 P.M	0	1.61	4.66
6.00 P.M	0	1.52	4.45

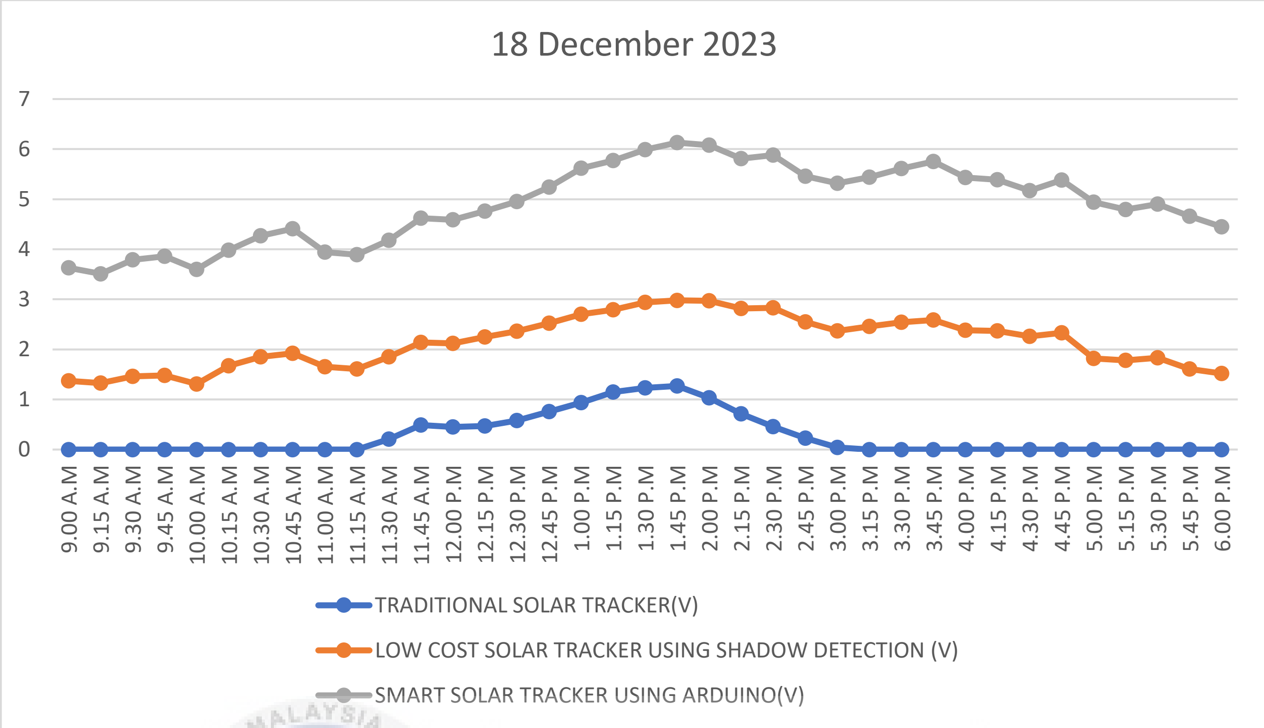

Figure 4.4; Comparison graph of 18 December 2023

On a sunny day, December 18, 2023, the voltage outputs from the three solar trackers showcase distinct performance characteristics. The Traditional Solar Tracker consistently registers zero voltage throughout the day and the peak achived is 1.27V at 2:45 PM, emphasizing its limited capability in effectively harnessing solar energy. The Low-Cost Solar Tracker using Shadow Detection exhibits moderate efficiency, reaching a peak of 2.98 V at 1:45 PM. This tracker demonstrates adaptability in optimizing solar panel orientation, especially during midday sunny intervals.

The Smart Solar Tracker using Arduino outperforms both counterparts, consistently achieving higher peaks. Its highest peak of 6.13 V occurs at 1:45 PM, showcasing advanced technology and precise solar tracking capabilities. The Arduino-based system demonstrates superior adaptability to changing sunlight angles and effectively maximizes energy production throughout the day.

Analyzing the peaks and lows, the Traditional Solar Tracker consistently falls short, while the Low-Cost Tracker achieves moderate efficiency. The Smart Solar Tracker using Arduino stands out with its impressive peak, emphasizing the significant impact of advanced technologies in optimizing solar tracking for maximum energy yield. This comparison underscores the crucial role of technology in enhancing the efficiency of solar trackers, especially in maximizing energy output under optimal sunny conditions.

4.2.5 Result on 19 December 2023 Sunny and Rainy Day

Table 4.5: Result on 19 December 2023

TIME	TRADITIONAL SOLAR TRACKER(V)	LOW COST SOLAR TRACKER USING SHADOW DETECTION (V)	SMART SOLAR TRACKER USING ARDUINO(V)
9.00 A.M	0	0.08	1.56
9.15 A.M	0	0.09	1.64
9.30 A.M	0	0.45	2.17
9.45 A.M	0	0.35	1.93
10.00 A.M	0	0.66	2.41
10.15 A.M	0	0.29	1.87
10.30 A.M	0	0.58	2.12
10.45 A.M	0	0.62	2.25
11.00 A.M	0	1.01	2.86
11.15 A.M	0	1.15	2.98
11.30 A.M	0.03	0.83	2.77
11.45 A.M	0.11	0.75	2.63
12.00 P.M	0.24	1.36	3.19
12.15 P.M	0.46	2.47	5.32
12.30 P.M	1.10	2.55	5.50
12.45 P.M	1.24	2.57	5.57
1.00 P.M	1.58	2.81	5.78
1.15 P.M	1.36	2.53	5.39
1.30 P.M	1.17	2.56	5.45
1.45 P.M	0.75	2.81	5.78
2.00 P.M	0.49	2.87	5.86
2.15 P.M	0.23	2.78	5.69
2.30 P.M	0.14	2.53	5.37
2.45 P.M	0.07	2.72	5.53
3.00 P.M	0	2.65	5.42
3.15 P.M	0	2.87	5.71
3.30 P.M	0	2.55	5.39
3.45 P.M	0	2.19	4.90
4.00 P.M	0	1.90	4.68
4.15 P.M	0	1.86	4.59
4.30 P.M	0	1.31	3.99
4.45 P.M	0	1.06	3.57
5.00 P.M	0	1.07	3.61
5.15 P.M	0	0.81	3.35
5.30 P.M	0	0.39	2.89
5.45 P.M	0	0.26	2.76
6.00 P.M	0	0.15	2.58

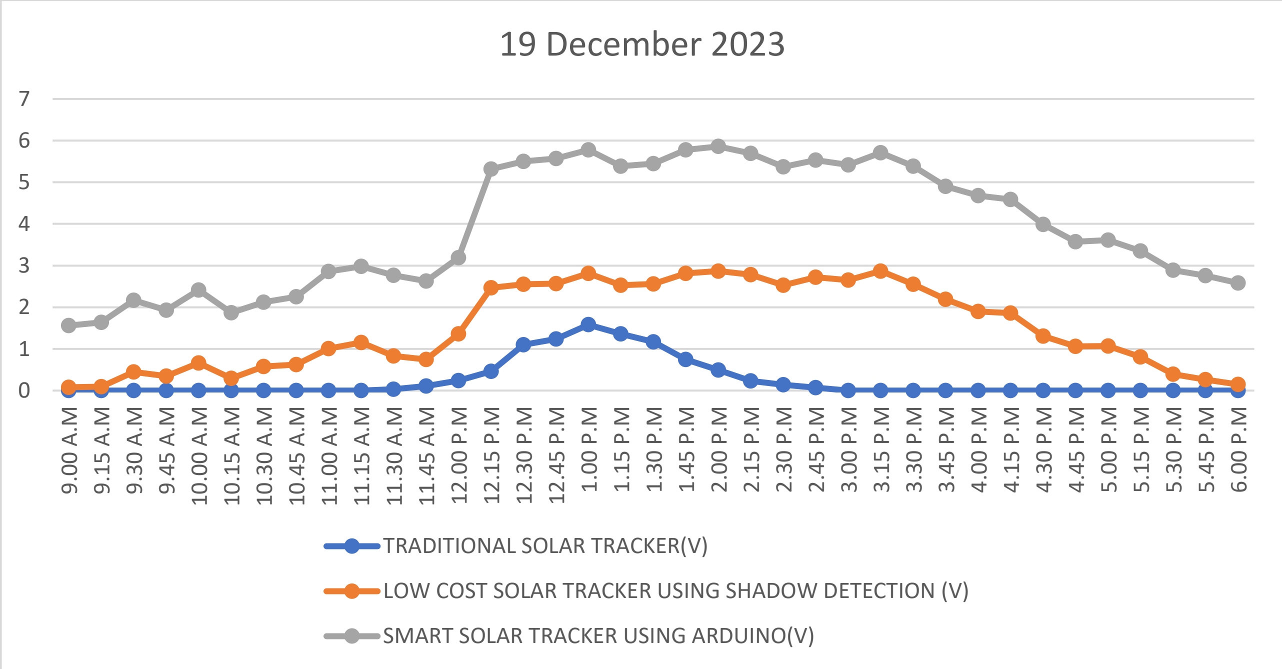

Figure 4.5; Comparison graph of 19 December 2023

On December 19, 2023, with a combination of sunny and rainy weather, the voltage outputs from the three solar trackers reveal distinctive performance patterns. The Traditional Solar Tracker consistently registers zero voltage and the highest peak was 1.58V at 1:00 PM, indicating its limitations in capturing solar energy, regardless of weather conditions. The Low-Cost Solar Tracker using Shadow Detection exhibits adaptability, achieving a peak of 2.87 V at 2:00 PM during a sunny interval. This tracker showcases improved efficiency, especially in optimal sunlight conditions, but struggles to maintain high peaks during rainy intervals.

The Smart Solar Tracker using Arduino emerges as the most efficient, achieving the highest peak of 5.86 V at 2:00 PM, demonstrating its advanced technology and precise solar tracking capabilities. The Arduino-based system maintains relatively high peaks even during rainy intervals, showcasing its adaptability and effectiveness in maximizing energy production.

Analysing the peaks and lows, the Traditional Solar Tracker consistently lags behind, and the Low-Cost Tracker achieves moderate efficiency, especially in sunny intervals. The Smart Solar Tracker using Arduino consistently outperforms both counterparts, underscoring the significant impact of advanced technologies in optimizing solar tracking for maximum energy yield under diverse weather conditions. This comparison highlights the crucial role of technology in enhancing the efficiency of solar trackers, ensuring a consistent energy output even during changing weather conditions.

4.2.6 Average Voltage Reading over 5 Days

Table 4.6: Average voltage reading result of 5 days

DATE	TRADITIONAL SOLAR TRACKER(V)	LOW COST SOLAR TRACKER USING SHADOW DETECTION (V)	SMART SOLAR TRACKER USING ARDUINO(V)
15 December 2023	0.44	1.80	4.49
16 December 2023	0.01	0.12	1.66
17 December 2023	0.35	2.18	4.37
18 December 2023	0.27	2.14	4.90
19 December 2023	0.24	1.53	3.92

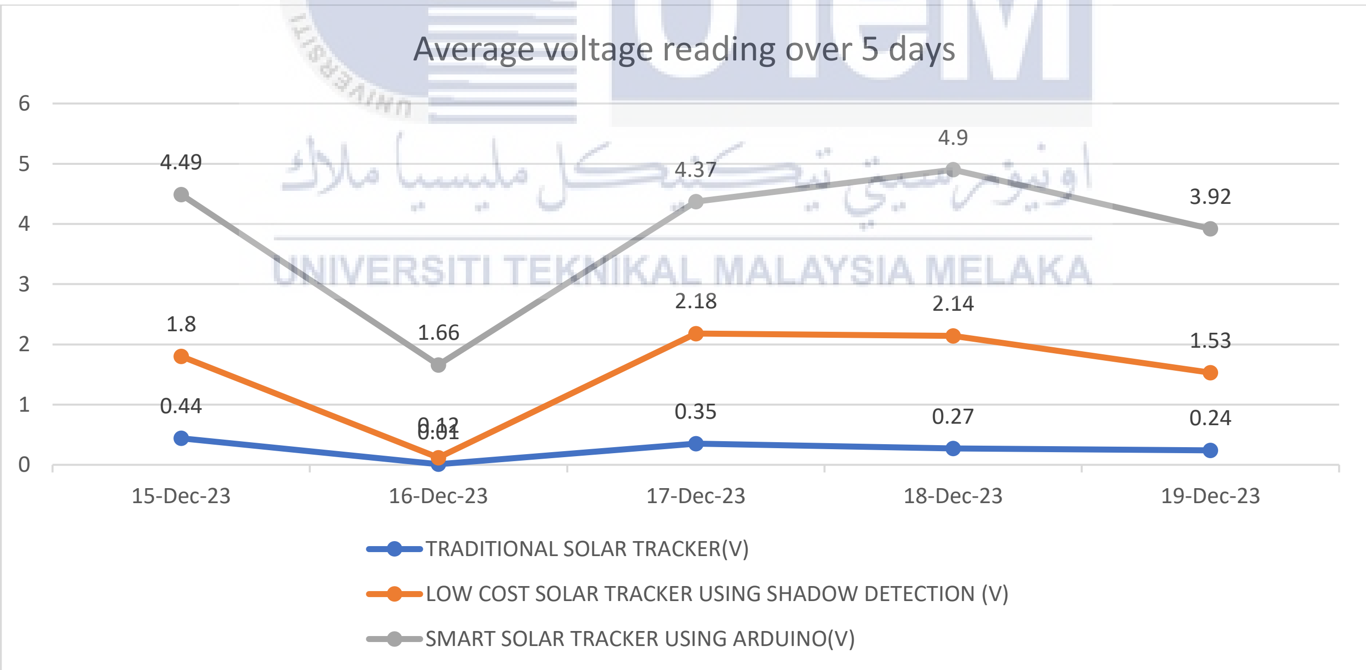

Figure 4.6; Comparison graph of 5 days

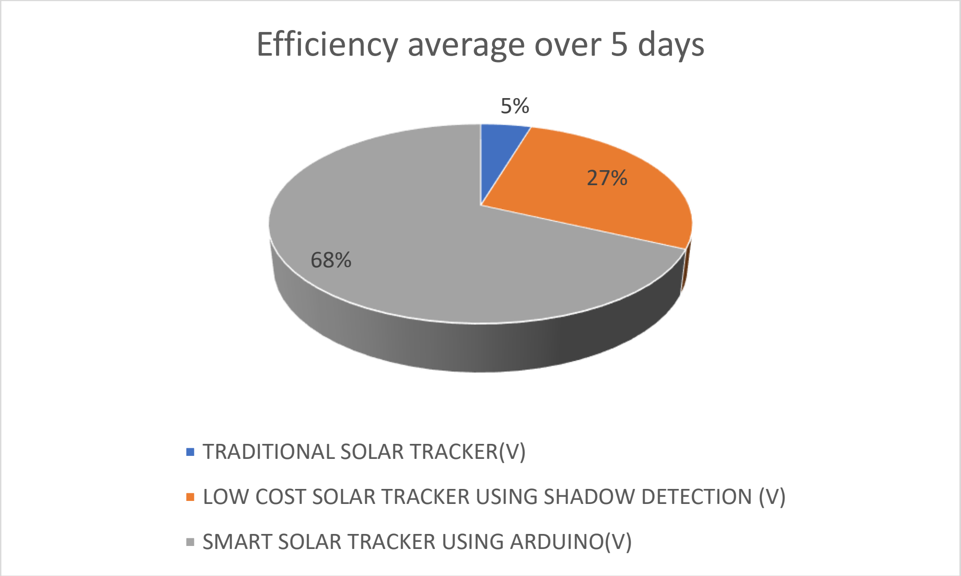

Figure 4.7; Comparison efficiency of 5 days

The examination of average voltage readings spanning five days, encompassing diverse weather conditions of sunny day, cloudy day, and rainy day reveals intriguing engineering insights into the performance of three distinct solar trackers. The Traditional Solar Tracker consistently exhibited the lowest average voltage readings, ranging from 0.24 V to 0.44 V across the five days. The overall efficiency output is 5%. This trend underscores its limited efficiency in harnessing solar energy, as it struggled to adapt to varying sunlight intensities and weather conditions. The conventional tracker's performance variability, even under different climatic conditions, indicates its inherent limitations in maximizing energy capture.

In contrast, the Low-Cost Solar Tracker using Shadow Detection demonstrated an intermediate performance with average voltage readings ranging from 0.12 V to 2.18 V. The overall efficiency is 27%. The wider range of values suggests its ability to adapt to changing sunlight conditions through shadow detection mechanisms. However, the tracker exhibited sensitivity to weather fluctuations, with voltage outputs fluctuating more noticeably during cloudy and rainy days. This adaptability, while commendable, implies a degree of vulnerability to environmental factors.

The standout performer was the Smart Solar Tracker using Arduino, consistently yielding higher and more stable average voltage readings between 1.66 V and 4.90 V. The overall efficiency is 68%. The advanced control mechanisms of the Arduino-based system demonstrated remarkable efficiency in optimizing solar tracking, even amidst varying climatic conditions. Notably, the tracker showcased superior stability and resilience, maintaining relatively high voltage outputs even on cloudy and rainy days. This resilience is a significant advantage, ensuring continuous energy production despite adverse weather conditions, thus addressing a critical concern in solar energy systems.

From an engineering standpoint, these findings underscore the critical role of advanced control systems, such as Arduino-based technology, in mitigating the impact of changing weather conditions on solar tracker performance. The ability to precisely adjust panel orientation and optimize energy capture in real-time is a significant advantage in ensuring consistent and efficient energy production. In term of costing smart solar tracker is 3 times higher compared to tradisional solar tracker whereas in terms of efficiency smart solar tracker using Arduino is 10 times compared to tradisional solar tracker. This comprehensive analysis not only highlights the importance of technological advancements in solar tracking systems but also emphasizes the need for robust designs that can operate seamlessly in diverse climatic scenarios. The Smart Solar Tracker's ability to deliver consistent and elevated voltage outputs in adverse weather conditions positions it as a promising solution for reliable and resilient solar energy harvesting systems.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In a nutshell of the Design and Implementation of a Smart Solar Tracker Using Arduino for Enhanced Energy Efficiency is a significant advancement in renewable energy technology. The main objective of this thesis was to understand, develop, and finally construct an intelligent solar tracking system that used Arduino microcontrollers to dynamically improve solar panel orientation. This effort was motivated by the need to overcome the limits of fixed solar systems, which frequently suffer from diminished efficiency due to insufficient sunlight exposure angles. This technology automatically modified the orientation of solar panels to correspond with the position of the sun, ensuring maximum sunlight exposure throughout the day. To evaluate the system's efficiency, reliability, and dependence on energy output, extensive testing and data collecting were carried out under a variety of environmental circumstances.

The findings precisely confirm the project's primary objective of increasing energy efficiency in solar power generation. In term of costing smart solar tracker is 3 times higher compared to tradisional solar tracker whereas in terms of efficiency smart solar tracker using Arduino is 10 times which is 100 percentage more efficient compared to tradisional solar tracker. By reacting to changing sunlight angles, the Smart Solar Tracker frequently performs static installations, resulting in a significant enhance in energy generation. The research provides beneficial information for renewable energy researchers and practitioners by searching into issues with design, resolving implementation problems, and enhancing performance. Because the Smart Solar Tracker is a tangible result of this study, it represents the project's successful completion. This accomplishment is not limited to theoretical advances; it offers potential for real-world applications, leading the way for a future in which better energy efficiency through smart solar monitoring is an essential component of sustainable energy solutions. In conclusion, the Design and Implementation of a Smart Solar Tracker Using Arduino not only achieved its stated goals, but it also developed the way for future advancement and innovation in the growing sector of renewable energy.

5.2 Recommendation

Two significant changes may be done to improve the efficiency of a smart solar tracker powered by Arduino. First of all, implementing Internet of Things (IoT) technology allows for monitoring and control from afar via a mobile application, giving users the flexibility to change settings at any moment. This development not only simplifies user engagement, but it also allows for real-time tracking modifications, which maximise solar panel orientation depending on changing conditions in the environment. Second, integrating a bigger capacity battery storage system improves energy storage capacities, allowing the solar tracker to run for longer periods of time, particularly during low sunlight or at night. This increased energy storage reassures a continuous power supply, adding to the smart solar tracker's increased dependability and overall performance. These developments, when combined, lay the path for a more user-friendly and efficient solar tracking system that combines remote accessibility with increased energy autonomy.

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APPENDIX

APPENDIX A Arduino Coding for servo angle installation and calibration

```
#include <Servo.h>

#define SERVOPINH  5 //horizontal servo
#define SERVOPINV  6 //vertical servo
bool operation_flag=true;

// Horizontal servo settings
Servo horizontal;             //horizontal servo
int servoh = 90;              //Initialize angle
int servohLimitHigh = 180;    //The maximum angle of rotation in the horizontal direction
int servohLimitLow = 0;       //The minimum angle of rotation in the horizontal direction

// Vertical Servo Settings
Servo vertical;               //vertical servo
int servov = 90;              //Initialize angle
int servovLimitHigh = 180;    //The maximum angle of rotation in the vertical direction
int servovLimitLow = 90;      //The minimum angle of rotation in the vertical direction


void setup()
{
  horizontal.attach(SERVOPINH);
  vertical.attach(SERVOPINV);
  horizontal.write(servoh);
  vertical.write(servov);
}


void loop()
{
}
```

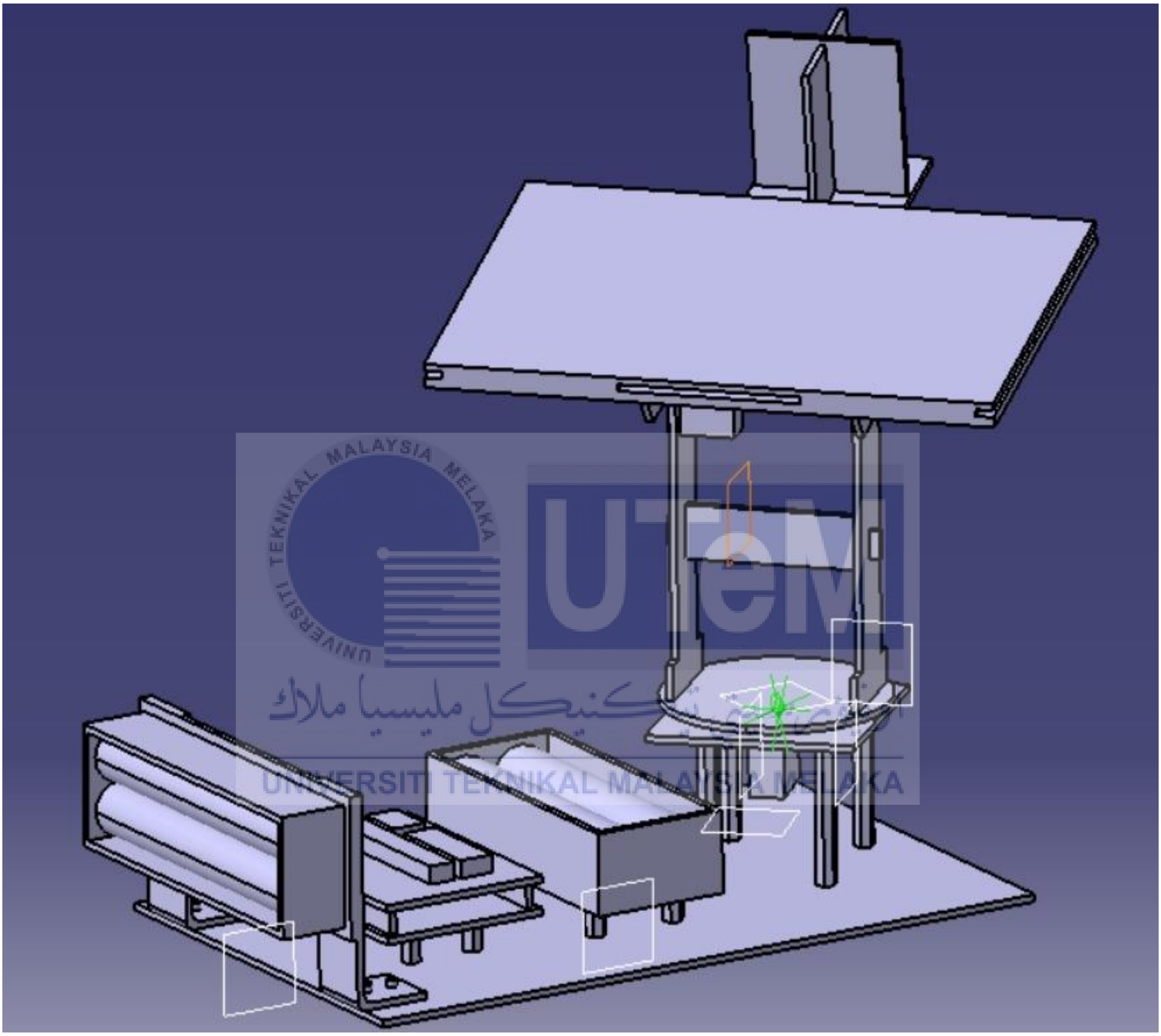
APPENDIX B Arduino programming coding for Solar Tracking

```
 #include <Servo.h>

#define SERVOPINH  7 // horizontal servo
#define SERVOPINV  6 // vertical servo

int tol = 120;       // The response range of illuminance
int dtime = 100;      // Delay parameter

// Horizontal servo settings
Servo horizontal;
int servoh = 90;
int servohLimitHigh = 180;
int servohLimitLow = 0;

// Vertical Servo Settings
Servo vertical;
int servov = 120;
int servovLimitHigh = 180;
int servovLimitLow = 0;

// 4 connection ports for photoresistor modules
const int ldrlt = A0;   // top left
const int ldrrt = A1;   // top right
const int ldrld = A2;   // down left
const int ldrrd = A3;   // down right

int prevServov = -1;
int prevServoh = -1;

void adjustServo(int &servoVar, int servoLimitLow, int servoLimitHigh, bool
condition) {
  if (condition) {
    servoVar++;
    if (servoVar > servoLimitHigh) {
      servoVar = servoLimitHigh;
    }
  } else if (!condition) {
    servoVar--;
    if (servoVar < servoLimitLow) {
      servoVar = servoLimitLow;
    }
  }
}

void setup() {
  horizontal.attach(SERVOPINH);
```

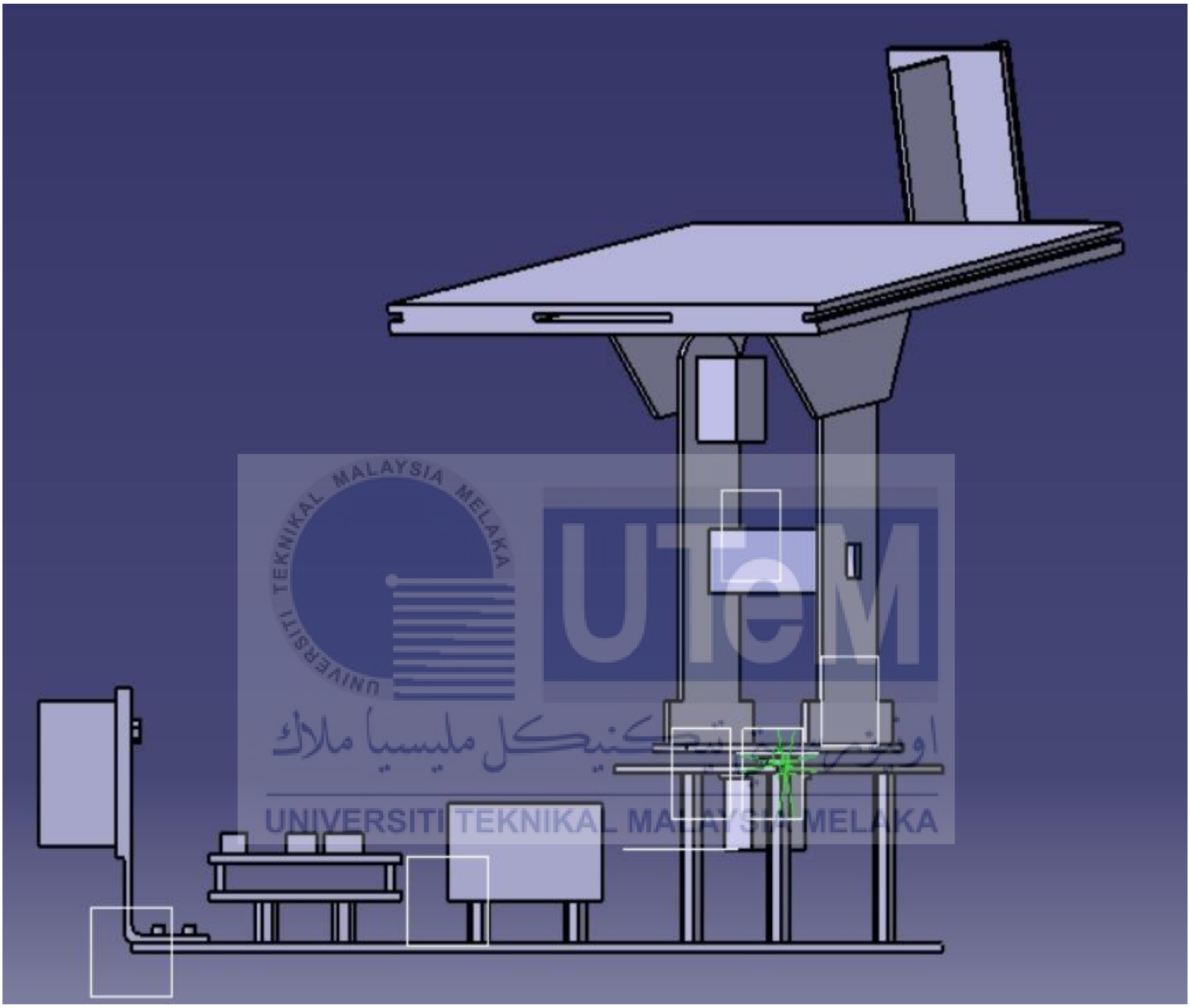
```
  vertical.attach(SERVOPINV);
  horizontal.write(servoh);
  vertical.write(servov);
  delay(100);
  Serial.begin(9600);
}

void loop() {
  // Read the illuminance values of 4 photoresistor modules respectively
  int lt = analogRead(ldrlt); // upper left
  int rt = analogRead(ldrrt); // top right
  int ld = analogRead(ldrld); // down left
  int rd = analogRead(ldrrd); // down right
  // Average readings from adjacent photoresistor modules
  int avt = (lt + rt) / 2;
  int avd = (ld + rd) / 2;
  int avl = (lt + ld) / 2;
  int avr = (rt + rd) / 2;
  int veg = (avt + avd + avl + avr) / 4;
  Serial.print(" lt:"); Serial.print(lt); Serial.print(" rt:");
Serial.print(rt); Serial.print(" ld:"); Serial.print(ld); Serial.print("
rd:"); Serial.print(rd);
  Serial.print(" avt:"); Serial.print(avt); Serial.print(" avd:");
Serial.print(avd); Serial.print(" avl:"); Serial.print(avl); Serial.print("
avr:"); Serial.print(avr);
  Serial.print(" veg:"); Serial.print(veg);

  // Then calculate the difference between the upper and lower rows and the
average value of the left and right rows
  int dvert = avt - avd;    // upper and lower rows
  int dhoriz = avl - avr;   // left and right rows
  Serial.print(" dvert= "); Serial.print(dvert);
  Serial.print(" dhoriz= "); Serial.print(dhoriz);

  // Check if the difference is within tolerance, otherwise change the
vertical angle
  if (-1 * tol > dvert || dvert > tol) {
    adjustServo(servov, servovLimitLow, servovLimitHigh, avt > avd);
  }
  // Check if the difference is within tolerance, otherwise change the
horizontal angle
  if (-1 * tol > dhoriz || dhoriz > tol) {
    adjustServo(servoh, servohLimitLow, servohLimitHigh, avr > avl);
  }
  //servoh=180;//servov=90;//servov -90-90, servoh 0-180
  //servov=-90;
  Serial.print(" servoh= "); Serial.print(servoh);
  Serial.print(" servov= "); Serial.println(servov);
```

```
  if (servov != prevServov) {
    vertical.writeMicroseconds(map(servov-90, 0, 180, 1000, 2000));
    prevServov = servov;
  }
  if (servoh != prevServoh) {
    horizontal.writeMicroseconds(map(servoh, 0, 180, 1000, 2000));
    prevServoh = servoh;
  }

  delay(dtime);
}
```

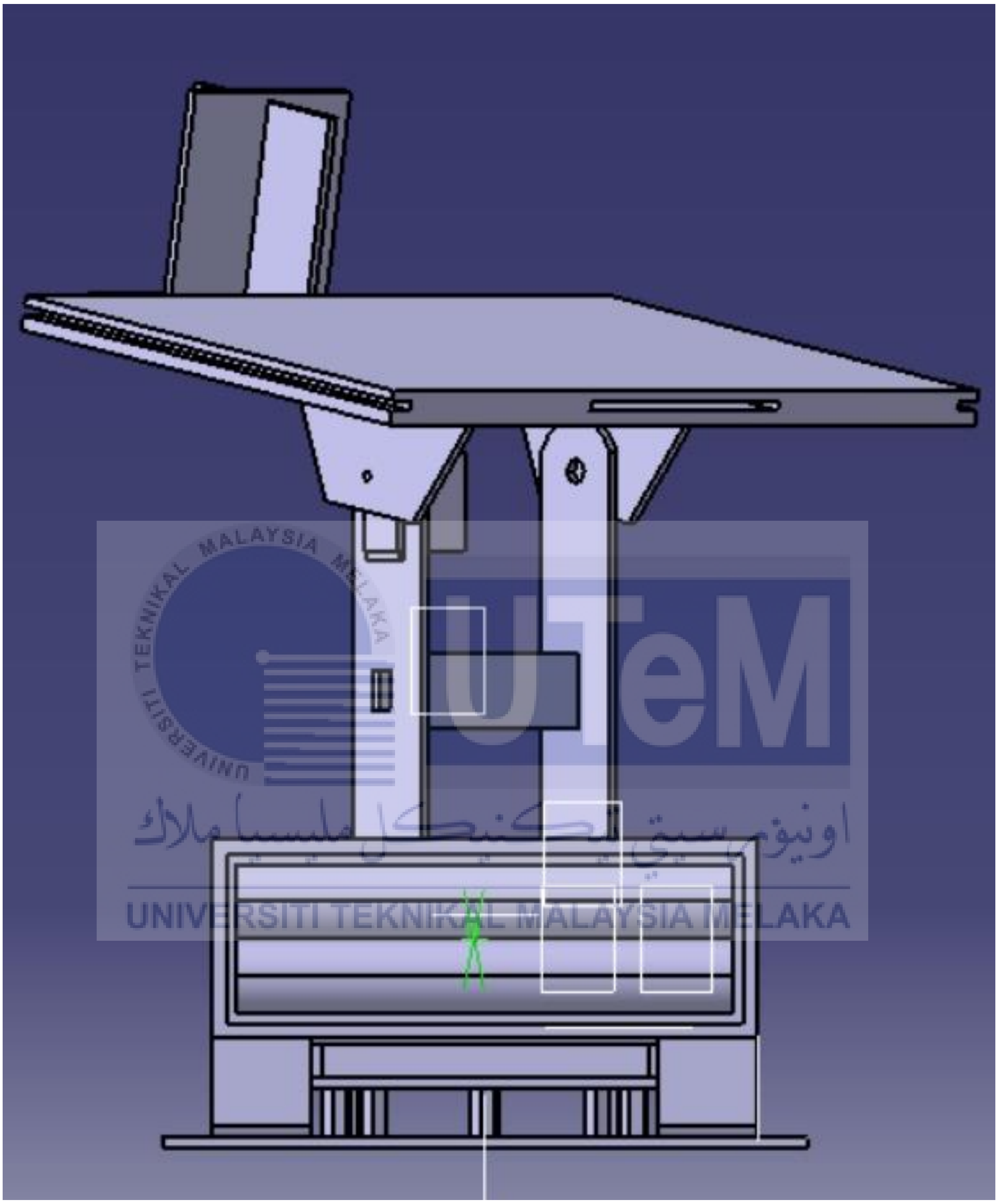
APPENDIX C Technical Drawing of Smart Solar Tracker using Arduino



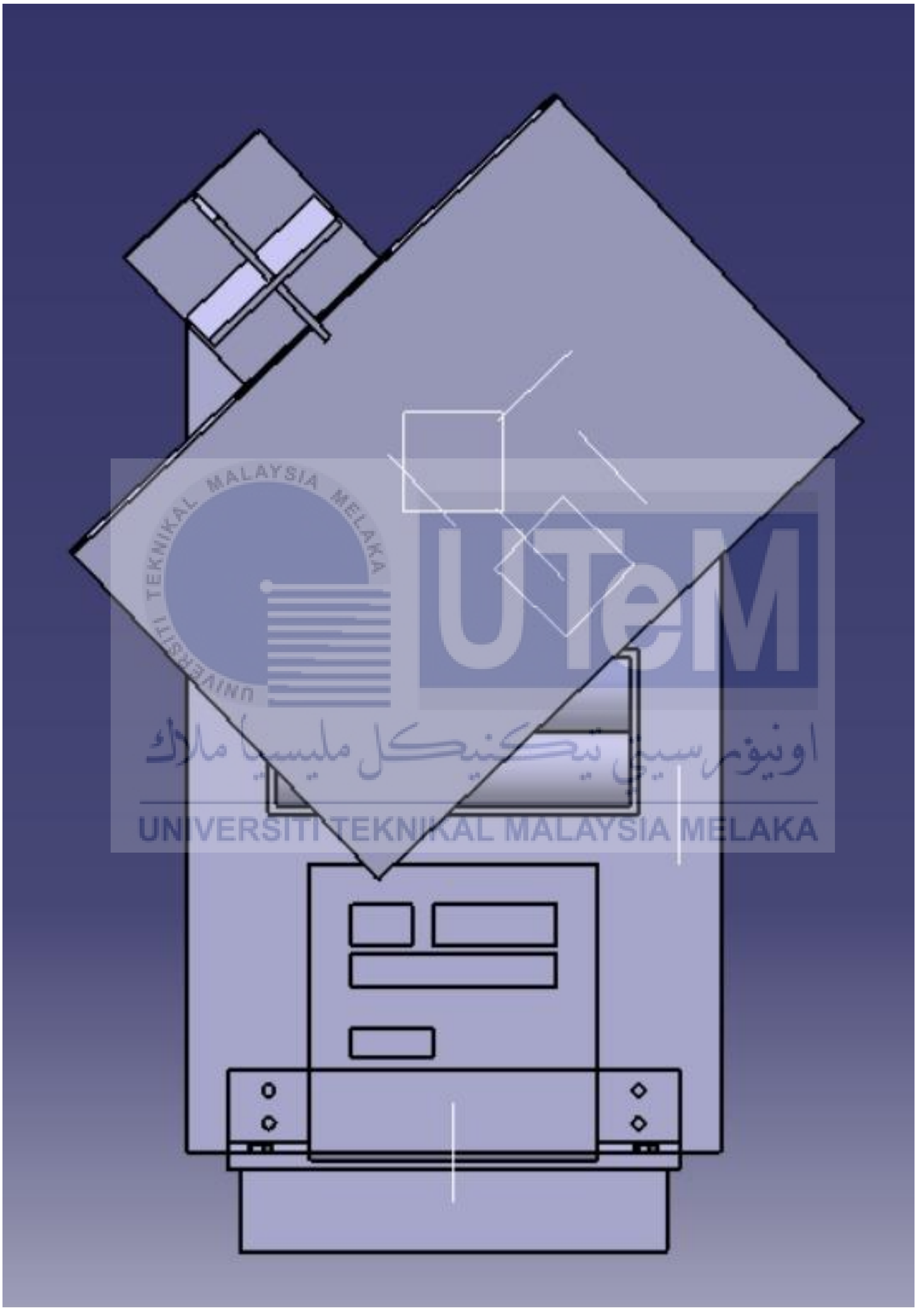
APPENDIX D Side View of Technical Drawing



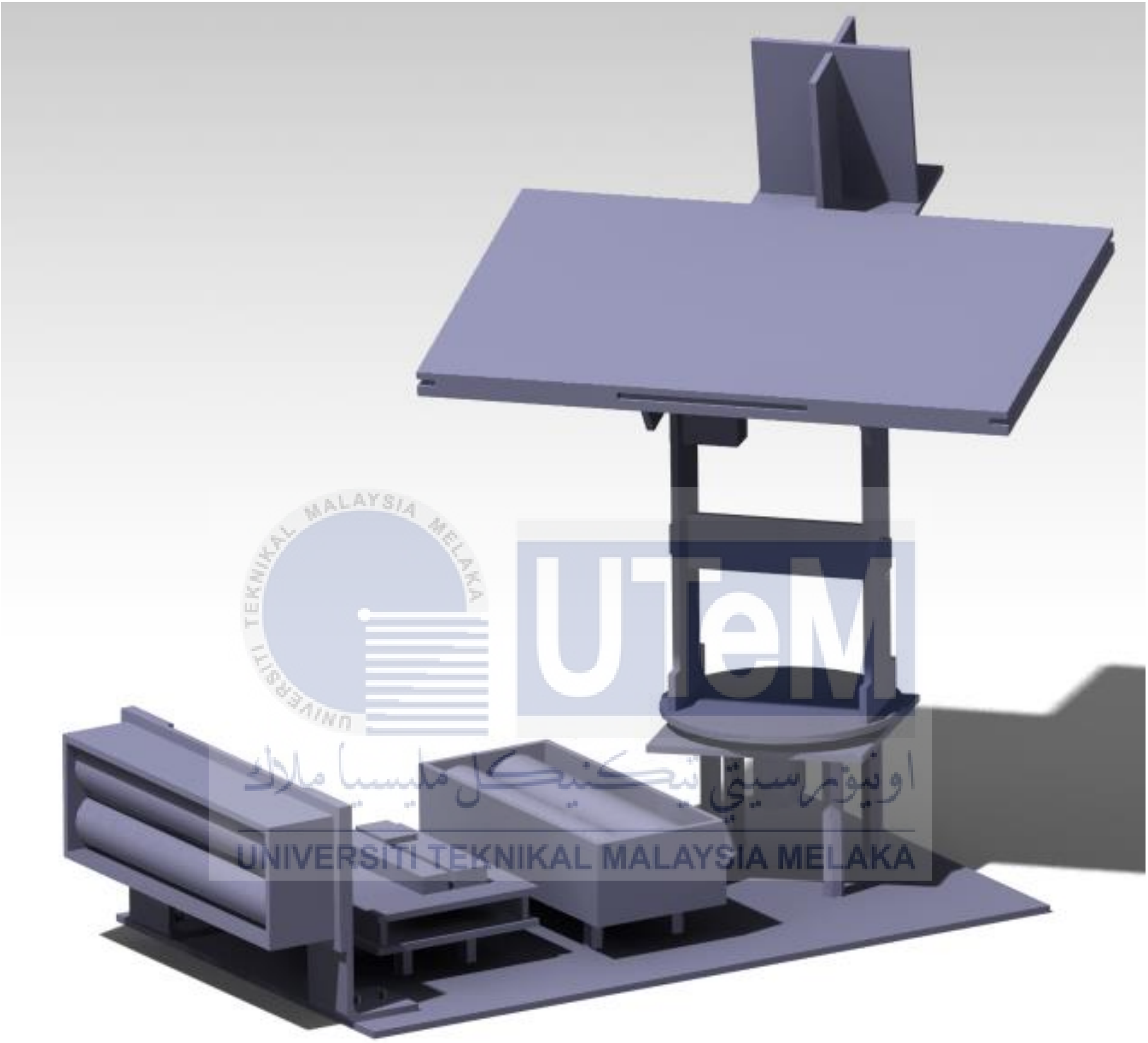
APPENDIX E Front View of Technical Drawing



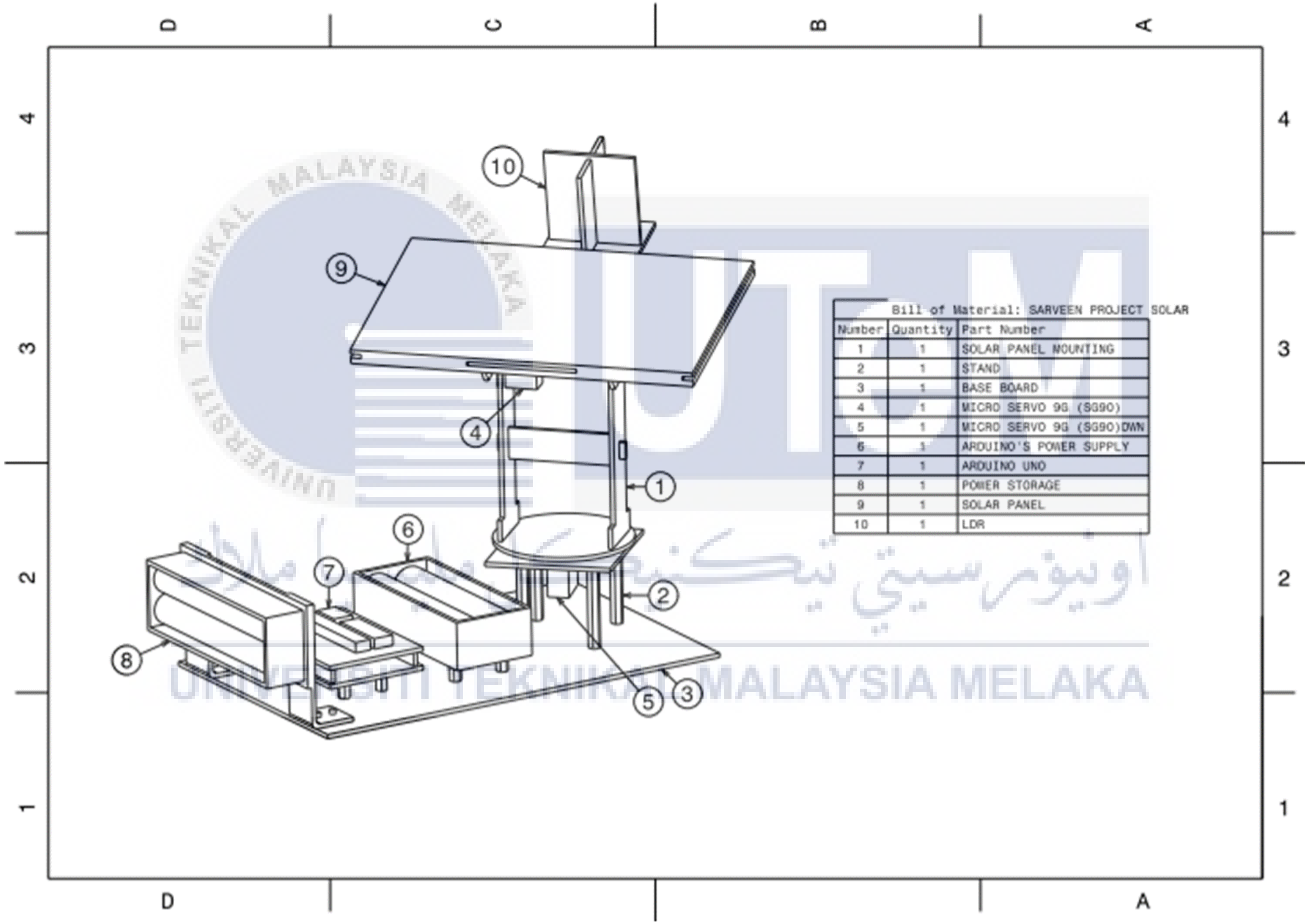
APPENDIX F Top View of Technical Drawing



APPENDIX G Isometric View of Smart Solar tracker using Arduino



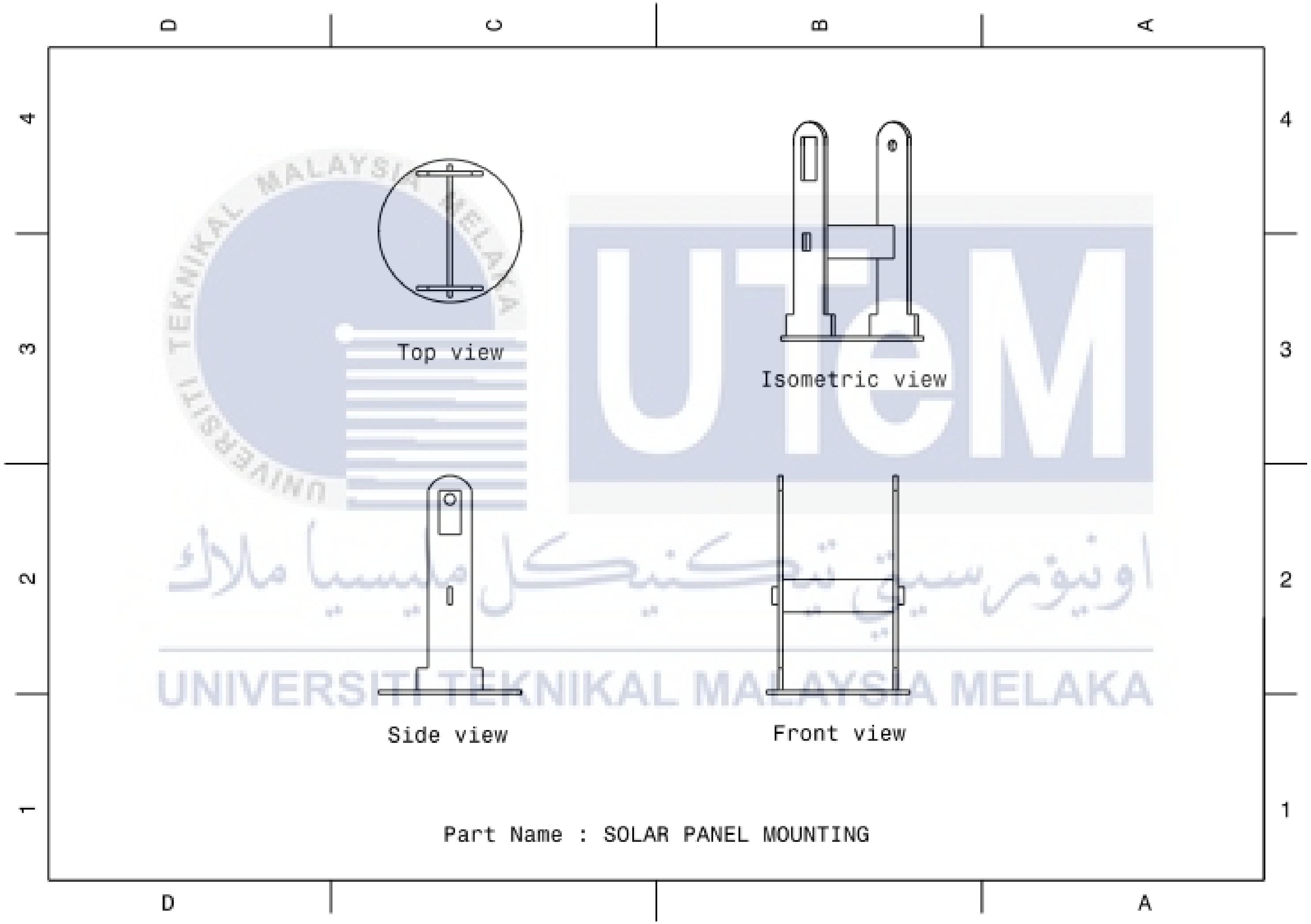
APPENDIX H Bill of Material



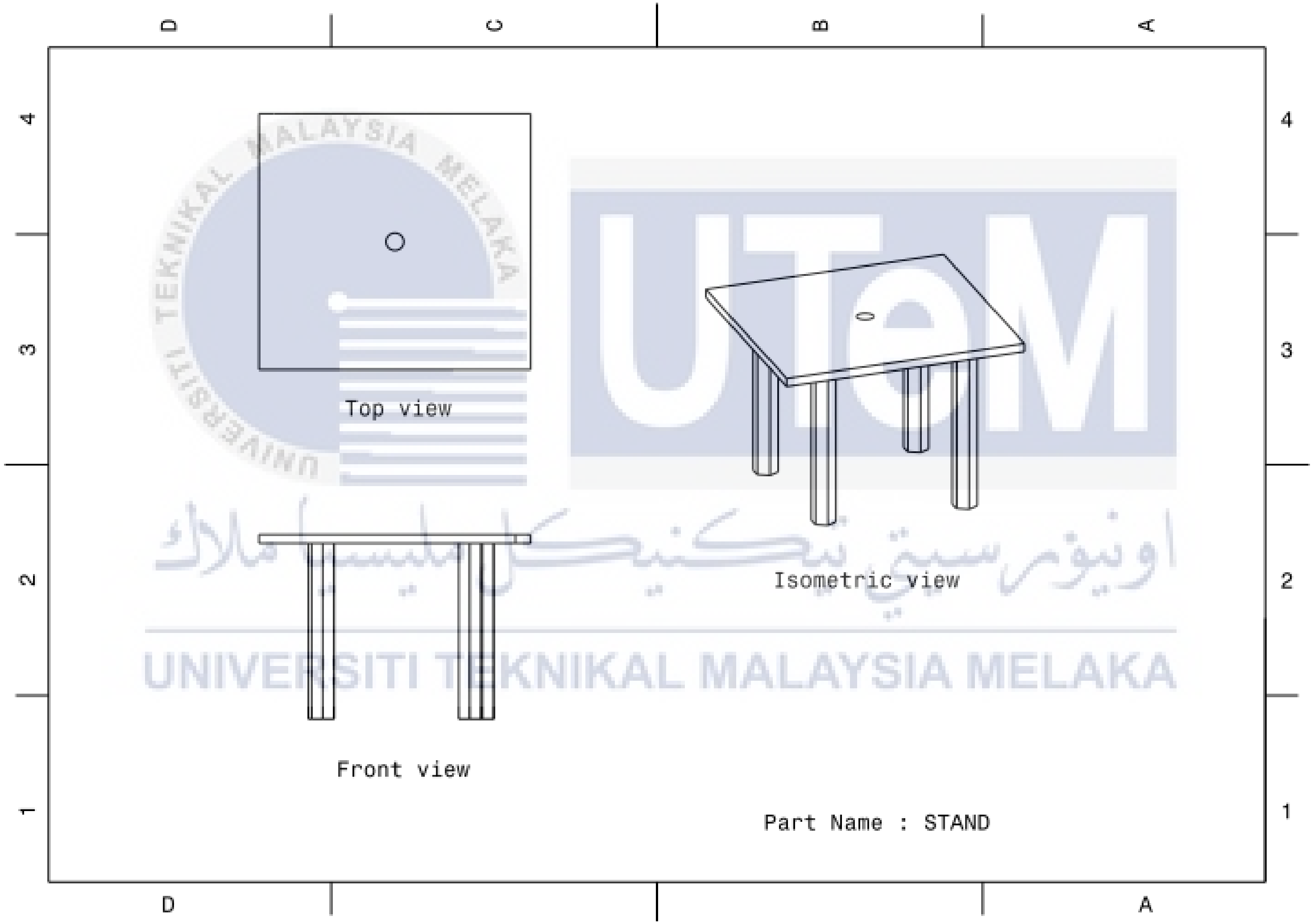
Bill of Material: SARVEEN PROJECT SOLAR

Number	Quantity	Part Number
1	1	SOLAR PANEL MOUNTING
2	1	STAND
3	1	BASE BOARD
4	1	MICRO SERVO 9G (SG90)
5	1	MICRO SERVO 9G (SG90)DWN
6	1	ARDUINO'S POWER SUPPLY
7	1	ARDUINO UNO
8	1	POWER STORAGE
9	1	SOLAR PANEL
10	1	LDR

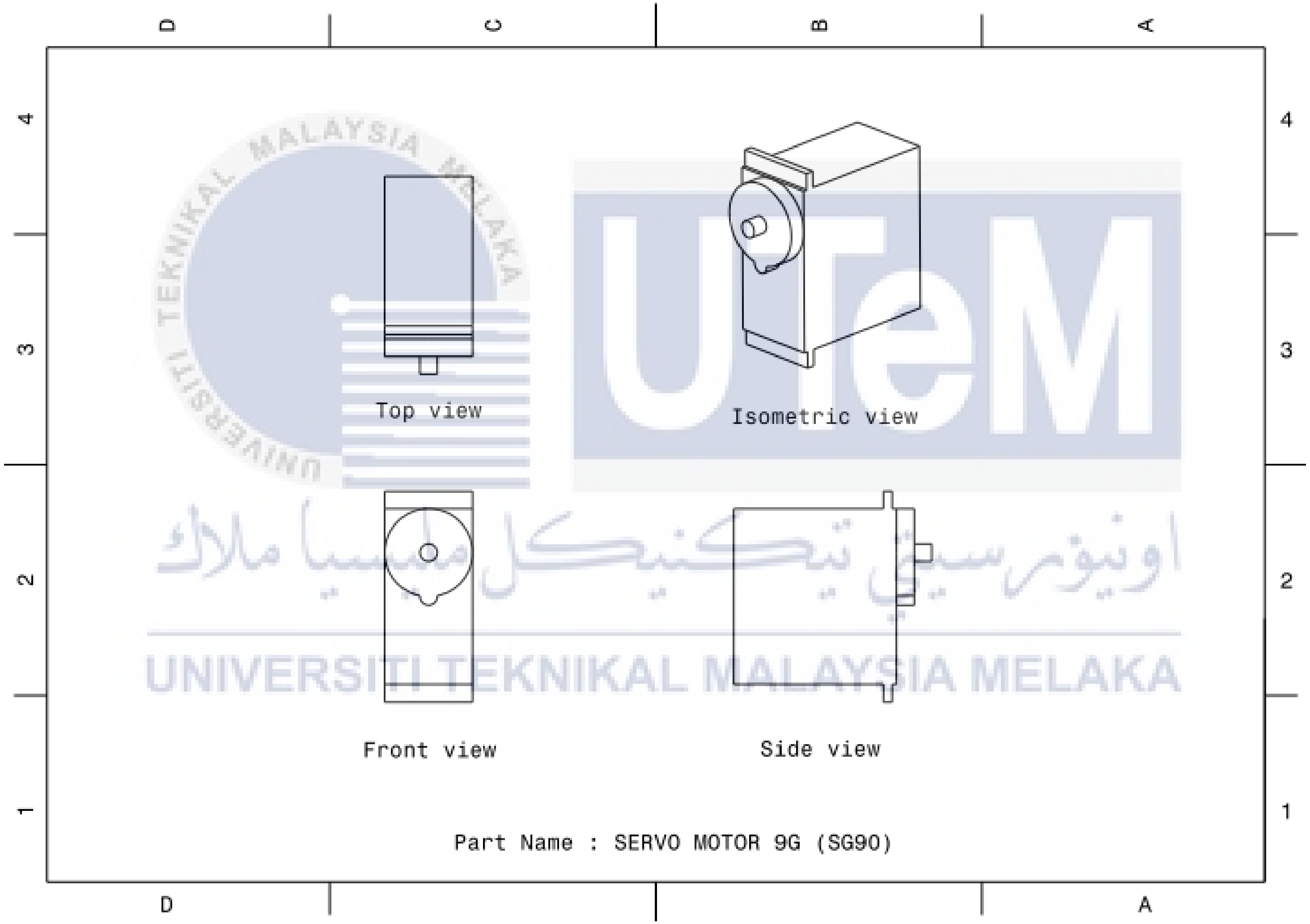
APPENDIX I Detail Drawing of Solar Panel Mounting



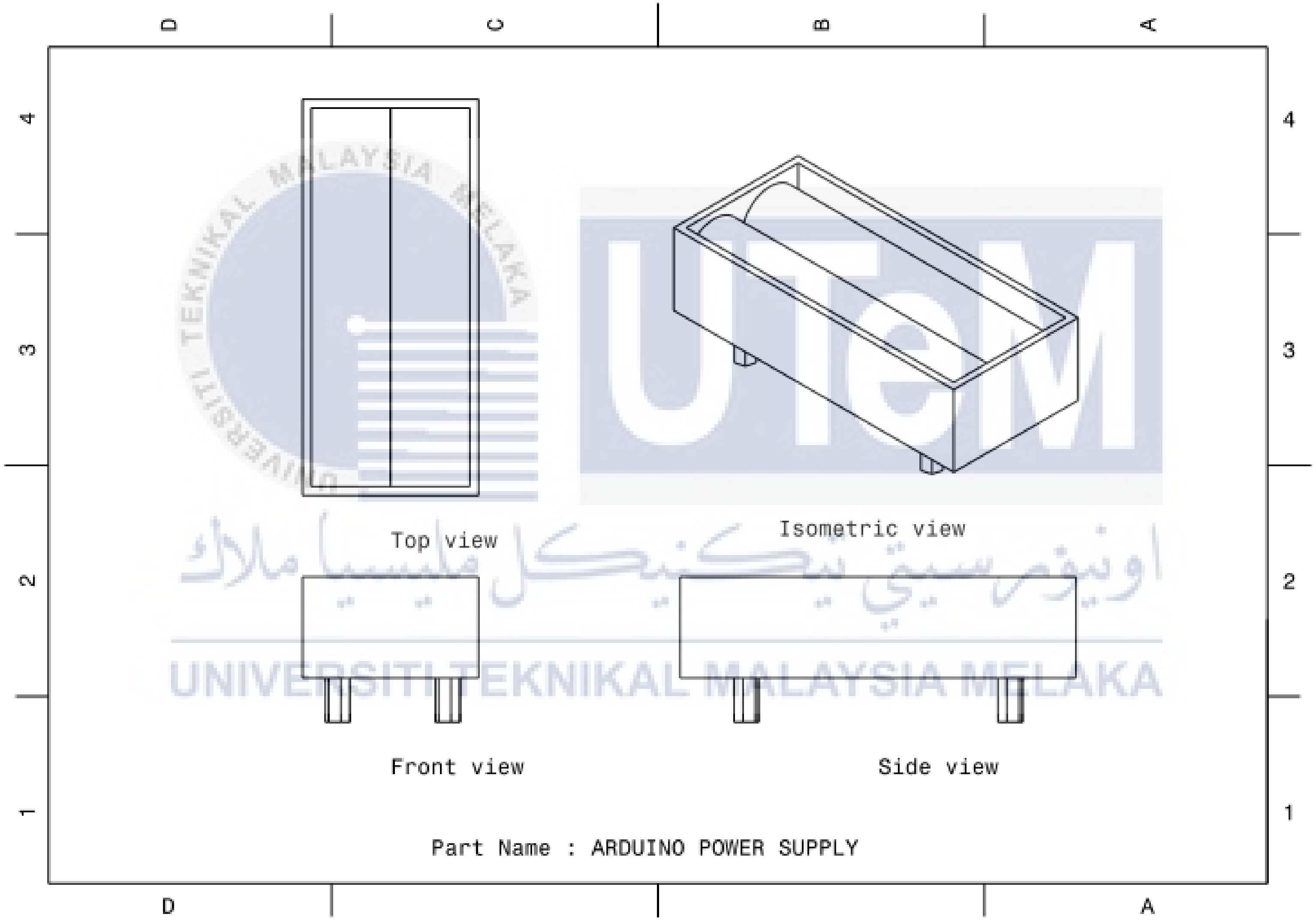
APPENDIX J Detail Drawing of Stand



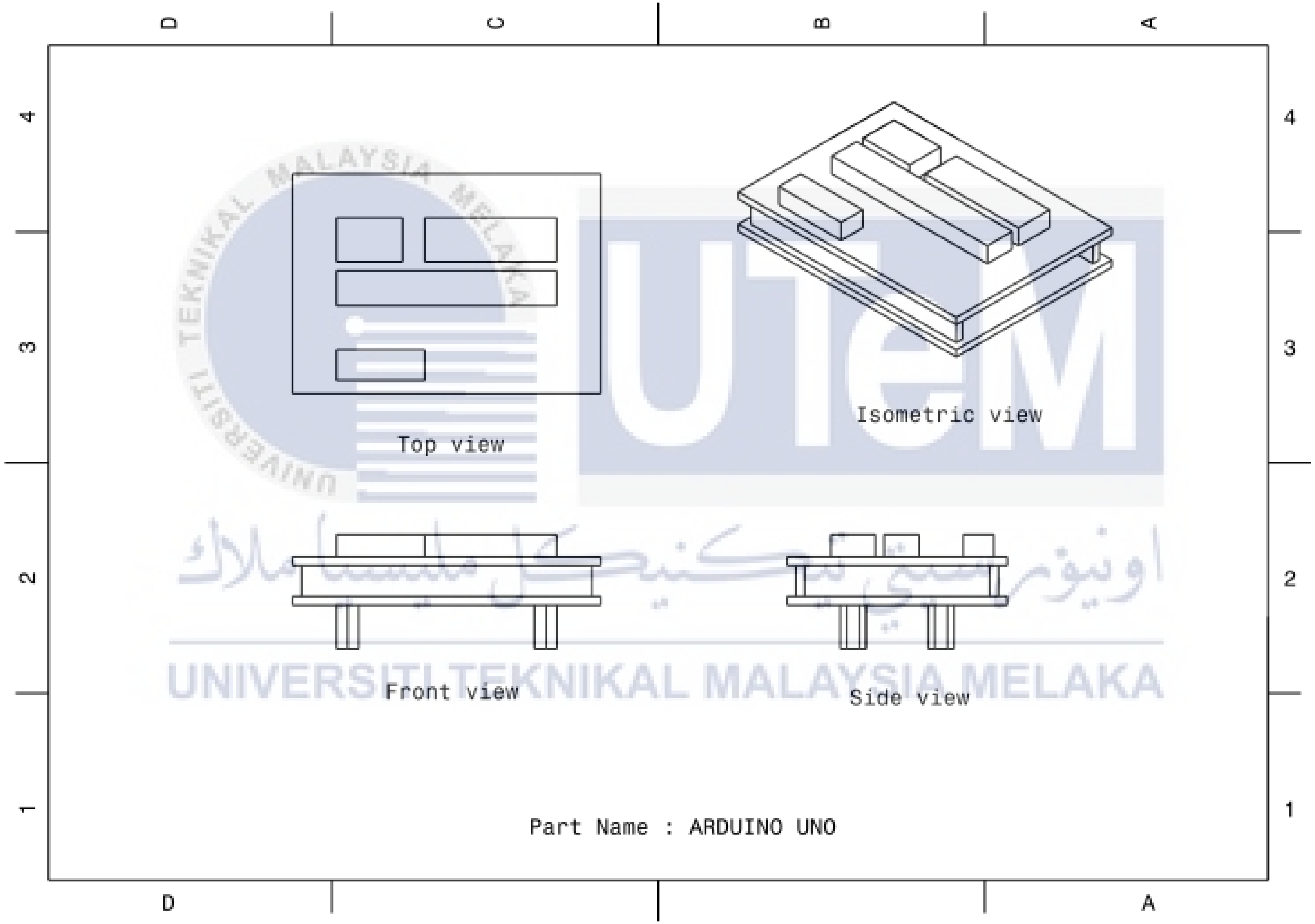
APPENDIX K Detail Drawing of Servo Motor



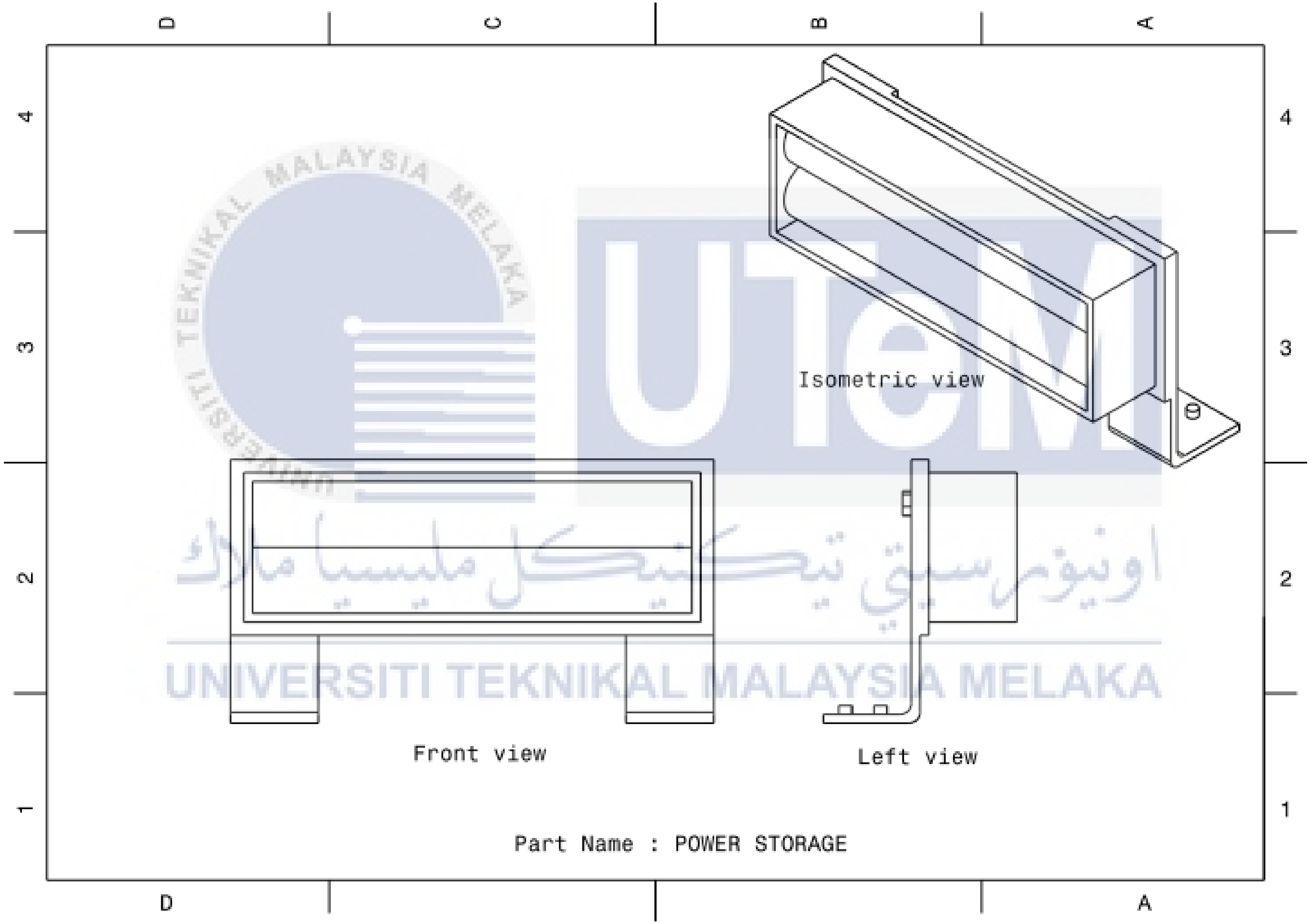
APPENDIX L Detail Drawing of Arduino Power Supply



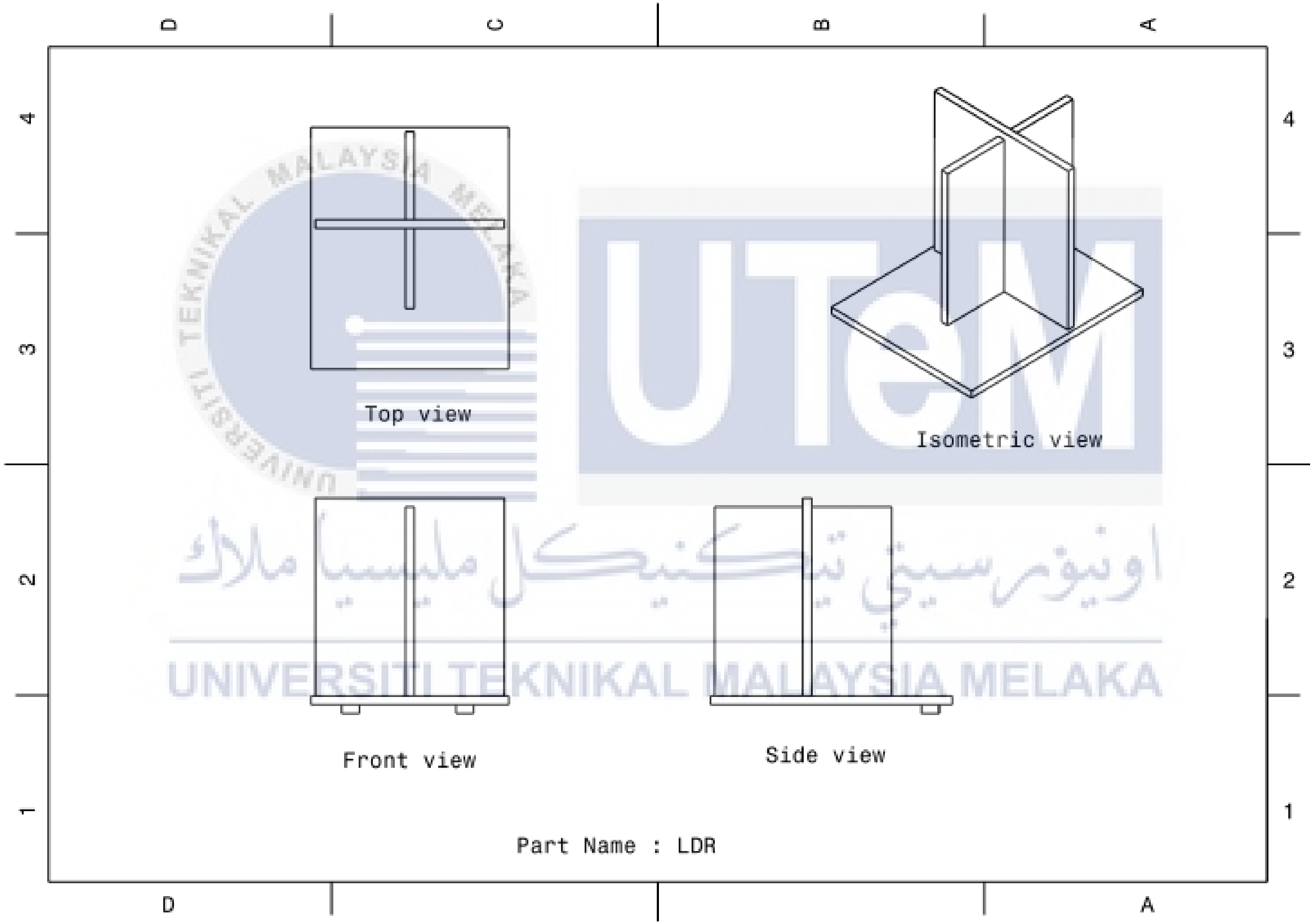
APPENDIX M Detail Drawing of Arduino UNO



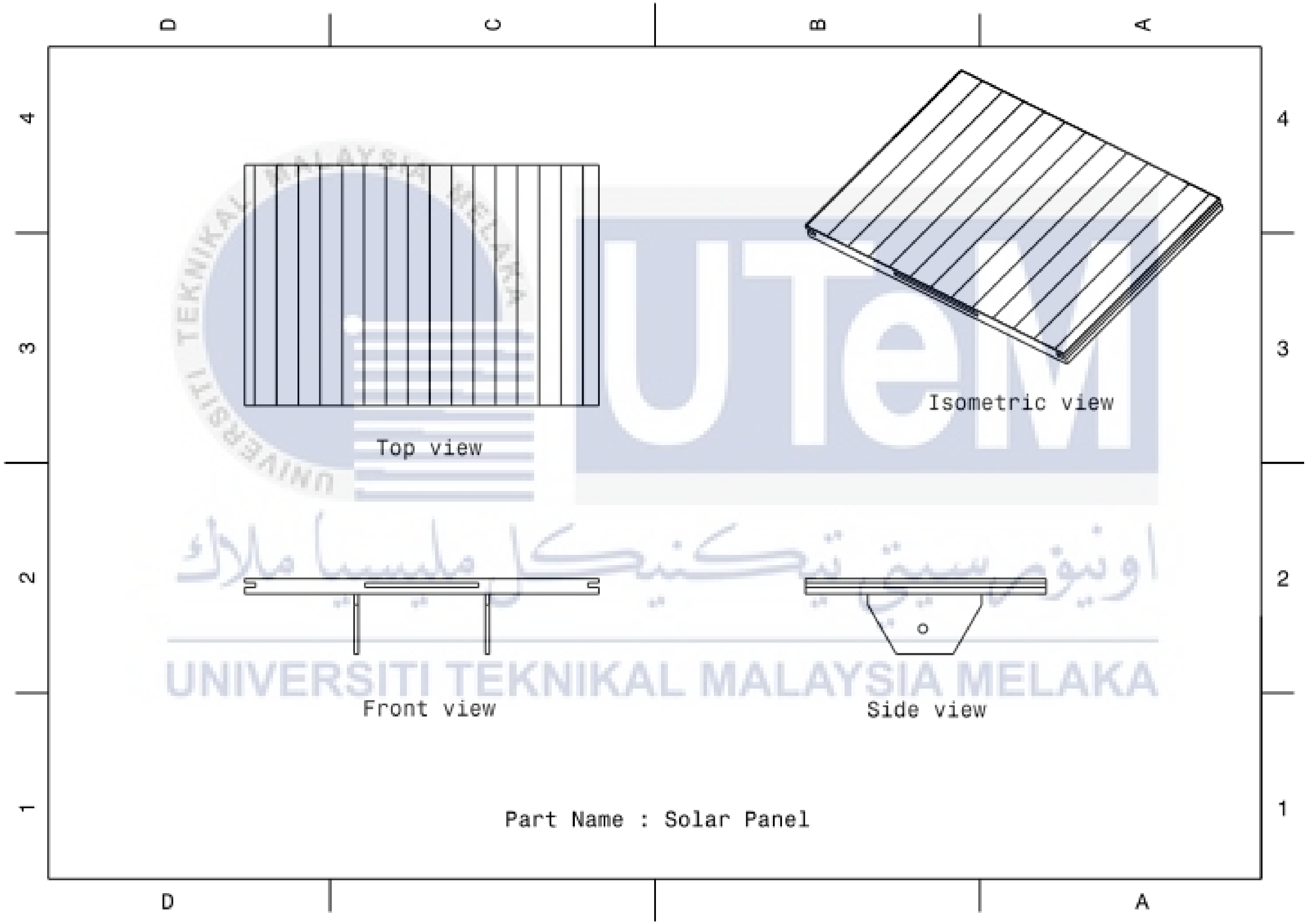
APPENDIX N Detail Drawing of Power Storage



APPENDIX O Detail Drawing of Light Dependent Resistent



APPENDIX P Detail Drawing of Solar Panel



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