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Abstract

The world today is being driven majorly by energy used in homes. A large portion of energy gets extracted, distributed, converted and consumed each and every day. The increased campaign on the use of renewable energy and conservation of environment has begun to bear fruits. There are many technologies supporting this campaign to make it a sustainable course. The quick development of hybrid cars to fully electrical cars has happened in a very short time. Toyota, Nissan, BMW, Tesla and Mitsubishi cars are just a few of the successful developments. Nowadays, in China, Japan and Europe there are lots of electronic bicycles and motorbikes. All these are just examples of technologies that are converting from the use of fossil fuels to reduce air pollution. The electronic vehicles including bikes need to be recharged since most of them use Li-Ion or Ni-Cad batteries. The use of renewable resources which is ubiquitous in nature is one of the best ways to promote a carbon free society. There are a number of Renewable Energy technologies including solar, wind, biomass, geothermal and biogas. Each of them has a fair portion of benefits and demerits. However, one of the most common to all the world is solar. This is because the sun shines all over the world. It is important to note that the sun shines more uniformly at the equator than at the tropics. Therefore, in order to maximise the potential of the sun it is necessary to ensure that the incident angle striking the surface of the panel is right angle. Therefore, to achieve this it is important to track the sun over the seasons and during the day. There are three technologies employed in setting the angle of insolation of solar PV panels. This project seeks to study the three technologies and find the suitable and sustainable of the three to be implanted. Maximizing of solar PV output through solar tracking is the key goal of this project. Whether this is possible and at what extra cost and benefit is the objective of this research.

Chapter 1. INTRODUCTION

For a long time, fossil fuels have driven the economies since the abandonment of the steam engine. During the late 1870's when the first four stroke engine was invented by Nikolaus Otto, many of the developments in the 19 Century to power vehicles with electricity stopped due to the high cost and the low efficiency. Fossil powered engines won the race, and fuel price was low during this period. Therefore, many companies developed 4-stroke engines to power cars and diesel generators for electricity generation. However, during the oil crisis of 1973, many economies felt the need to stop overdependence on oil. It was during this time that the continued development of the electric car and electric powered machines got a lot of support. However, the war was lost again and many of the projects got minimum funding. The following oil price shock in 1990 and Energy crisis in 2000 gave the developed countries another shock and this led to the rapid development of e-vehicles. However, the efficiency was low and therefore hybrid vehicles were developed as the technology continued to be studied. In addition, after the signing of the Kyoto protocol in 1992, during the United Nations Framework for Climate Change (UNFCCC) there was a big boost to the more reason why air pollution from industries running on coal and crude oil need to change. Therefore, the growth of renewable energy has had a long history and continued support despite the challenges.

This is the era of embracing renewable energy technologies and ripping all the benefits that can be obtained from the environment. The use of renewable energy in Europe has far much advanced that when Feed In Tariffs were introduced, many households were getting paid for the electricity produced that they were making profits from the sell of solar energy to the utility grids. Net metering was also another technology that was introduced to encourage households to sell to the utility as they use. Many households realized profits with this program too. There was a time in Europe when the utility was pleading to residents to use more electricity because there was a lot of surplus in the grid.

The reason why solar PV technology has far more support than the other technologies is because, it is easy to maintain, quite easy to install and also there is minimal tear and wear.

In addition, solar power is more predictable than wind. However, the only demerit is that it is highly affected by changes in the weather pattern like rain and clouds. It is also a fact that there is no generation at night. Most installed solar PV systems have their panels fixed in at a certain 'optimum' angle. This cannot be optimised beyond what is already being produced because of the earth motion the intensity of the solar beams changed during the day and seasons causing

the output power to change and therefore not optimizing the maximum power when using stationary PV panels.

This project will focus on how to increase the generated energy form PV panels by introducing a tracking system that track the sun during the day. This system be controlled by a Raspberry Pi coupled to stepper motors and light sensors to track the sunlight.

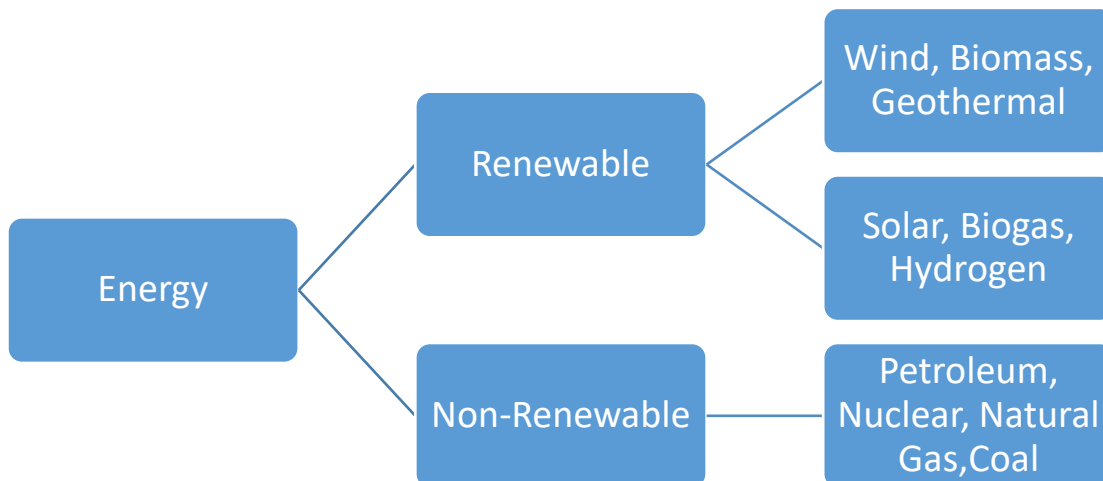


Figure 1:Types of energy sources

1.1 Aim of the work

The aim of this work is to design and implement a Raspberry Pi system connected to a stepper motor that will move a PV panel to truck the sun. This will optimize the output of the solar PV system because it will ensure that the incident light is always at 90° on the panel surface.

1.2 Motivation

According to research conducted by Khan (2018) [1], most energy consumed comes from buildings. This creates about 87% of the greenhouse gas emissions. Therefore, there is a high need to practice energy conservation as well as renewable energy generation. This is because electricity generated from thermal power plants involves burning fossil fuels like coal, oil, and natural gas. Wind power and solar PV generation can be used to power a number of households. The process of generating electricity from these resources produces very low greenhouse gas emissions.

1.3 Project Justification

Increased demand for electricity is increasing however, the main source of fuel which is being used to generate electricity is depleting (oil, gas and coal). Considerations into alternative sources of energy has made renewables more popular. Solar is the most common of all other available resources. In addition, solar energy is the most abundant and is comparatively easy to convert to electrical energy. In order to make the project worthwhile his project seeks to optimise the power output as well as a Raspberry Pi based solar tracking system that can be implemented.

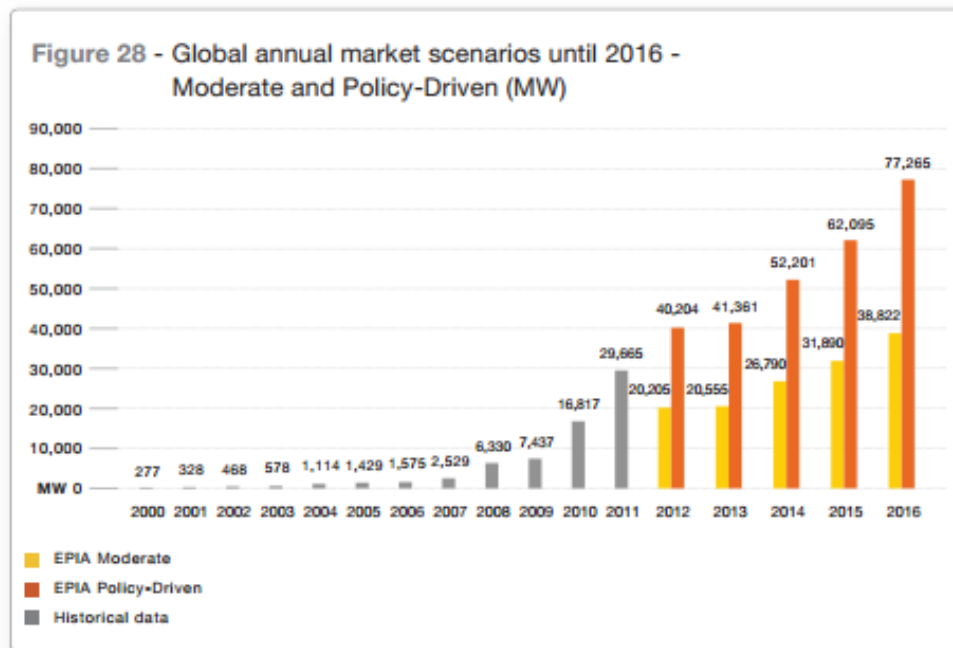


Figure 2: Photovoltaic generation during the last years (source: <https://cleantechnica.com/wpengine.netdna-ssl.com>)

The demand for electricity keeps increasing year by year but the main resources; oil, gas and even coal are depleting. Due to reduction of non-renewable resources, people are considering use of alternate sources of energy. From all other available resources, solar energy is the most abundant and is comparatively easy to convert to electrical energy. This project seeks to address the challenge of accurate, low power as well as economical microcontroller based solar tracking system that can be implemented using the allocated time and resources so as to track the relative motion of the sun in the sky during daylight. The system is therefore very beneficial especially during morning and afternoon hours.

Figure 2 shows the continued increment in the installation of PV panels since 2004. This has been promoted by the reduced price and increased efficiency of solar PV. Distributed Grid connected systems are gaining a lot of popularity because of the ease and safety of installing

on the roofs. In addition, the installation of solar PV doesn't require a lot prefeasibility study unlike wind which needs prefeasibility study before installation [2].

1.4 Work objectives

This project will be achieved by the following objectives;

- To design and develop a hardware circuit that sense the light intensity.
- To integrate the signal from the sensors to the Raspberry Pi and produce a control command.
- To design and develop a two-axis turning system for the solar panels using stepper motors.

1.5 Report Organisation

This report is organised in five chapters that arranged as follows:

Chapter 1, introduction: In this chapter, a short introduction for the main technical points for the proposed project idea will be presented.

Chapter 2, Background: This chapter will illustrate the background knowledge and some literature review for the sun tracking technique and algorithms, LDR, signal conditioning, stepper motor, and Raspberry Pi circuit board.

Chapter 3, Proposed System Block Diagram: The main blocks for the proposed system and the hardware designed circuits for each block of this project are shown in this chapter.

Chapter 4, system software: This chapter will illustrate the software that will be written to control the different hardware parts that have seen designed and explain the software design procedure.

Chapter 5, Conclusion: The conclusions from this work are introduced in this chapter.

Chapter 2. LITERATURE REVIEW

Over the past two decades, the need for the development of solar energy increased by an average of 40% per year M. F. Khan (2005). Before manufacturers got problems installing large systems to ensure stable operation for at least 20 years with the minimization of operational costs, the volume of maintenance and downtime. The industry needs to further reduce costs in order to compete with producers of electricity from fossil fuels. Use reliable and accurate system for tracking the sun contributes to cost reduction irrespective of whether to use photovoltaic batteries (PV), the concentrating photovoltaic battery (CPV) or a concentrator solar power (CSP) Al Soud (2010). Sun tracking system helps to increase the power output of photovoltaic panels. Thus, two-axis tracking system can provide a performance increase of up to 40% and allow full use of solar energy systems in the CPV and CSP. For maximum power generation, these systems must have the highest performance characteristics such as rigidity and accurate positioning, even in the most adverse conditions. Accuracy of tracking the position of the sun depends on the technology used. Thus, when using PV technology required precision is ± 1 degree, while the application CPV $\pm 0,1$ degrees. Therefore it is important to minimize the backlash or “Backlash” in such systems. Otherwise, under the influence of wind elements of the system will be shaken, resulting in reduced efficiency.

In this chapter the principals of the proposed system will be shown in details. The changing position of the sun and sun tracking technique will be discussed, also the light detected resistor, the stepper motor, Raspberry Pi , and signal conditioning will be presented.

2.1 Tracking the sun

The term tracking the sun is used to refer, to following the suns position in relation to a point on the surface on the ground below. In order to achieve maximum insolation, the suns rays need to strike the surface of the panel at right angles.

The techniques used to track the sun include; Single axis tracking, where only the daily position of the sun is tracked from East to West. This technique has a single degree of freedom and therefore only one actuator is needed.

Dual axis solar tracking involves two degrees of freedom and therefore it is easy to track the exact position of the sun throughout the year. The first two techniques are not continuous movement, and therefore the movement interval is programmed

Active solar tracking is also another category where the solar panels are continuously moved to track the suns position. However, passive solar tracking, is also available. This technique

uses high low point gas put in cylinders to enable the tracking of the sun depending on which side is hotter,

Chronological tracking is independent of sensors and therefore much easier to implement. However, the response of the sun during cloud cover is not good. This kind of system is dependent on time driven by an internal clock.

Solar tracking algorithms need the knowledge of how the solar changes with altitude, solar azimuth angle, elevation and solar zenith angle.

2.2 Sun Position (sun Path)

As mentioned previously, day and night occur as a result of the earth's continuous rotation. The four seasons of the year occur as a result of the revolution of the earth around the sun Nader Barsoum (2011). The rotation of the earth is on a fixed plane deviating from the vertical axis with about 23.5° .

The solar day, and it is the time needed for a specific point on earth that is pointing to a particular point on the sun to complete one rotation and return to the same point. Solar day are variable during the year, but the average length is 24 hours. This variation is because of three reasons;

1. The earth's orbit around the sun is oval and not circular.
2. The celestial equator and the sun's apparent motion are not parallel to each other, The precession of the Earth's axis.

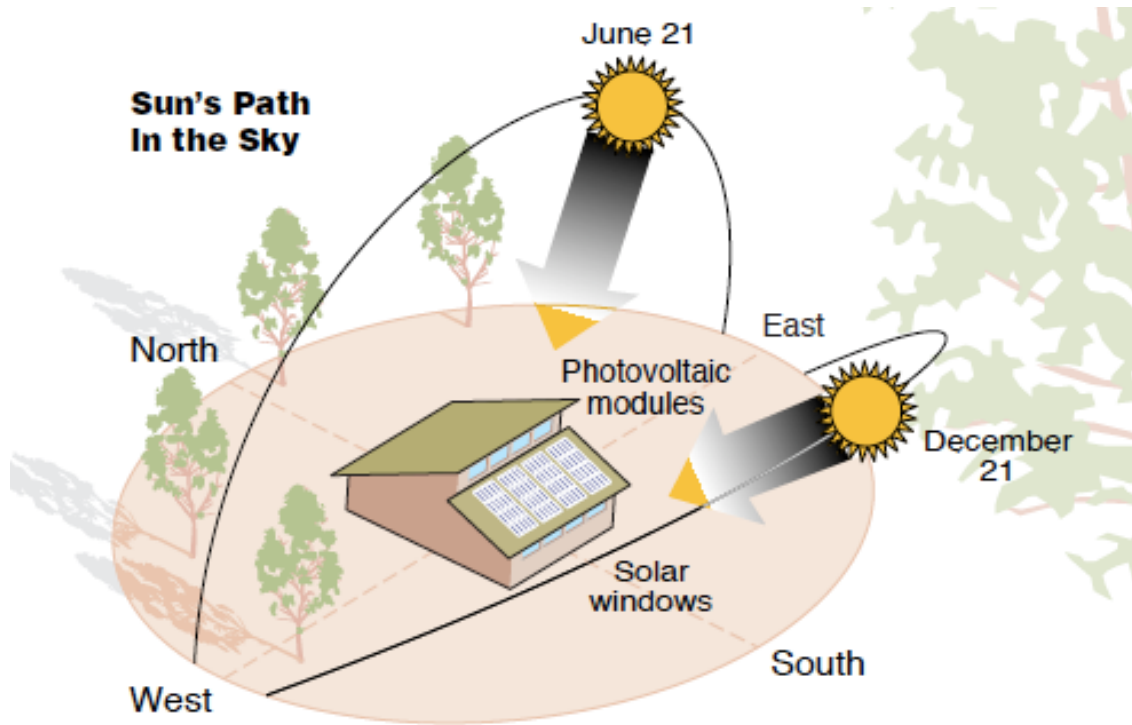


Figure 3: Sun path during the day and seasons

For simplicity, the time taken by the Earth to complete one rotation is 24 hours which is based on one solar day T.A. Papalias (2006). This means that the earth rotates 15° per hour and if one assumes that the earth is fixed in its position then the sun appears to move approximately at a constant speed across the sky and will produce a daily solar arc. This phenomenon is vividly illustrated in Figure 3.

It is clear from Figure 3 that the sun's path with respect to a residential house during one day and for different seasons. As shown in Figure 3, the sun forms an arc during its movement for one day and that arc is not fixed and it moves depending on the season. This figure also shows PV panels fixed on the roof top of the house, these panels are fixed with an angle to face the moving sun. In this kind of installation, the peak generation occurs between 10:00 to 12:00 assuming no cloud cover, after this period, the production of the solar PV starts to drop. However, during 10:00 to 14:00, there is still high insolation and it's only that the angle has changed. Therefore, in order to increase the density of solar radiation received by the panel, changing the angle with respect to the movement of the sun increases the production of the PV panels compared to the vertical fixed ones R. Condit(2004).

Tracking the sun only during the day requires only one axis movement. In order to track the sun for all seasons, a two-axis system is required. This kind of system is effective at the tropics where the sun has very low and high angles during summer and winter.

2.3 Two-Axis Tracking System

According to Hallas (2012), the two-axis solar tracker is based on the mobile support structure through which maximum amount of energy can be produced. In this system, the position of solar panels is regularly changes with respective to the sunlight throughout the whole day. This system is widely used in solar energy production, especially devices and trackers. In mainstream market, this technology is less known because of its complexity, expensiveness and low how know in the market.

However, other trackers like flat fixed, frame with low rotating and monopole are easily available in the market. The present dual-axis (vertical and horizontal axis) solar tracker is rotating to follow the route by tracing the sun. In this system, these both axes are integral mechanisms of metal grid structure that are hold up at its centre and periphery on the wheels. In this way, the structure and solar tracker are rotating on a defined central point in line with the trackers' vertical axis are supported. In addition, the structure integrating the horizontal axis where one board is at least situated to receive the panels or solar modules. There may be one or more than one board that are rotating on the horizontal axis and support the solar panels in maintaining the perpendicular direction to the sunlight rays (Neber et al, 2013).

The solar panels are using for capturing the solar energy that are assembled or fixed in the metal solar tracker, particularly in more than one boards to that to form a standardized structure. These boards are forming the plane that is retaining perpendicular position towards the rays of sunlight. The main purpose of maintaining the perpendicular position is to capture the maximum amount of solar energy.

Miller et al (2011) mentioned that the board of structure is manufactured with two movements e.g. rotation for vertical axis and rotation for horizontal axis, and each axis is perpendicular to each other (see Figure 4). Therefore, the plane of solar modules also rotates with two movements.

The lower point of vertical axis defined towards the ground so that tracker could move to fixed point. However, the horizontal axis that is perpendicular to vertical axis makes possible the rotation of board or boards. On account of more than one board, the rotation takes place in synchronized way, framing a solitary panel. The solitary panel is recommended for better

performance, but eventually it moves in asynchronous way e.g. independent. This takes place, when traction elements of any board are not properly working.

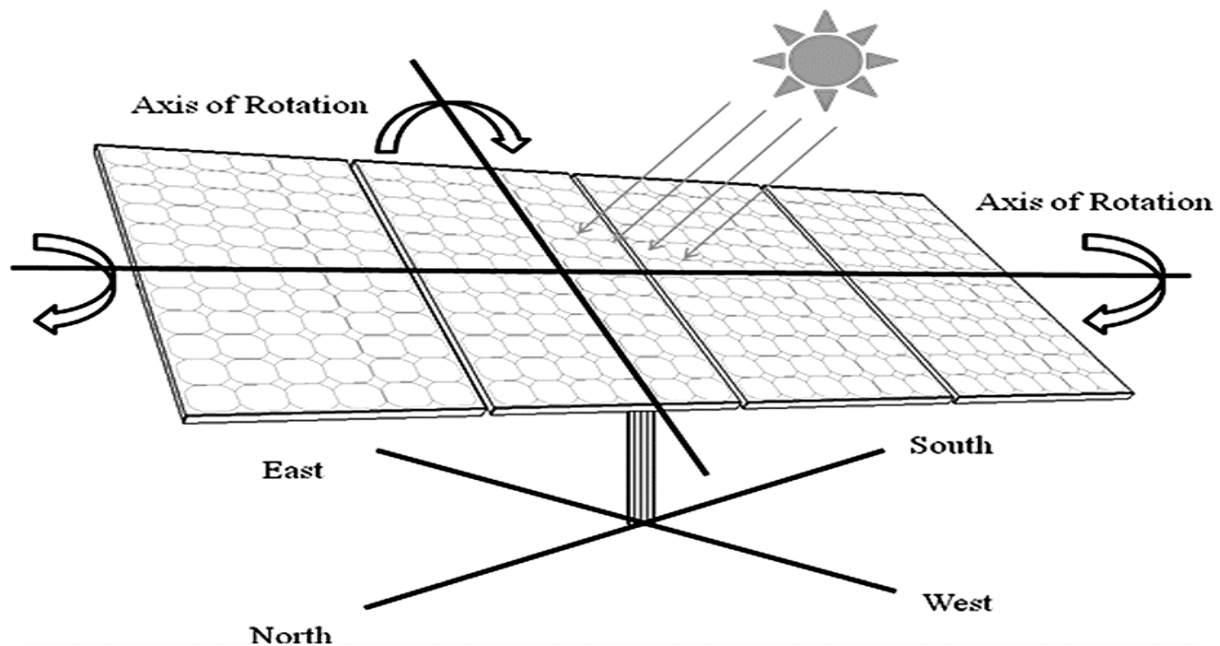


Figure 4: Dual-axis Tracking System

This system gives suitability of maintaining the perpendicularity of solar panels with the rays of sunlight, irrespective of the position of sun that change throughout the day. The plane of panels produced with minimum one board, sustaining solar panels and integrating the structure of solar tracker. These boards are supported on the defined structure that rotates with respect to the fixed central point to a footing so that entire assembly could be locked (Lin et al, 2014). Through this implementation supports the mechanical system to accommodate the installation of any suitable flat surface with hardness sufficient for movement on her wheel base frame, simplifies the technology of mounting installation and its operation. Implementation of the solar battery module, staggered on a suspended frame reduces wind and possible snow load, and increases the stiffness of the supporting frame. Due to the presence of basic and additional position sensors in the guidance system of the sun, there is no need to control the current position of the installation, and no need to bind to the astronomical time and latitude that necessarily the closest analogue of the invention. Used as sensors multi-junction solar cells having the highest sensitivity to direct sunlight to prevent false triggering on radiation sources and improve the accuracy of tracking the position of the visible solar disk. Increased output voltage of these elements allows the use of a simple circuit motor control tracking (Lorenzo et al, 2011).

There are a number of Factors to consider at the time of installing dual-axis systems. Selecting tracking system depends on many factors, including the size of the installation, electricity rates, latitude and local weather. Horizontal single-axis tracking systems are commonly used in solar power plants and large-scale projects. The combination of improving energy efficiency, low cost and ease of installation resulting in significant savings. In addition, especially for photovoltaic plants desired performance after noon to cope during peak consumption.

Horizontal single-axis tracking device also greatly improves the performance during the spring and summer, when the sun is high in the sky. Frame stiffness and ease mechanism entails a high reliability, reducing maintenance costs (Alexandru & Pozna, 2010). Since the panels are horizontal, they can be compactly placed on the axis of the tube, without fear that they will shade each other, as well as leaving them easily accessible for cleaning. Vertical axis positioning systems only rotate around a vertical axis, the panels are fastened on the vertically at a fixed, controlled or monitored angle. Such a tracking system with a fixed or (seasonally) adjustable angle suitable for high latitudes, where the top point on the apparent solar path is not very high, but that leads to the long summer days when the sun moves in a long arc.

2.4 Benefits of Dual-axis Tracking System

The dual axis solar panels, they differ from conventional or fixed photovoltaic solar panels, which allow us to address rotatable photovoltaic modules towards the sun throughout the day, in order to generate a higher return on solar power. Regarding the price, the dual axis solar panels are more expensive than traditional, but its operation is more efficient. They cost more because they work through a complex structure, consisting of a support system of a post on a fixed pivot post [8].

The latest technology in the market gives the flexibility to position the plate, and turn the engine works through a decisive factor in the high cost of this type of solar device. Besides the price, user must have to consider that need to allocate more space for the installation of this solar module.

As the fixed solar panels, purchasing solar panels dual axis includes the installation, but as with every purchase, it is important to verify this, because unlike conventional, technical assistance is indispensable. The maintenance of solar installations double axel not need different fixed plates maintenance, but be aware of engine corrosion and tracking system, for if you get to spoil, they would have to invest more in repair. They may seem too many inconveniences for this type of installation, however this type of solar panels are considered most effective when

generating electricity or heat in the market, providing as much as 10 to 25% that fixed system depending on the geographical location. (Rhif, 2011).

For Example; a 30W PV, the generated power of the trackable system will be 30W for about 10 hours a day for a sunny day, for the standard fixed panels the generated power will be 10 % less i.e:

$$\text{Fixed PV generated power} = 30 - (30 \times 0.1) = 27 \text{ W}$$

The feed in tariff rate is adjusted annually by the UK government as on 8 February 2016 the rate was 4.39 pence per kilowatt hour (kwh). For stable PV and making an assume for a system that generates 1 kwh , the generation will be about:

$$\text{Fixed PV generated power} = 1000 \times 0.1 = 900 \text{ W}$$

Then the money generated from this system is

$$\text{Profit} = 0.9 \times 4.39 = 3.951 \text{ p}$$

For an average of 10 hours of generation, the system will generate money equals to 39.5 p. the tracking system on the other hand will generated 43.9 p during the same period which is 4.4 p more than the fixed system for each 1kWh per one day.

2.5 Main Methods for Sun Tracking

There are many different ways to perform the Maximum power point (MPP) racking that can be classified either as direct or indirect methods. The direct method uses voltage and DC and checks the AC power values as output. It uses the values to adjust the carrying MPP searching movements (Parida et al, 2011). The indirect method uses an external signal to estimate the MPP; these signals are given by measuring irradiation, temperature of the power, current shorted or open circuit voltage of a solar cell. The techniques used to improve the efficiency of PV system with indirect monitoring methods, the maximum power point are twofold: The method track the voltage-based maximum power point tracking (VMPPT) and point tracking method current-based maximum power tracking (CMPPT) (Sarvi et al, 2013).

As shown in figure 2.3, the tracker can be guided by the sun in three ways:

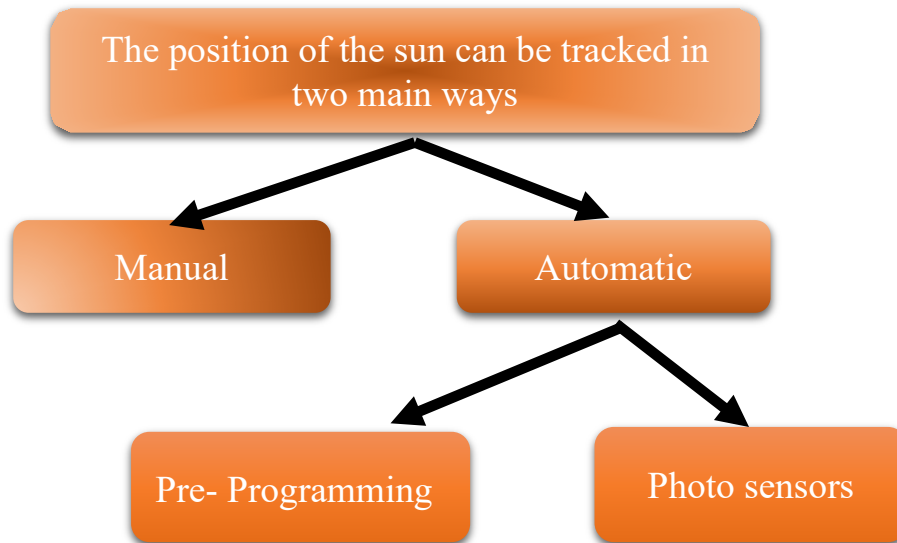


Figure 2.3 Main methods for tracking system

1. Manual Method, Primitive, the most reliable - operator performs seasonal orientation tracker manually. This method is the least effective but no instrumentation and a minimum of moving parts making it as reliable. Problems in the mechanical parts are rare. This method of orientation of solar panels is rarely used (Mousazadeh et al, 2009).
2. Using Photo sensors. Distribution method is unreliable. Is a combination of two or three photoelectric sensors are arranged at an angle of 45° relative to the plane of the panels, i.e. 90° relative to each other. Sensors are placed in the shells so as to be perceived only a narrow beam of light. In case, the solar panel plane perpendicular to sunlight then each sensor enters the same beam, thus the voltage on all the sensors of the same. As the sun moves, the sensor voltage begins to differ and control system includes a drive until it corrects the position of the panel so that the voltage sensor was the same again. The principle of operation of the system simple, but it is not reliable. Control system with a photo sensor has two major drawbacks: firstly, sensors often contaminated, resulting in a longer work require calibration. The second disadvantage is that the system does not work in cloudy weather. Mechanical problems - quite frequent phenomenon for this type of drive (Sungur, 2007) (Huynh et al, 2013).
3. Pre-Programmed. Autonomous control system with solar panels is programmed according to the cycles of movement of the sun. Most reliable system environment

uses electric actuators, requires little operator intervention. Changes in the program are executed quickly, remotely if necessary. Such systems are commonly used in commercial solar power plants (Abu-Khader et al, 2008).

In this system, the movement of the solar tracker is determined by the angles of elevation and azimuth of the sun by mathematical calculations, determining the movement Dual axis tracker solar panels and orienting toward the sun. These systems are simpler, but have disturbances in the system and have a low accuracy in severe climates.

2.6 Main Tracking System Components

The main components used in the additional monitoring mechanism, trackers described below [9].

A. Solar Panel

Solar panels are formed by multiple cells that convert light into electricity. These cells depend on the photovoltaic effect by which light energy produced positive and negative charges in two neighbouring semiconductors of different type, thereby producing an electric field capable of generate a current.

B. Light sensors

A closed loop follower needs a sensor light. A photoelectric sensor or photocell is a device address that responds to the change in light intensity. These sensors require a transmitter component that generates light and a receiver component that receives the light generated by the sender. Light sensors are used to detect the light level and produce an output representative signal relative to the amount of light detected (Rizk & Chaiko, 2008).

C. Electric motors

Followers typically use electric motors to generate the movement of its axis, and these can be dc or of steps. A DC motor is essentially a machine that converts electrical energy to motion or mechanical work through electromagnetic means. In some of the designs engines used DC because the voltage generated by photovoltaic systems DC is also one of its advantages and can be regulated engine speed continuously Gerro (2014).

The stepper motor is an electromechanical device that converts a series of electrical pulses into discrete angular displacements, advances to a number of degrees depending on their inputs control. The stepper motors are suitable for Open loop systems, and databases using the position of the sun that can become movement's very precise angle.

D. Solar tracker

It is an electromechanical device, which aims to track the movement of the light source. Its main application is to change the position of photovoltaic modules (solar panels) to obtain maximum efficiency. When sunlight falls at right angle, there is minimum reflectance and therefore, the maximum use of sunlight rays is maximized Warren Gay(2001).

E. Converters and inverters

In solar tracking systems converters of different types are used that can convert the energy of a form to another, depending on the configuration that has the solar tracker. Converter that require the system types most commonly used in the conversion trackers are DC-DC and AC-CD. The function of an inverter is to change an input voltage of a symmetrical DC current output voltage alternatively, with the magnitude and frequency desired by the designer. Inverters are also used to convert the current continuously generated by photovoltaic solar panels accumulators and batteries, etc. alternating current and this way to be injected into the grid or used in isolated electrical installations (Siri, 2007). The ideal output waveform voltage inverter should be sinusoidal. Good technique to achieve this is to use the technique of achieving PWM Sine the main component is much larger the higher harmonics.

Factors that must be considered to make efficient solar tracker are: module efficiency photovoltaic, mechanical sizing, electrical control electronic converter and the site where system will be installed. These factors are considered to maximize output contribution and minimize energy consumption energy of the solar tracker.

2.6.1 Photo voltaic (PV) Panel

To understand the operation of a PV panel, one must know the properties of the sun light and the nature of the material that will be used to convert the light to electric power. Solar panels are formed by multiple cells, each cell consists from two semiconductor types Positive (P) and negative (n) to form a PN junction. A light with a certain wavelength that the PN junction is

expose to will ionise the atoms in the junction area by giving them energy which is enough to produce negative charges (electrons) and positive charges (holes). The holes will move towards the positive layer of the PV and the electrons will move in the opposite direction towards the negative layer as shown in figure 2.4.

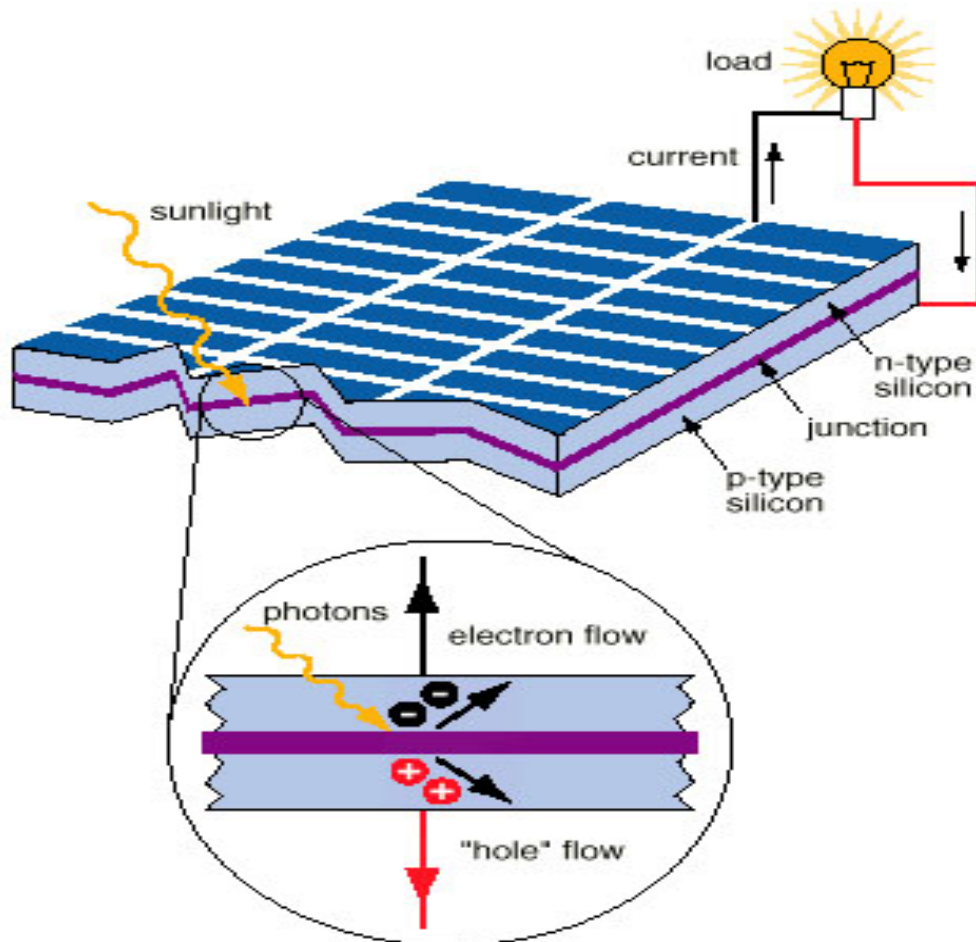


Figure 2.4 internal structure of a PV panel

Because of the internal potential of the energy barrier the generated opposite charges will be recombined only outside the material when they pass through the external connected circuit. If a closed electrical circuit with an electrical load connected to a PV with its surface exposed to the light, then the generated free electrons will have to move through the connected load to be recombined with the free generated holes. This electron movement is called the electrical current and with this mechanism the light power is converted to electrical power. There are different size and power ratings available in the market, figure 2.5 shows an example of these different sizes.



Figure 2.5 Available sizes of PV panel

2.6.2 Light sensors (photo resistors)

Photo resistors are electronic devices that produce voltage or change in resistance when exposed to irradiation at a certain wavelength. The most common light sensor is a photocell, which is also the basic unit of a solar PV. An LDR (Light Dependent Resistor) is a device whose resistivity is a function of incident electromagnetic irradiation. The most common LDR semiconductor materials are cadmium sulphide (CdS) type and gallium arsenide (GaAs) type. When there is incident irradiation, the electrons move from the valence band to the conduction band increasing conductivity of these material, thus its resistivity inversely proportional to the light intensity. This can be expressed as;

$$R = AE^c$$

Note: Where E is illumination in lux, R is resistance in ohms and A & C are constants. C varies from 0.7 to 0.9 depending on the sulphide used.

Figure 5 illustrates the appearance of a CdS photocell. Using a voltage divider circuit, the photocell will be connected in series with a resistor and a voltage source, the output will be taken from the two-resistor junction node as shown in Figure 6. When the value of the Photocell resistivity changes regarding the intensity of light falling on to it, the junction point voltage will change too, this will translate the light intensity changes to a voltage signal. The output signal is conditioned and read by the microcontroller which will produce a corresponding signal

to drive the stepper motors which will then move the PV panels to the direction of maximum light intensity.



Figure 5: CdS Photo resistor

LDR were selected for this project because they have good power handling characteristics. Their only set back is the resistance recovery rate when light changes within a short interval of time is slow. However, this is not an immediate problem since small changes in intensity can cause the stepper motors to jitter and heat up.

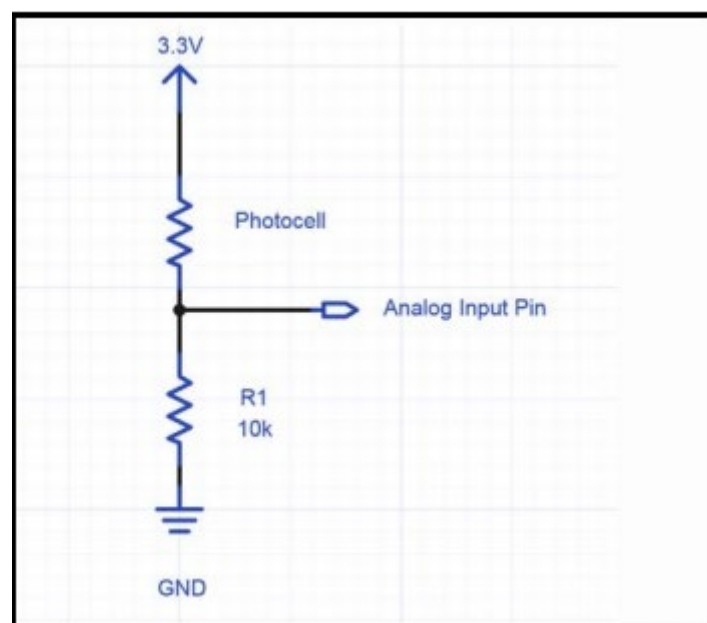


Figure 6: CdS LDR Connected

Chapter 3. METHODOLOGY

In order to achieve the three objectives of this project, the path to follow will be accomplished by;

- Understanding how LDR works. In order to do this, a small experiment was conducted to test the performance of the sensor. Study how to sense the sunlight how to measure its value using a microcontroller.
- Design and implement the required circuits that interface the sensor analogue output with the digital input of the microcontroller.
- Calibrate the implemented circuit to give the accurate readings for the further usage inside the implemented circuit.

3.1 Testing of LDR

The connection was as shown in Figure 6. The results are shown in Table 1.

Table 1: Performance Results of LDR

Measured Resistance	Condition
10.24K Ω	Dark (black vinyl tape placed over cell)- Night
7K Ω	Average (normal room lighting level)- Cloudy
1K Ω	Bright (flashlight directly in front of cell)- sunny

From the results, a 10 K Ω resistor was used in the circuit in order to achieve the widest output range possible.

The relationship between the resistance of the sensor and the light intensity is;

$$R_{LDR} = \left(\frac{100}{LUX} \right) K$$

R_{LDR} is the variable resistance of the LDR.

Therefore, since we are using a voltage divider circuit,

$$V_o = V_{CC} \left\{ \frac{R}{R_{LDR} + R} \right\}$$

The analog output V_o is the signal going to the microcontroller.

3.1.1 Arrangement of the LDR

The use of 4-axis tracking will be explored in this project since, from literature review, it can be seen that tracking improves the performance of a solar PV system. In order to track the sun's position and orientation (azimuth angle) four sensors will be used. There are two methods to perform this. One is having the sensors placed at the four corners of the solar PV. However, this method is not ideal since the sun will illuminate on all the LDRs perpendicularly at all times and therefore there will be no tracking.

The other method is to use shade formation in order to detect the position of the sun. In this method, all the four LDR's are placed close to each other but separated by four opaque boards as shown in Figure 7.

The irradiation and hence find the position of sun relative to the panel is obtained after interpreting the differential readings from the sensors. The efficiency of this method is based on the fact that the sides which are not exposed to the sun receive a shadow and therefore it is possible to detect the side with more irradiation.

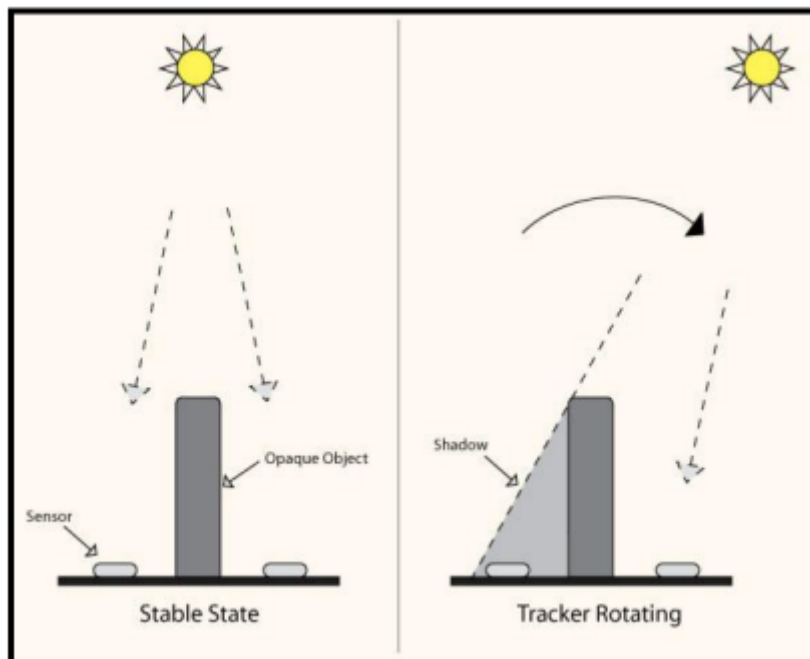


Figure 7: LDR (CdS) Positioning:

This method, has one demerit. In cloudy and foggy weather it tends to give mixed signals to the microcontroller. However, such weather days, the sensor system can be switched off or switched to default fixed optimum angle.

The use of four sensors makes the axis movement to be more targeted.

3.1.2 Analog to Digital Converter

The analog signal cannot be translated by a Raspberry pi. Therefore using an ADC is necessary. Using The MCP3008 ADC can solve the problem. It is less costly and much easier to connect added to the fact that a Raspberry pi has a GPIO reader

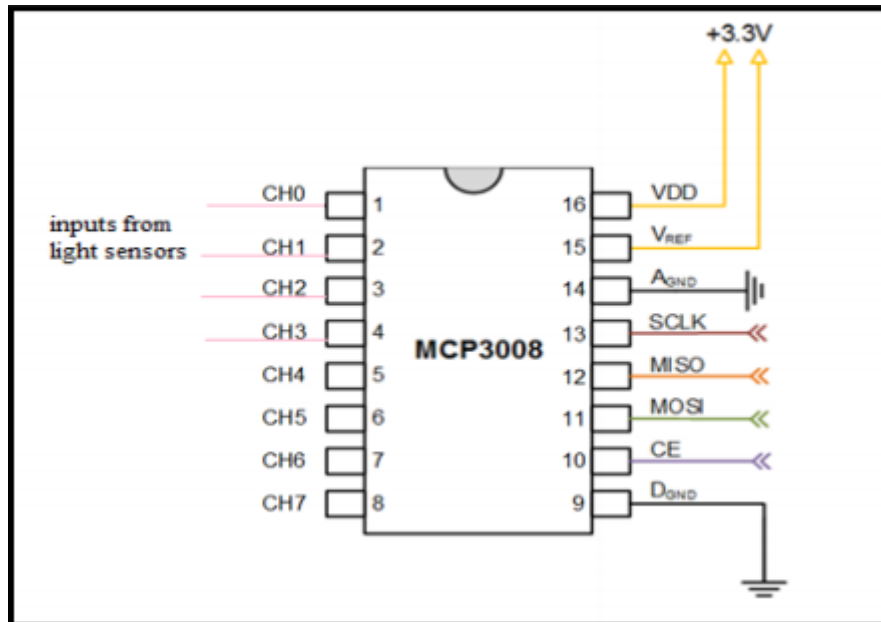


Figure 8: ADC Converter (MCP3008)

Using the Serial Peripheral Interface (SPI) of the Raspberry Pi, the communication with the light sensors will be achieved. Four connections are needed for an SPI protocol ; Clock(CLK) Master Slave Input (MOSI), Master Slave Output (MISO) and Chip Select (CS).

3.2 Stepper Motor

This section will include, study on the main types of stepper motor, also the main systems that controls the different types of stepper motors. In addition, what is the benefit of introducing stepper motor to the PV renewable generation systems.

- Study how to interface the digital output of the microcontroller with the stepper motor.
- Prepare the required programs that will be loaded to the microcontroller circuit board, which will be used to implement the proposed system.
- Design and implement the required circuits that will interface the Raspberry Pi.

The signals from the Raspberry Pi will be sent to stepper motor driver to move power the stepper motors accordingly.

3.2.1 Stepper Motor Properties

Stepper motors unlike direct current (DC) motors are a brushless type of motor. Its structure consists of a stator with electromagnet nodes arranged in alternating polarity i.e. north pole - south pole – north pole, and a rotor with permanent magnet nodes arranged in a similar manner. By applying current to the stator and energizing the coils, the magnetism generated in the stator, attract the rotor poles and by switching electromagnets on and off in a systematic way, the rotor is can be continuously driven.

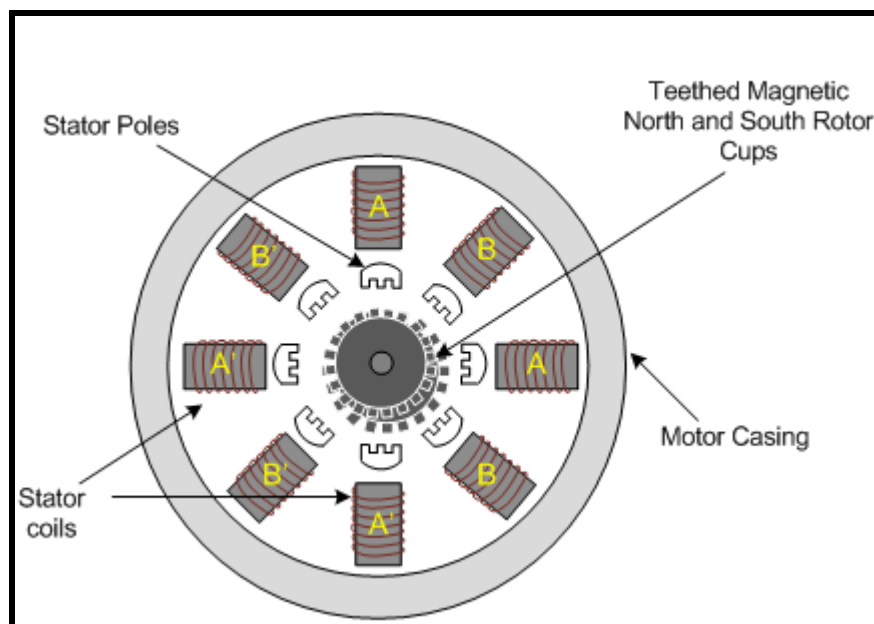


Figure 9: Stepper Motor internal structure. [ElmoMC]

Due to its serrated magnetic poles in the rotor and the stator, stepper motors tend to move in discrete steps with each sequence of stator coil activation. This enables the motor to be operated with a relatively high degree of precision. Stepper motors are capable of developing high torque but their torque output decreases with speed as shown in the figure below.

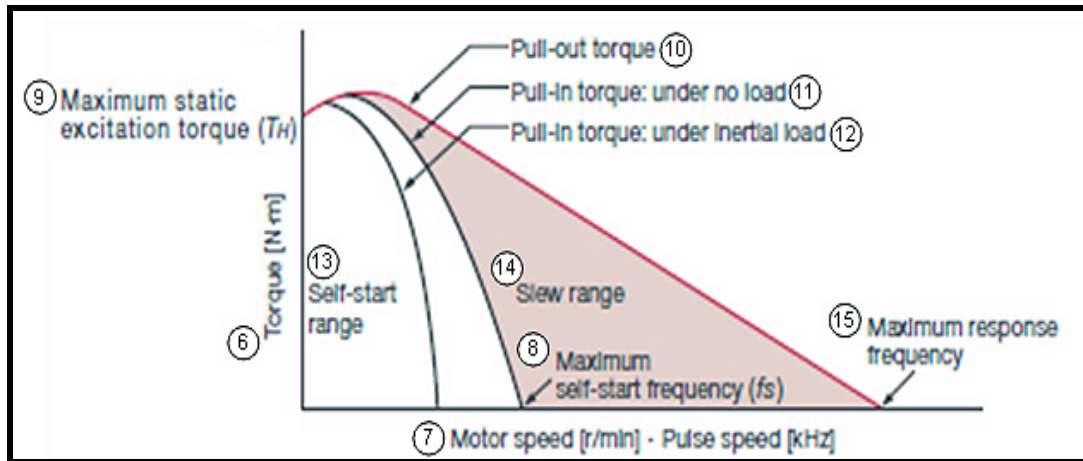


Figure 10: Typical stepper motor speed vs torque characteristics [Orient Motors]

3.2.2 Stepper Motor Types:

Stepper motors can be classified based on construction: Variable reluctance (VR), Permanent magnet (PM) and Hybrid synchronous (HS), or winding type: bipolar, unipolar.

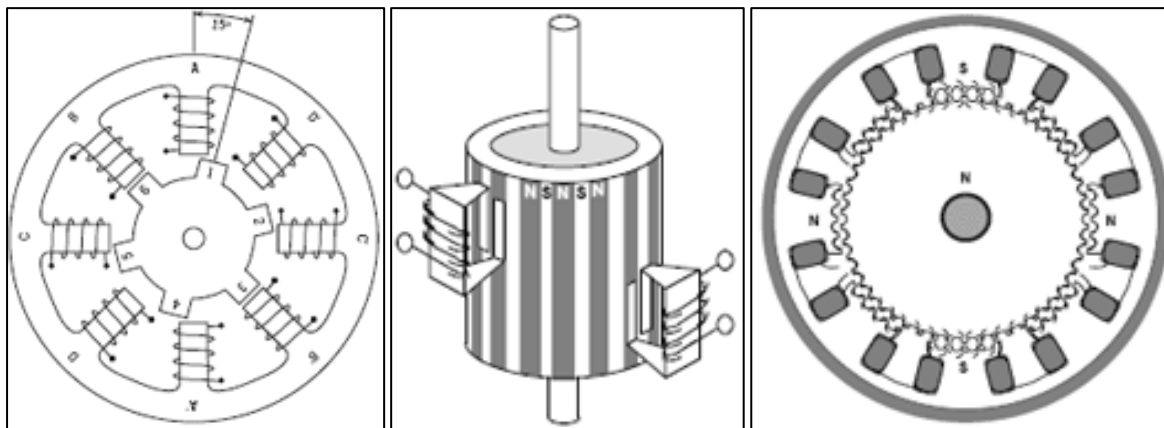


Figure 11: Stepper motor types: a. Variable Reluctance, b. Permanent Magnet, c. Hybrid [robotiksistem]

Variable Reluctance: These are the simplest type of stepper motors in terms of construction. They consist of a soft iron core with a gear shape and an electromagnet stator with protruding nodes. When the stator windings are energized, magnetism is induced in the soft iron rotor, creating poles. These poles in the rotor are attracted to the poles of the stator and the motor moves one step. In principle, the smaller the overlapping area between the rotor and stator poles, the more magnetic attraction force is generated. These types of motors tend to be smaller and faster than the permanent magnet type of similar design due to the lightness of the soft iron core.

Permanent Magnet: The PM rotor design involves the arrangement of alternating magnetic strips of north and south poles. The stator has electromagnetic nodes which are then powered

to attract the rotor poles. Sequential activation of the stator nodes leads to motion of the rotor. Due to the rotor having permanent magnets, PM motor produce higher torque and have better torque characteristics than VR stepper motors.

Hybrid: These motors combine the advantages of both PM and VR stepper motors. They have higher speed, torque and resolution by introducing attaching two serrated gear profiles on the rotor, each with different polarity and rotationally offset to each other. Such improvements in the construction boosts performance but also makes hybrid motors more expensive than PM motors.

PM motors and hybrid motors are the most commonly used types and PM motors are usually used in project implementation due to cost, unless the application necessitates high torque or resolution requirements.

Bipolar and unipolar: The electro magnet winding in the stator of a stepper motor can be arranged with just the leads of each coil (Bipolar) i.e. A/-A and B/-B, or a common terminal can be added to the centre of each coil as shown in the figure below (Unipolar).

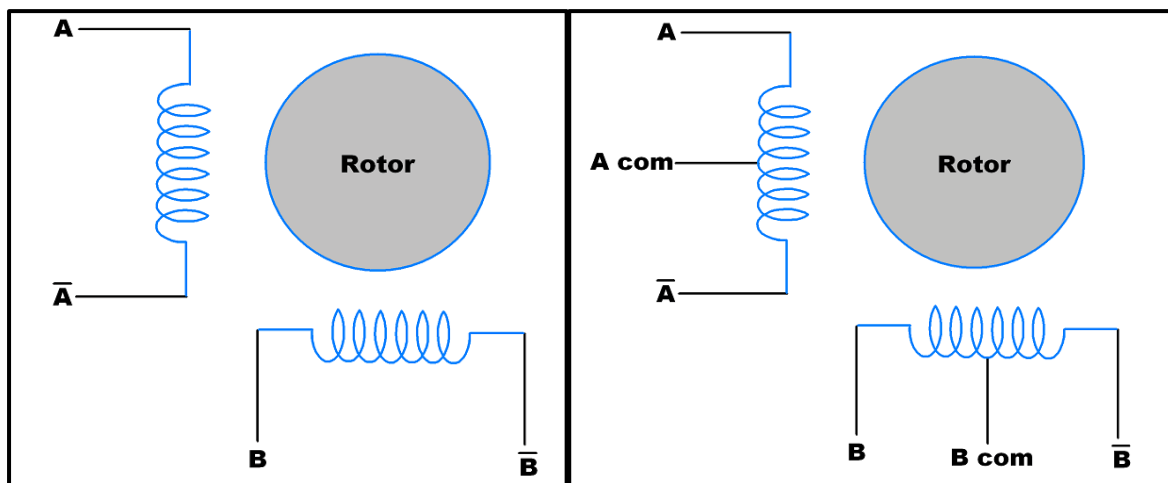
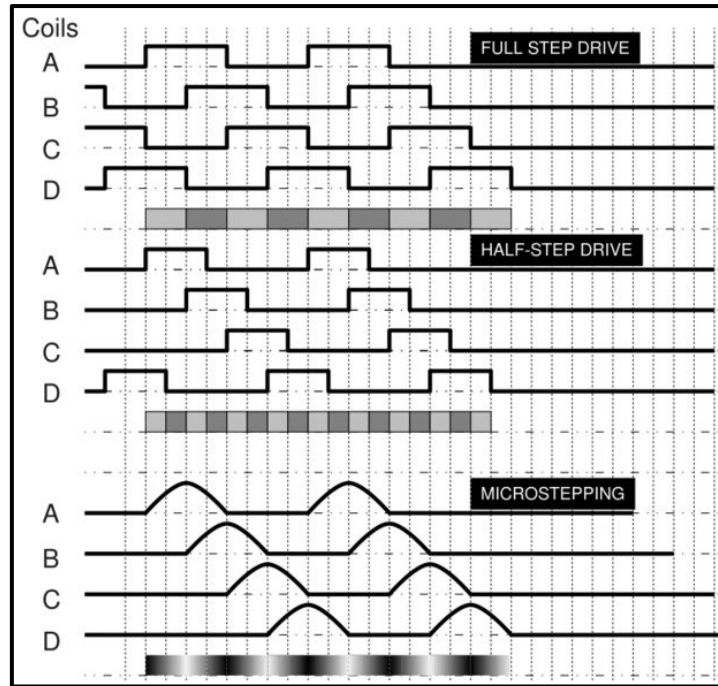


Figure 12: Bipolar and Unipolar stepper motor terminal arrangement

3.2.3 Stepper Motor Driving

3.2.3.1 Driving Modes

Stepper motors are operated by applying voltage to the stator coils in a predetermined sequence in order to produce the desired rotation on the rotor shaft. The changing of the voltages can be controlled by a microcontroller which applies pulses to the stepper motor terminals. By changing the sequence of pulse application to the motor terminals it results to various types of motor driving modes i.e. full stepping, half stepping and micro stepping.



The figure above shows the pulse sequences to each of the motor terminals to achieve, full step, half step and micro-stepping.

In full stepping, two motor coils are powered at every time step. This results to the rotor making one full step at each time step. In order to increase step resolution, the motor can be driven by energizing only 1 coil at a time. This makes the rotor move only half a step at each time step resulting in motion that has twice the resolution as compared to full stepping. Despite the increase in resolution, half stepping results in a reduction in torque. When position precision and step resolution is critical, micro-stepping is usually employed. This involved using a continuously varying voltage on the terminals, as opposed to pulse voltage in full and half stepping. This mode leads to reduction in motor torque output and can only be implemented in bipolar style motors.

3.2.3.2 Step Angle

The motor step angle is a key parameter when driving a stepper motor in order to control position. The step angle changes depending on the driving mode. The standard calculate for the full step angle is done using the following equation:

$$\text{Step angle } (\theta) = \frac{360^\circ}{\text{steps per rotation}}$$

The step angle can be calculated or obtained from the motor data sheet. In the case of half stepping the step angle doubles.

3.2.4 Stepper Motor Selection

Stepper motors have several key advantages that made them ideal in the implementation for this project. These include:

1. Rotate in discrete steps thus have high positional precision and repeatability of motion.
2. They are brushless thus low maintenance.
3. They are considerably cheap.
4. High holding torque

These were key aspects in the implementation of the project and guided the decision for the use of stepping motors. Two unipolar hybrid stepper motors were used in the implementation of this project; 5v and 12v. They both required 512 steps to complete each rotation which results in a step-angle of 0.7 of a degree. The 5v motor was selected since it consumes little power and it can be driven directly by the microcontroller. This makes the system economical in construction and operation. This motor was used to move the upper panel which was used in track the linear path of the sun in the horizontal axis. The parabolic motion of the sun requires to be driven by a high torque motor and this was implemented using the 12v stepper motor which was powered by an external power supply.

3.3 Stepper Motor Driver Circuit

To enable the microcontroller to interact with the stepper motor, especially the 12v, a stepper motor driver IC was required. The ULN2003 is a stepper motor driver, consisting of Darlington arrays. A schematic of the circuit connection is as shown below:

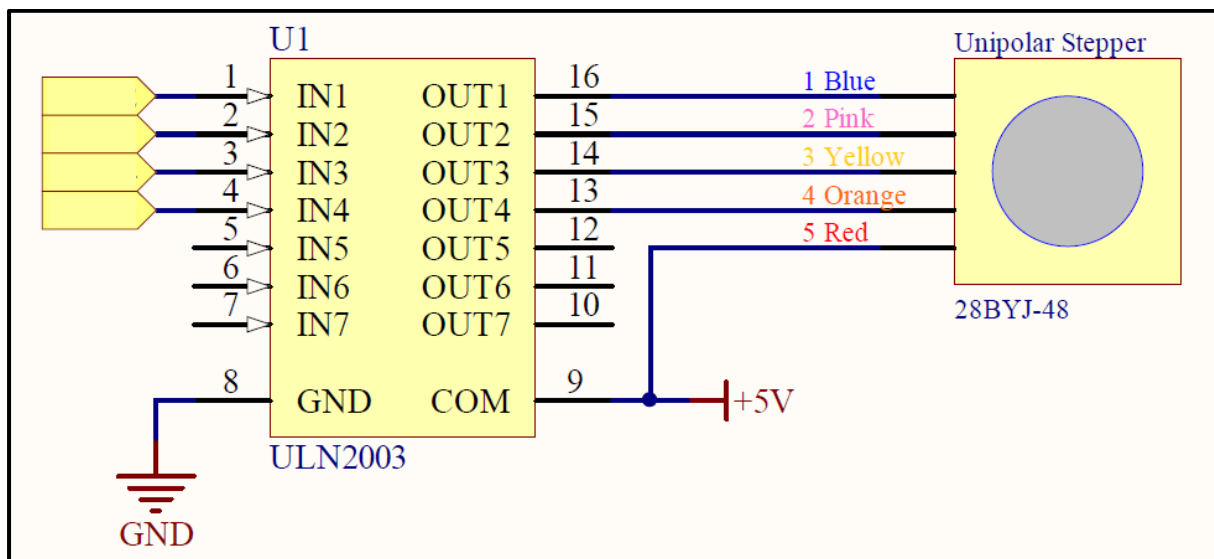


Figure 13: Typical ULN2003 Connection circuit diagram

In this circuit, the motor rotation speed and direction will be controlled by the signal into pin 1-4 which are sent from the microcontroller. The ULN2003 is economical, can operate motors of 5-12v and is compatible with the stepper motors intended for use in the project.

3.4 Limit Switches

To add a safety feature to the device to ensure the motors do not run past the panel's range of motion, 4 limit switches were added to the system. They were placed such that when the motors run and the panel reaches the end of its motion range, the limit switches come into contact with the panel and are activated. This sends signal to the microcontroller which can then stop the motors motion and prevent any damage to components.

3.5 Microcontroller (RASPBERRY PI 1 MODEL B+)

The selected microcontroller for this project is the Raspberry PI model B+. It is powered by an ARM micro controller IC which is a capable and micro-processor with the following features:

- ARMI176JZF-S 700 Mhz processor.
- USB ports
- Ethernet port
- 40 pin connectors
- Low power consumption

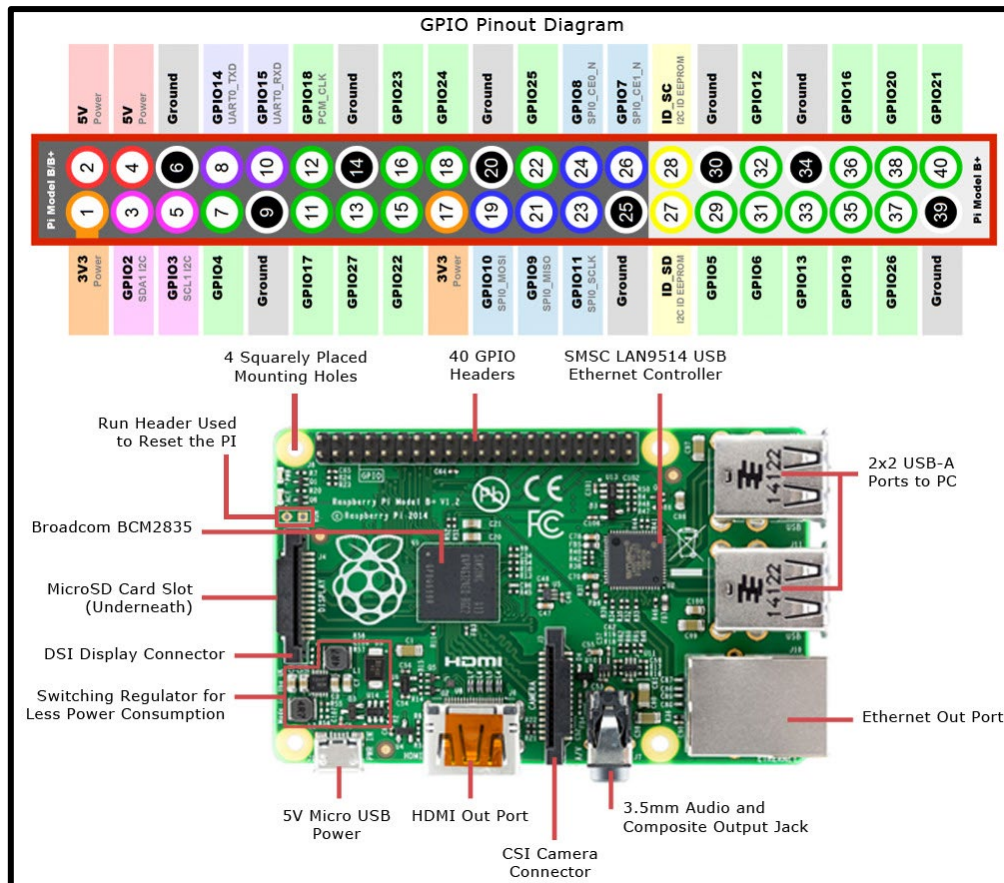


Figure 14: Raspberry pi microcontroller board layout with GPIO pinout diagram

The microcontroller can be setup with a variety of operating systems and programming languages. In this project the standard RASBIAN operating system was used with Python selected as the programming language. Due to Python's being a simple but powerful programming language, it was selected as the base for this project.

3.6 Power Supply

A power supply was necessary in the implementation of the project, in order to supply power to the various ICS. These include the micro-controller, stepper motors, motor drivers and ADCs. The Universal Battery Elimination Circuit (UBEC) and a 12v battery were chosen as the power supply to the system. UBEC is a DC voltage Buck converter that is able to operate at a consistent efficiency despite the input current unlike liner voltage regulators such as LM78** series. UBEC are also cost effective and were found to be suitable for use in this project. The power requirements for the system were: Micro-controller and ICs – 5v and Stepper motors – 5v and 12v. The UBEC was used to step down the battery voltage from 12v to 5v and had a maximum current output of 3A.

3.7 Circuit and Control Algorithm Design

The circuit to the system was designed using the Proteus circuit design application which resulted in the circuit illustrated in the appendix. The control algorithm for the system was implemented in Python programming language. The control flow of the algorithm was implemented using the following pseudo code:

1. Setup the raspberry pi and make the necessary pin declarations.
2. Perform an initialization process where the motors are set to the home position.
3. Loop: Check the readings from the LDRs and input them into the micro-controller through the ADC
4. Compare the LDR values and determine in which direction the panel should be moved.
5. Before motor actuation, check if the limit switches have been activated.
6. IF: the limit switches are not activated, move the motors
7. ELSE: send the system to sleep for 1 minute
8. End-Loop:

The circuit and flowchart below illustrate how the circuit connections were implemented and how the program will flow. The actual Python code is illustrated in the Appendix 1.

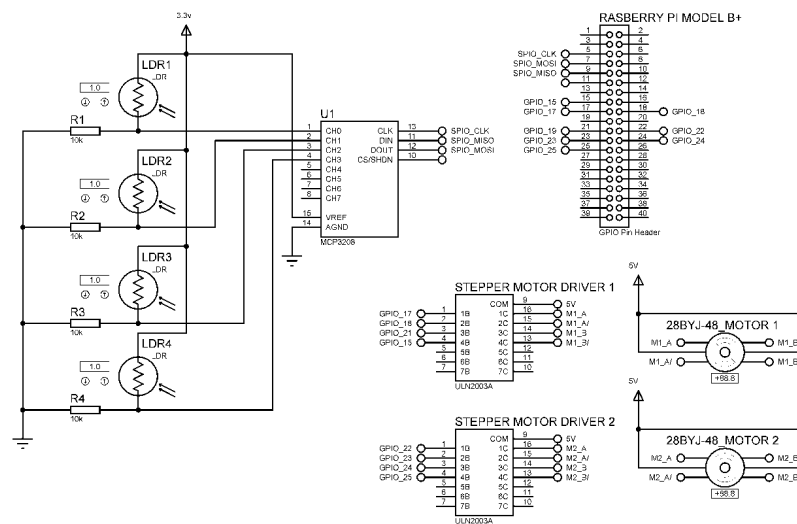


Figure 15: System Circuit implemented in Proteus.

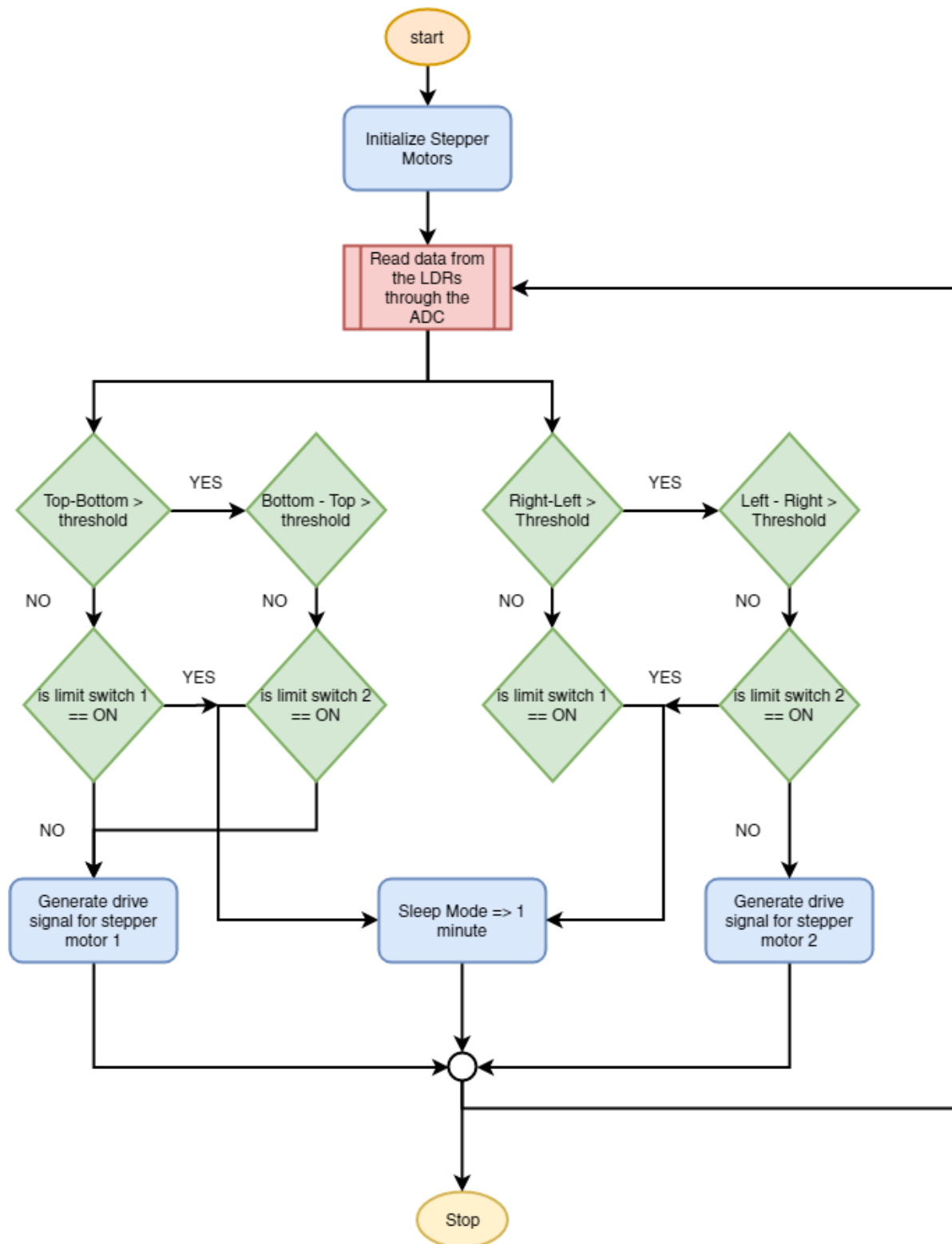


Figure 16: Control Algorithm Flow Chart.

These are the main Bill of Materials (BOM) that may be needed for the success of the project.

Table 2: Bill of Materials (BOM)

PART	QUANTITY	SPECIFICATION	SHOP	Price (USD)
Stepper Motor Drivers	1	TMCM-1630-4U	https://www.digikey.com	\$163
FET transistors	4	MOSFET P-CH 20V 4A SOT-23	https://www.digikey.com	\$0.54 (2.16)
Schottky Diodes	4	DIODE ARRAY SCHOTTKY 100V D2PAK	https://www.digikey.com	\$1.67 (6.68)
Ultrasonic Sensor	4	HC_SR04	https://www.digikey.com	\$38 (152)
Optical Sensors	4	CNY70 344	https://www.digikey.com	\$1.39 (1.56)
Stepper Motors	2	12V DC MOTOR 122RPM W/ENCODER	https://www.digikey.com	\$34.11 (68.22)
Bumper Switches	6	SWITCH TACTILE SPST-NO 0.05A 12V	https://www.digikey.com	\$0.51 (3.06)
RESISTOR, 20kOhm_5%	3	R6, R5, R4	https://www.digikey.com	6.48
BJT_NPN, 2N2222A	3	Q3, Q2, Q1	https://www.digikey.com	\$1.39 (1.56)
ADC Converter	1	U3	https://www.digikey.com	\$1.67 (6.68)
Connection Cables	2 Rolls	U4	https://www.digikey.com	\$0.54 (2.16)
Terminal Crimps	1 Set	R1, R2, R3	https://www.digikey.com	\$0.51 (3.06)
Status LED (Assorted)	1 Set	LED2	https://www.digikey.com	\$0.54 (2.16)
Total Cost				169.48

3.8 Stepper motor Power Calculation

In order to calculate the power needed in the stepper motor, the design from Solid works was used.

The assumptions made in this design include:

The weight of the panels is 12kg

The weight of the supporting structure is 13kg

Total weight = 12kg + 13kg = 25kg.

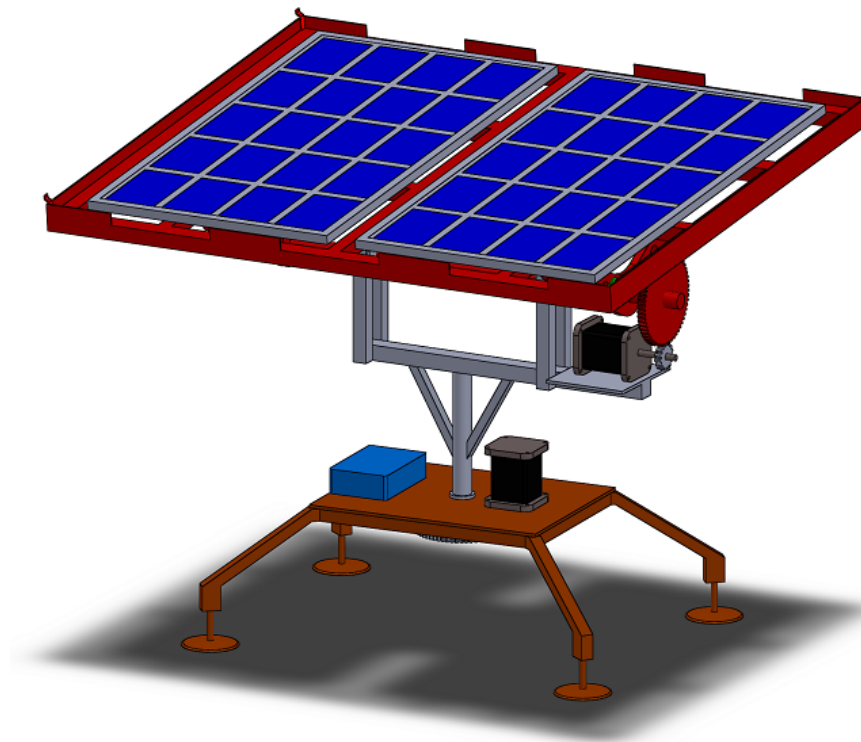


Figure 17: Orthographic view of the design

There are two stepper motors; 1 for the X-axis and one for the Z-axis (Azimuth angle)

Free Body Diagram illustration

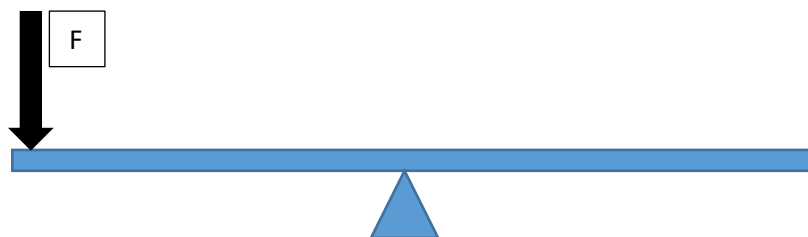


Figure 2: Free Body Diagram

$$F = (12.5\text{kg} \times 9.8)\text{N}$$

$$\text{Moment} = (12.5 \times 9.8)\text{N} \times 1\text{m} = 122.5\text{Nm}$$

$$\text{Moment (azimuth)} = (12.5\text{kg} \times 9.8)\text{N} \times 0.85\text{m} = 104.125\text{Nm}$$

$$\text{ear Ratio} = 8\text{hrs} \times 60\text{Mins} = 480 \text{ Steps}$$

The steps will be doubled since the panel does not move 360 degrees.

Therefore:

$$480 \times 2 = 960 \text{ Steps}$$

For every 10 mins the stepper motor will be moving, therefore;

$$960 \frac{\text{steps}}{10} \text{ mins} = 96 \text{ steps per day}$$

Assuming these to be the number of teeth in the driven gear.

Therefore:

$$\frac{96 \text{ Teeth}}{8} = 12 \text{ Teeth (driving gear)}$$

Therefore, the gear ratio; 8:1

Torque required in the stepper motors will be:

$$\frac{122.5}{8} = 15.31 \text{ Nm}$$

$$\frac{104.25}{8} = 13.01 \text{ Nm}$$

To consider a factor of safety for the stepper motors, from the literature review, 2.4 was seen as suitable factor of safety considering strong winds.

$$15.31 \text{ Nm} \times 2.4 = 30.744 \text{ Nm}$$

In order to produce 30.744, the stepper motor can be run in two modes, the suitable stepper motor specs;

3Phase Stepper with 5.8A

Mode I: Using 3 phases

$$\text{Power} = I^2 R = 5.8^2 \times 0.62 = 20 \text{ W per phase.}$$

Therefore, for the three phases, the motor will consume = $20 \text{ W} \times 3 = \mathbf{60 \text{ W} \times 2 \text{ motors} = 120 \text{ W}}$

Mode II: Using 2 Phases

In 2 phase mode, the stepper consumes 4.5A per phase

$$\text{Therefore } 4.5^2 \times 0.6 = 12 \text{ W}$$

The maximum power that is consumed in this configuration is $\mathbf{24 \text{ W} \times 2 \text{ motors} = 48 \text{ W}}$

3.9 Mechanical Design

The mechanical design was conceptualised using Solid Works design software. Individual components were designed before the final assembly drawing was illustrated. The main design views are illustrated in Appendix II. The designed comprises of various components which include

- ❖ A tilt able panel holder capable of holding two panels of medium size (164mm by 99mm). This provides the system with the capability to change position with respect to sun movement (rotates along the horizontal axis).
- ❖ A vertical frame/rotator which allows the system to rotate at 360 degrees along the vertical axis to allow the system to change the position for different seasons. It has a provision to hold the panel holder and allow rotation is also has a provision to hold the first stepper motor that will be controlling the rotation of the panel holder
- ❖ A base to provide the system with required stability it has a provision to hold the second stepper motor that will control the rotation of the frame/rotator.
- ❖ Gears are used to transmit the torque required to move the system accordingly.
- ❖ Light sensors are used to sense the light intensity and transmit the data to the control circuit for interpretation. They are four in number and are located at the top of the panel holder at the corners.

A dual axis system was designed. The components of the dual axis system were designed in SOLIDWORKS and mechanism analysis was performed to ensure that the mechanism is working as required. This was done by carrying out a detailed motion study. The mechanism is capable of rotating an angle of 360 degrees with respect to the vertical axis and 270 degrees along the horizontal axis. This will provide the system with maximum exposure to sun light if implemented appropriately to contribute in increasing the efficiency of solar energy generation.

3D illustration of the design is illustrated bellow

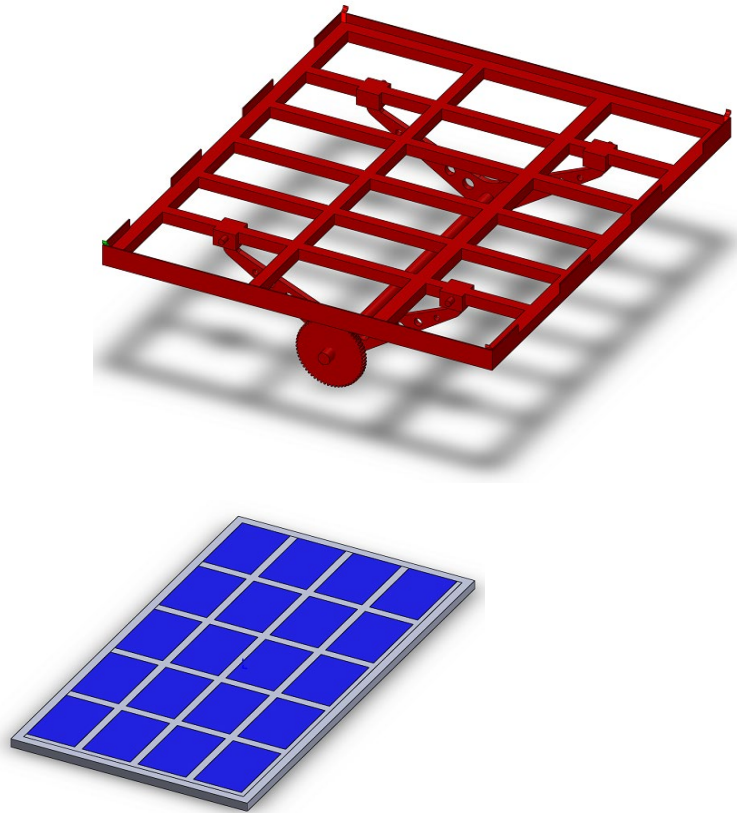


Figure 19: The panel holder and Photovoltaic Panel

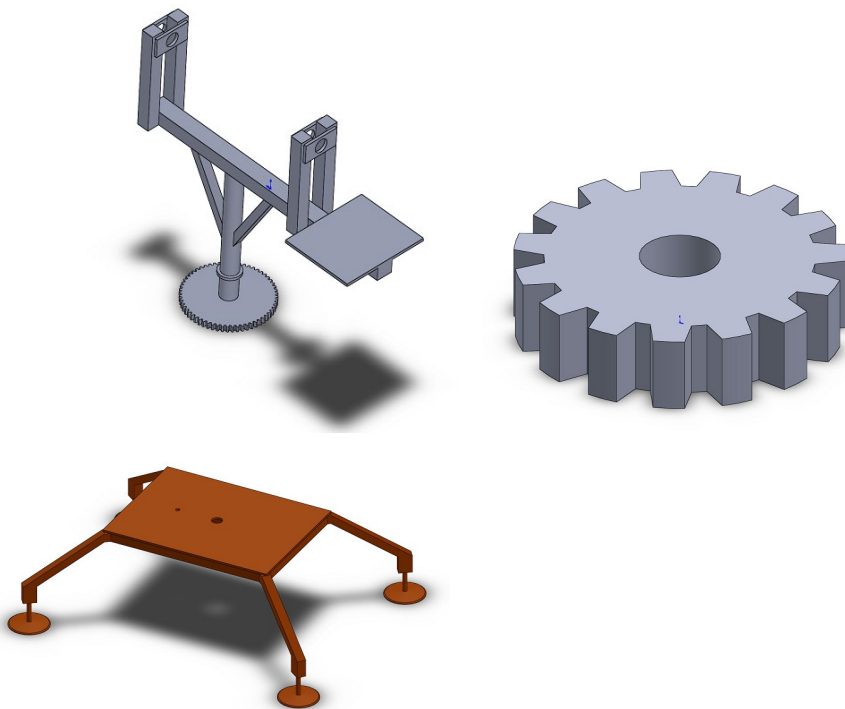


Figure 20: Frame/vertical rotator, Drive gear and the base

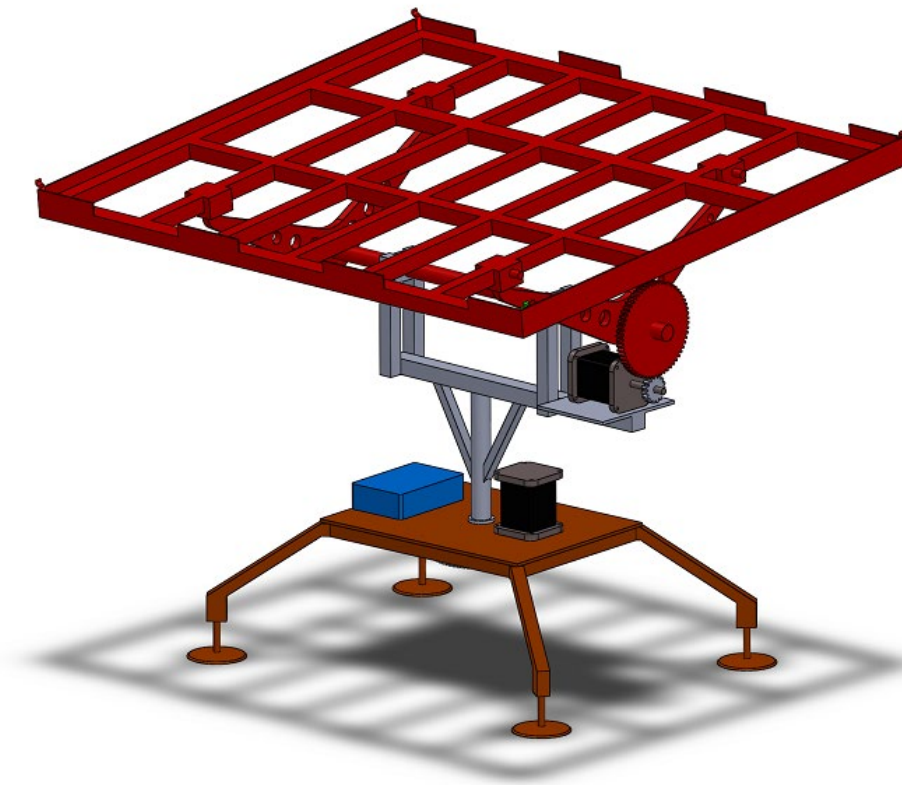


Figure 21: The frame without the PV pannels connected

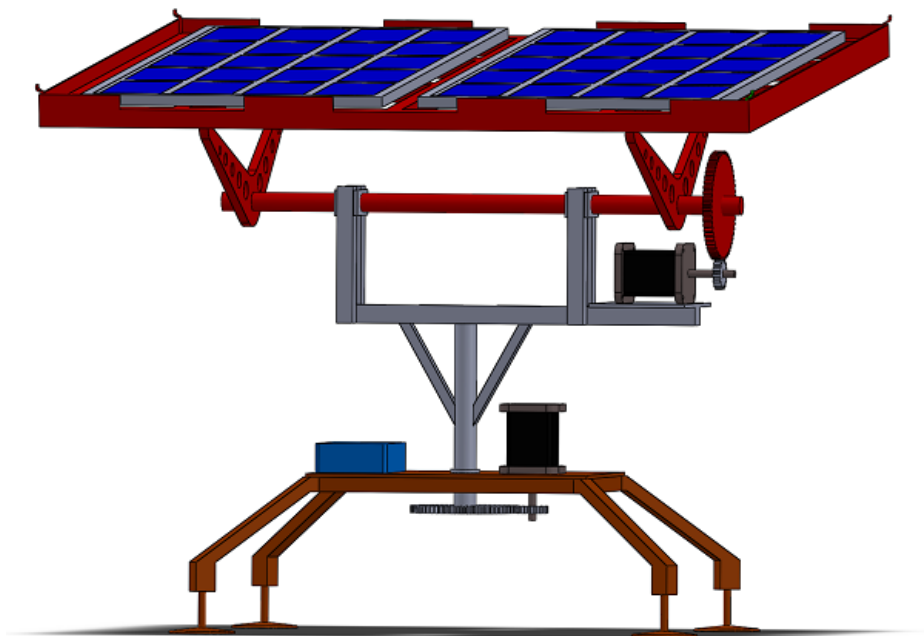


Figure 22: Clearly shows the stepper motors using spur gears to trasmit the torque to the pannel and the frame

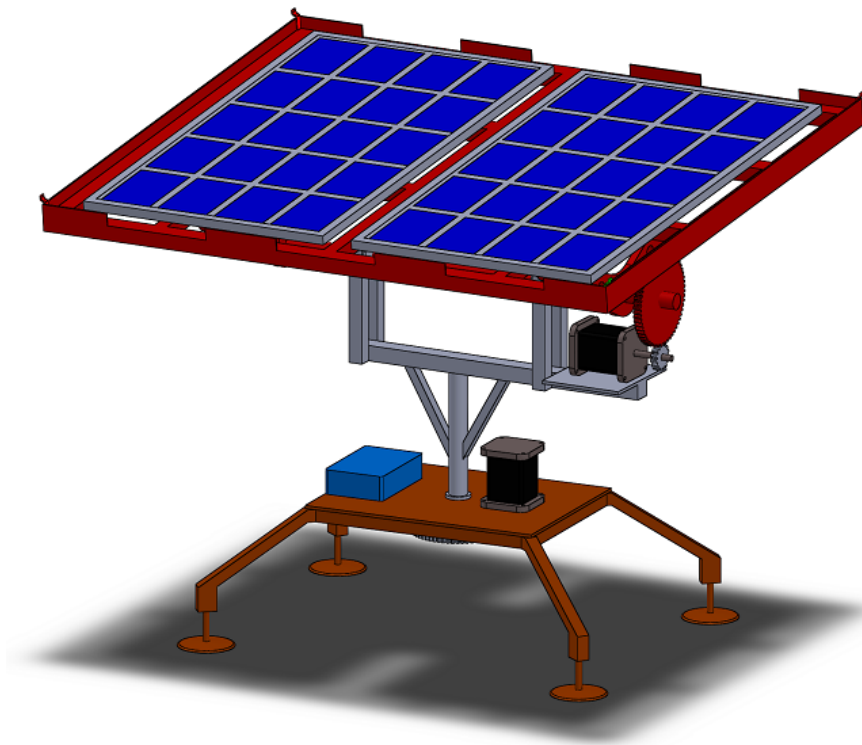


Figure 23: Orthographic view of the design

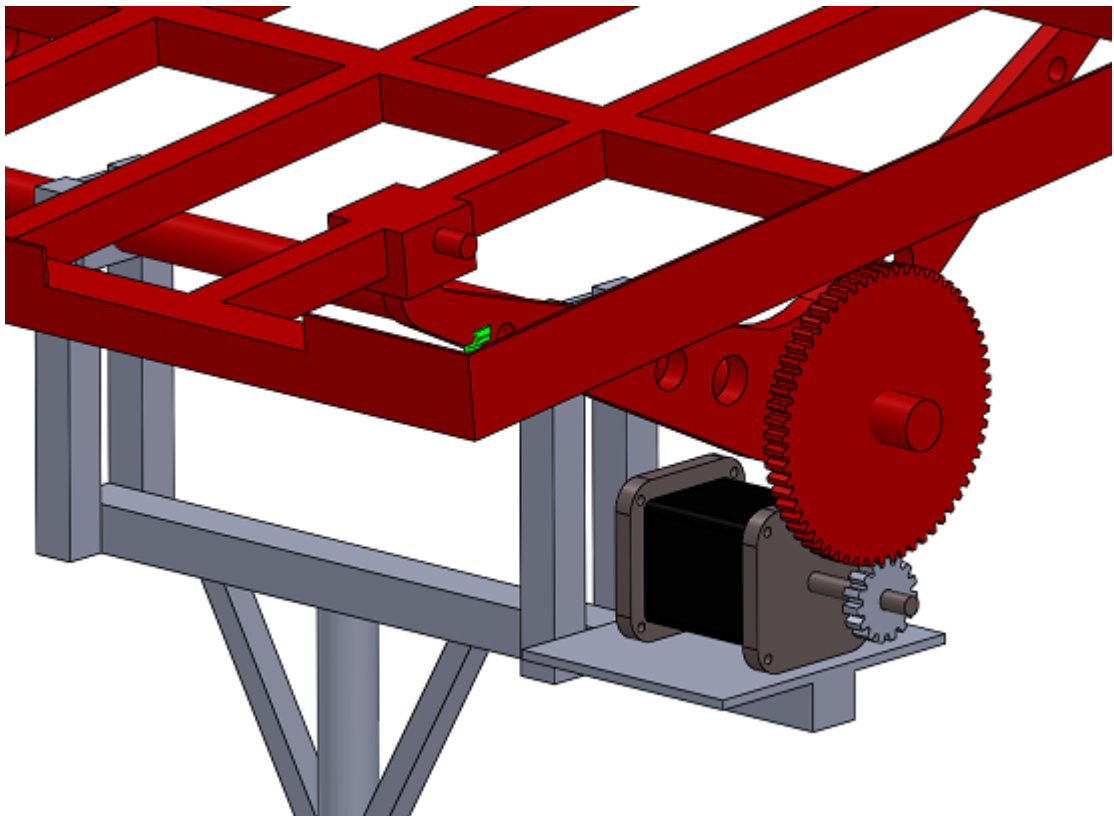


Figure 24: First axis rotation to control the panel holder only (rotates along the horizontal axis)

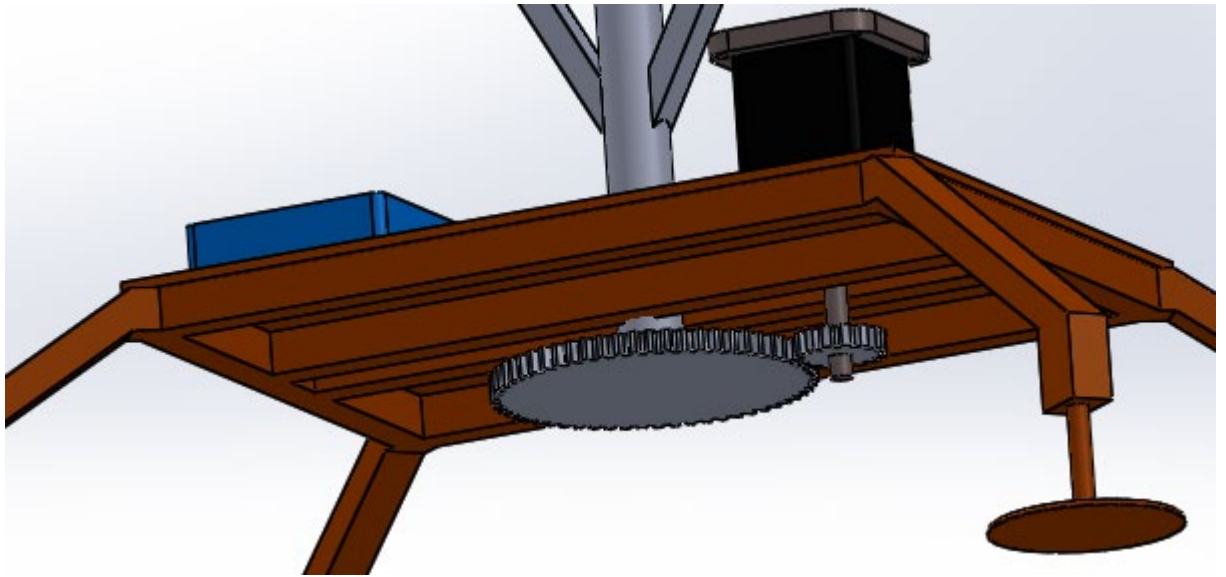


Figure 25: Second axis rotation to control the whole system rotate along the vertical axis

3.10 Calculations

3.10.1 Starting torque for motor 1

Torque required to start the rotation of the panel holder is calculated as follows

Torque is the twisting force that tends to cause rotation and can be obtained by the product of force and radius of rotation

$$Torque = F \times R \times (\sin \theta)$$

Where F= Force

R = radius

θ = force inclination angle

For this system the force acting on the mechanism comprises of the weight of the components and friction.

Torque required to cause rotation in motor 1

Components include; panel holder, shaft, gears and two solar panels

Total weight of the components is given by

$$Force = mass(kg) \times gravity$$

$$1500N + 500N = 2000N$$

$$Force = Mg + \mu Mg$$

$$\text{coefficient of friction for steel clean and dry surface}(\mu) = 0.5$$

$$Force (F) = 2000N + (0.5 \times 2000)$$

$$Force (F) = 3000N$$

$$Torque (T) = F \times R$$

$$R = \text{radius of the driven gear}$$

$$R = 150mm (0.15m)$$

$$T = 3000 \times 0.15$$

$$T = 450Nm$$

The gear small gear radius $r = 22.5mm (0.0225m)$

To determine the torque on the gear we find the gear ration

$$Gear\ ratio (GR) = \frac{R}{r} = \frac{T}{t}$$

$$(GR) = \frac{150}{22.5} = \frac{450}{t}$$

$$t = 65.5Nm$$

The torque to route the mechanism is $65.5Nm$

3.10.2 Torque required by motor 2

Torque required to route the rotation about the vertical axis is as follows

$$Total\ force = 3000 + (0.5 \times 3000)$$

$$F = 4500N$$

$$T = 4500 \times 0.15$$

$$T = 675Nm$$

$$Gr = 150/22.5 = 675/t$$

$$T = 101.25Nm$$

3.11 Material selection

The solar tracker system comprises of a base to support the rotating vertical frame and two medium size solar PV panels. This means that the structure will be exposed to a lot of stress and fatigue and since this structure is a long-term design it should be made of strong enough material to prevent any failure. A solar tracker frame is designed last for over 7 years. The material chosen for the manufacture of this design is alloy steel. Alloy steel has excellent structural strength that will bear with the requirement of the design.

Alloy steel has a yield strength of 620mpa. The structure should therefore be designed such that the maximum stress that emanate from the loads it will be carrying do not exceed this

value. For safe working condition that will not result to unexpected failure the maximum stress experienced by the designed structure should be less than the materials yield strength by half. This load is referred to as the safe working load.

Material chosen has high resistance to corrosion. It is an alloy of elements such as chromium, nickel, molybdenum, silicon, Sulphur and nitrogen which contribute to its improved resistance to corrosion. This is a great feature since the structure will always be exposed to the atmospheric corrosion.

Alloy steel has great manufacturability which will facilitate ease of production. Manufacturability is obtained through characteristics such as good machinability in annealed condition, it can be formed using conventional methods since it has high ductility and it also has good weldability using conventional techniques.

3.12 Safety factor

Safety factor is used in describing load carrying capacity of a structure of a component beyond the intended loads. It shows how much the designed component/structure is stronger than expected. It is calculated by dividing the yield stress of the components material and the maximum stress experienced by the component. Mainly the maximum stress is obtained through an extensive analysis performed on the component through FEA or hand calculation. The safety factor of engineering components is supposed to be more than two for safety purposes.

Finite Element Analysis

Model name: pannel holder
Study name: Static 2(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 9826.4

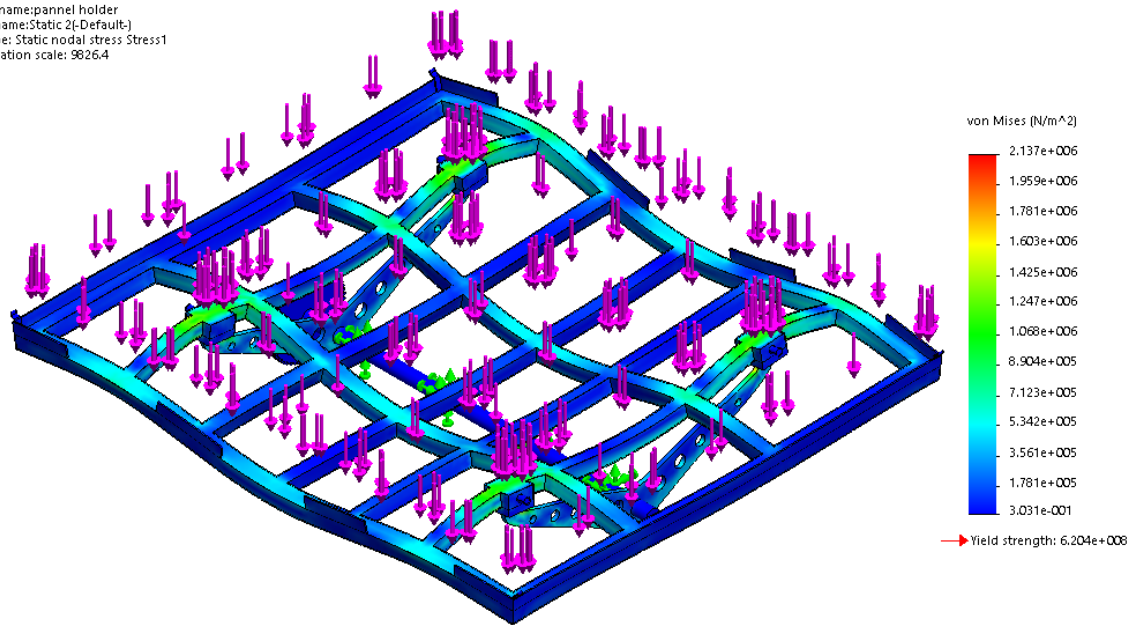


Figure 26: Stress analysis results for the panel holder

Maximum stress is 213.7mpa and the yield stress of the material is 620.4mpa

The safety factor is achieved by dividing the two as follows

$$\frac{620.4mpa}{213.7mpa} = 2.9$$

The deformation experienced by holder is 0.002mm. Allowable elongation alloy steel is 40% which would amount to 5mm. the elongation within the allowable limit.

Model name: pannel holder
 Study name: Static 2(-Default-)
 Plot type: Static displacement Displacement1
 Deformation scale: 9826.4

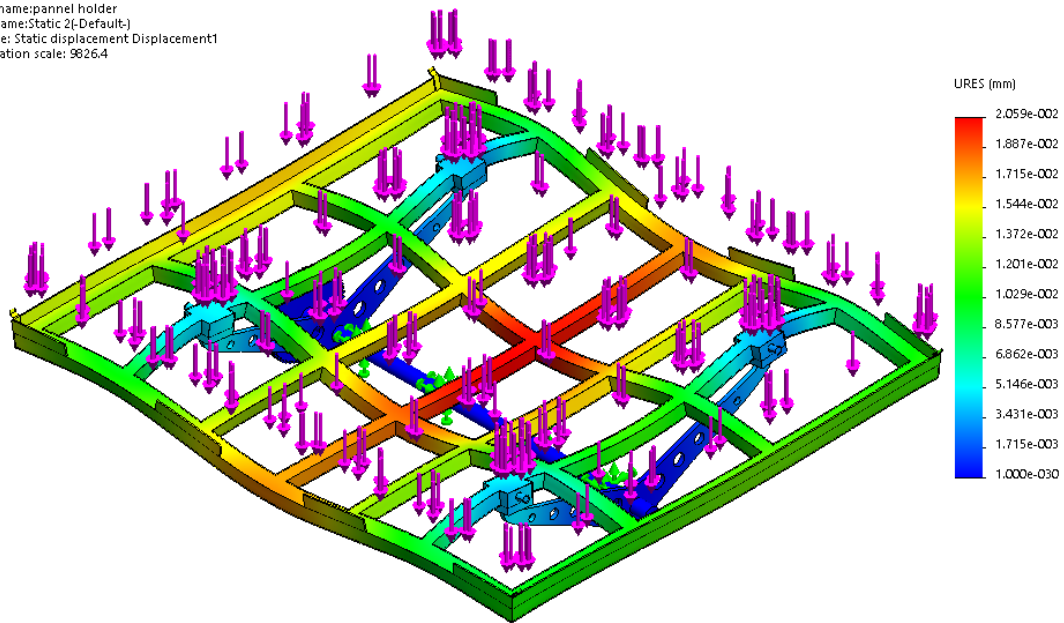
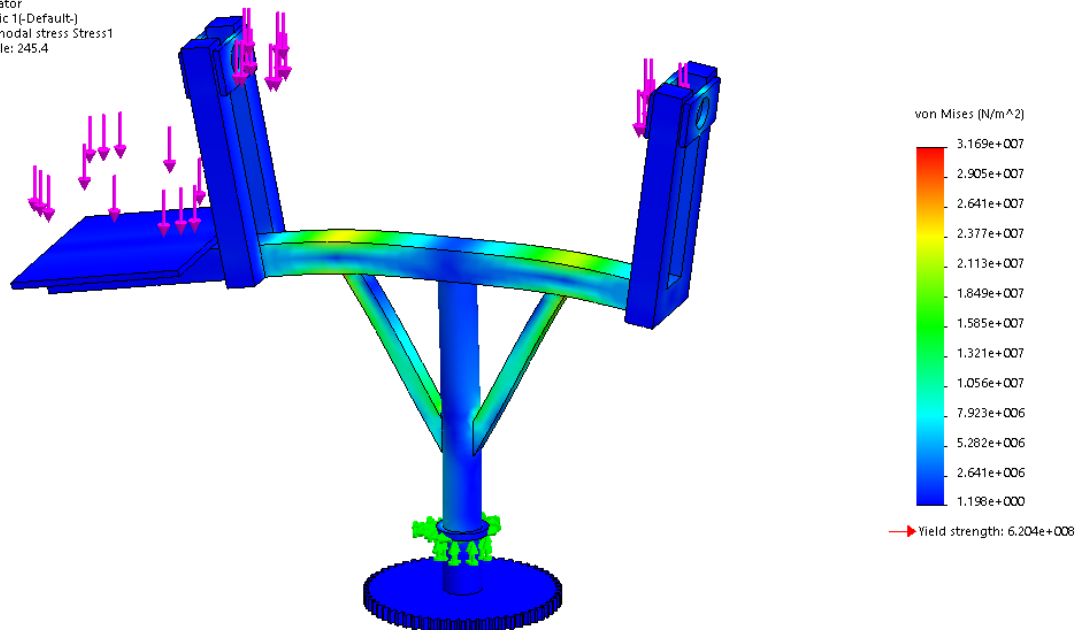


Figure 27: Deformation results for panel holder design

Model name: rotator
 Study name: Static 1(-Default-)
 Plot type: Static nodal stress Stress1
 Deformation scale: 245.4



3.12.1 Stress results for the frame

Maximum von-misses stress experienced by the frame at a load of 3000N is 316.9mpa therefore the safety factor is 1.96

$$\frac{620.4mpa}{316.9mpa} = 2.9$$

The deformation is found to be 0.4171mm which is within the allowable range of 40 % elongation

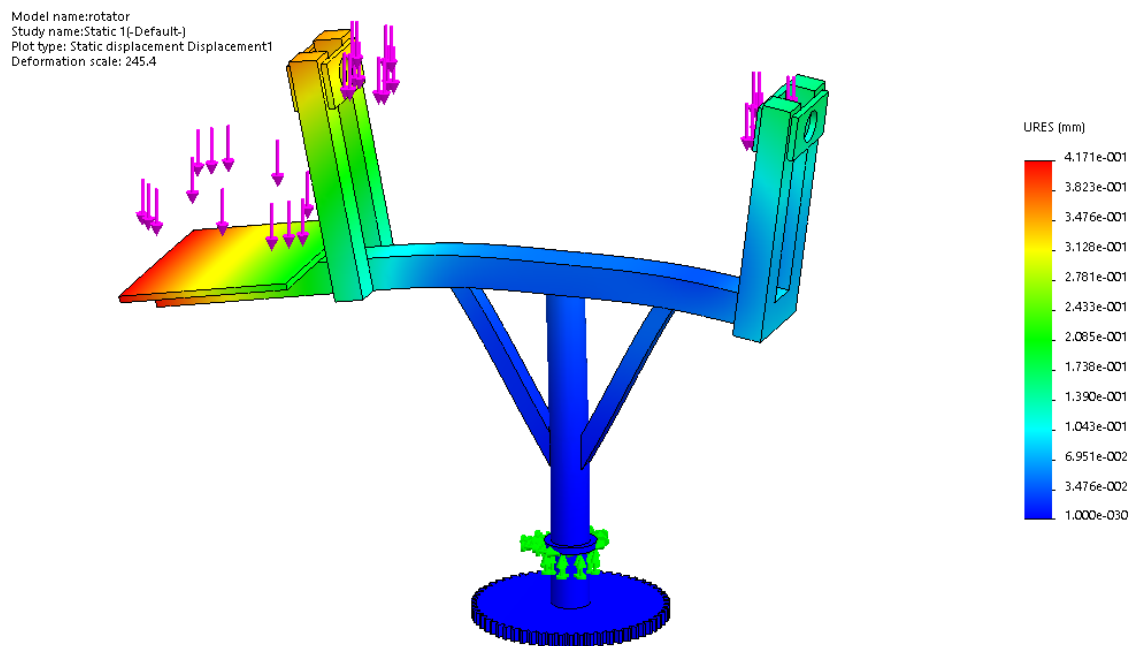


Figure 28: Bend results for the frame

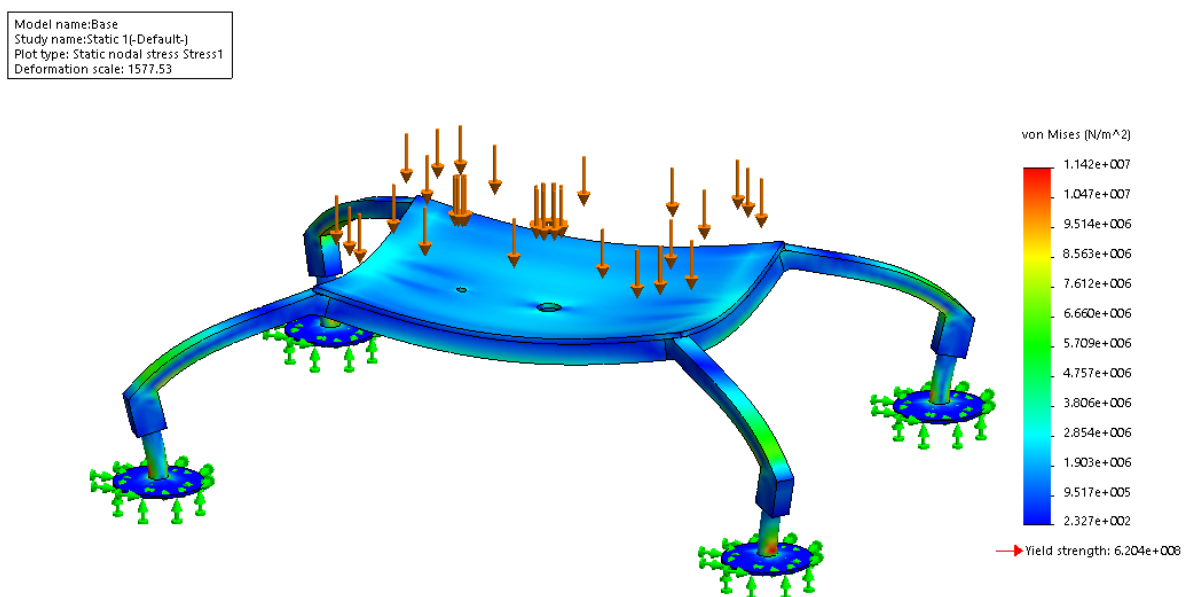


Figure 29: FEA Stress results for the base

The base supports all the components of the structure and provides stability it experiences a lot of stress but it was designed to withstand high amount of stress. It experiences a maximum stress of 114.2mpa which result in a safety factor of 5.43. maximum deformation 0.0933mm less than the allowable 40% elongation.

Model name:Base
Study name:Static 1(-Default-)
Plot type: Static displacement Displacement1
Deformation scale: 1577.53

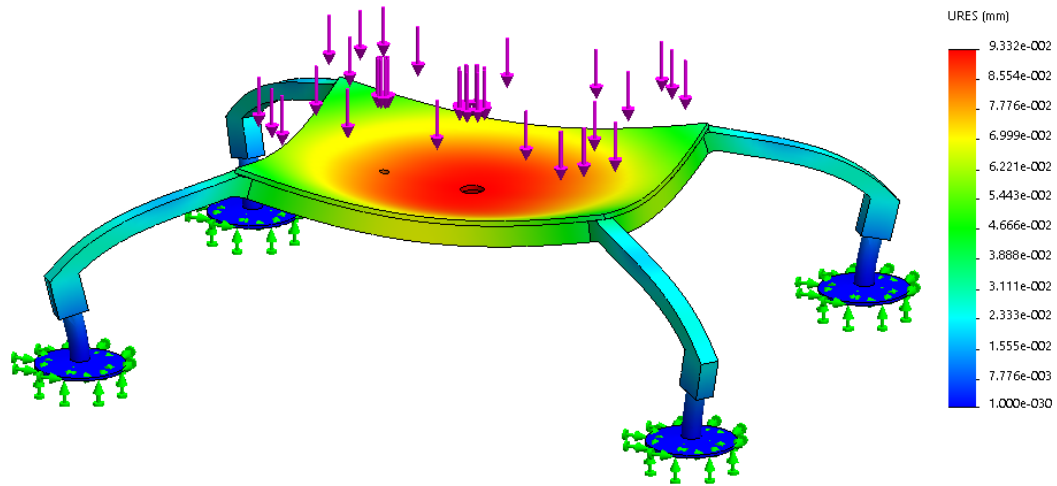


Figure 30: FEA Deformation results for the base

Table 3: Cost of manufacturing

component	cost
Rectangular alloy Steel bars 2 bars	\$25
Alloy steel Flat plates ($\frac{1}{4}$ sheet)	\$5
Welding cost	\$10
Measuring and Cutting	\$5
Total production cost	\$45

Chapter 4. CONCLUSION AND RECOMMENDATIONS

The objective of this project was the development of solar tracking system able to improve the power generating capacity of solar panels by quantity of direct sunlight hitting the panels. The system was implemented as designed and the project objectives were met. The system was able to track the sun's movement throughout the day. When compared to a fixed solar array, it is expected that the solar tracker can improve power generation in the range of 20-25%.

Further improvements that can be implemented in the system include the inclusion of low power Light sensors with higher efficiency. This will increase the system's overall performance. A challenge that was faced that affected the panel's power generation capability was dust settling on the panel surface. A protective cover can be used and additional control features implemented so that when the panel efficiency drops due to dust coverage, an alert can be sent for further action.

Chapter 5. Reference

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Appendix

5.1 Appendix I

```
#!/usr/bin/python

"""
In the beginning we call all the modules that will be used within the code
using the import keyword.
"""

from mcp3208 import MCP3208
import math
import os                      # Used to
import RPi.GPIO as gpio       # Necessary in order to access input and output pins of the
raspberrypi                   #
import spidev                  # Used for communication via serial port
import time

adc = MCP3208()

# Pin definitions for the
motor1PINS = [17,18,21,22]
motor2PINS = [4, 25, 24, 23]

SEQA = [(17,), (17,18), (18,), (18,21), (21,), (21,22), (2,), (2,17)]
RSEQA = [(22,), (22,21), (21,), (21,18), (18,), (18,17), (17,), (17,22)]
SEQB = [(4,), (4,25), (25,), (25,24), (24,), (24,23), (23,), (23,4)]
RSEQB = [(23,), (23,24), (24,), (24,21), (25,), (25,4), (4,), (4,23)]

DELAY = 0.001

gpio.setmode(gpio.BCM)
for pin in motor1PINS:
    gpio.set(pin, gpio.OUT)
for pin in motor2PINS:

    gpio.setup(pin, gpio.OUT)

def stepper(sequence, motor1PINS):
    for step in sequence:
        for pin in motor1PINS:
            gpio.output(pin, gpio.HIGH)
            if pin in step else gpio.output(pin, gpio.LOW)

def stepper(sequence, motor2PINS):
    for step in sequence:
        for pin in motor2PINS:
            gpio.ouput(pin, gpio.HIGH)
            if pin in step else gpio.output(pin, gpio.LOW)
    for pin in motor2PINS:
        gpio.output(pin, gpio.HIGH)
```

```

        if pin in step else gpio.output(pin, gpio.LOW)
        time.sleep(DELAY)

# First open SPI bus

spi = spidev.SpiDev()

spi.open(0,0)

def get_adc(channel):

    #First pull raw data from the chip

    r = spi.xfer2([1, (8+channel)<<4,0])

    #Process the raw data into something understandable

    adcout = ((r[1]&3)<<8)+r[2] #get bit value

    return adcout

try:

    while True:

        #Initialize what sensor is where
        get_adc(0)
        LDR1 = get_adc(0)
        time.sleep(0.05)
        get_adc(1)
        LDR1 = get_adc(1)
        time.sleep(0.05)
        get_adc(2)
        LDR1 = get_adc(2)
        time.sleep(0.05)
        get_adc(3)
        LDR1 = get_adc(3)
        time.sleep(0.05)

        #print out the LDR readings
        print("LDR1:{{}}; LDR2:{{}};LDR3:{{}}, LDR4:{{}} ".format(LDR1, LDR1, LDR3, LDR4))
        #set conditions for limit switches
        limit1 = 2
        limit2 = 3
        gpio.setmode(gpio.BCM)

        gpio.setup(limit1, gpio.IN)
            time.sleep(DELAY)
            gpio.setmode(gpio.BCM)
            gpio.setup(limit2,gpio.IN)
            time.sleep(DELAY)

        #set the conditions for sensors

```

```

top = (LDR1+LDR2)/2
time.sleep(DELAY*2)
bottom = (LDR3+LDR4)/2
time.sleep(DELAY*2)

right = (LDR2+LDR4)/2
time.sleep(DELAY*2)
left = (LDR1+LDR3)/2
time.sleep(DELAY*2)

#set conditions for stepper motor to rotate
threshold = 5
diff1 = right - left      #difference between levels of radiation right to left
time.sleep(0.05)
diff2 = top - bottom      #difference between levels of radiation top to bottom
time.sleep(0.05)

if(gpio.input(limit2) == False):
    time.sleep(60)
elif(gpio.input(limit2) == True) and (diff2 > threshold or -1*threshold > diff2)
and (top > bottom):
    for _ in xrange(20):
        stepper(SEQA, motor1PINS)
        time.sleep(0.01)

if (gpio.input(limit1) == False):
    time.sleep(60)
elif(gpio.input(limit1) == True) and (diff2 > threshold or -1*threshold >
diff2) and (bottom > top):
    for _ in xrange(20):
        stepper(RSEQA, motor1PINS)
        time.sleep(0.01)

if ( diff1 > threshold or -1*threshold > diff1) and (left > right):
    for _ in xrange(20):
        stepper(SEQB, motor2PINS)
        time.sleep(0.01)

elif ( diff1 > threshold or -1*threshold > diff1) and (right > left):
    for _ in xrange(20):
        stepper(RSEQB, motor2PINS)
        time.sleep(0.01)

except KeyboardInterrupt

    gpio.cleanup()

```

5.2 Appendix II

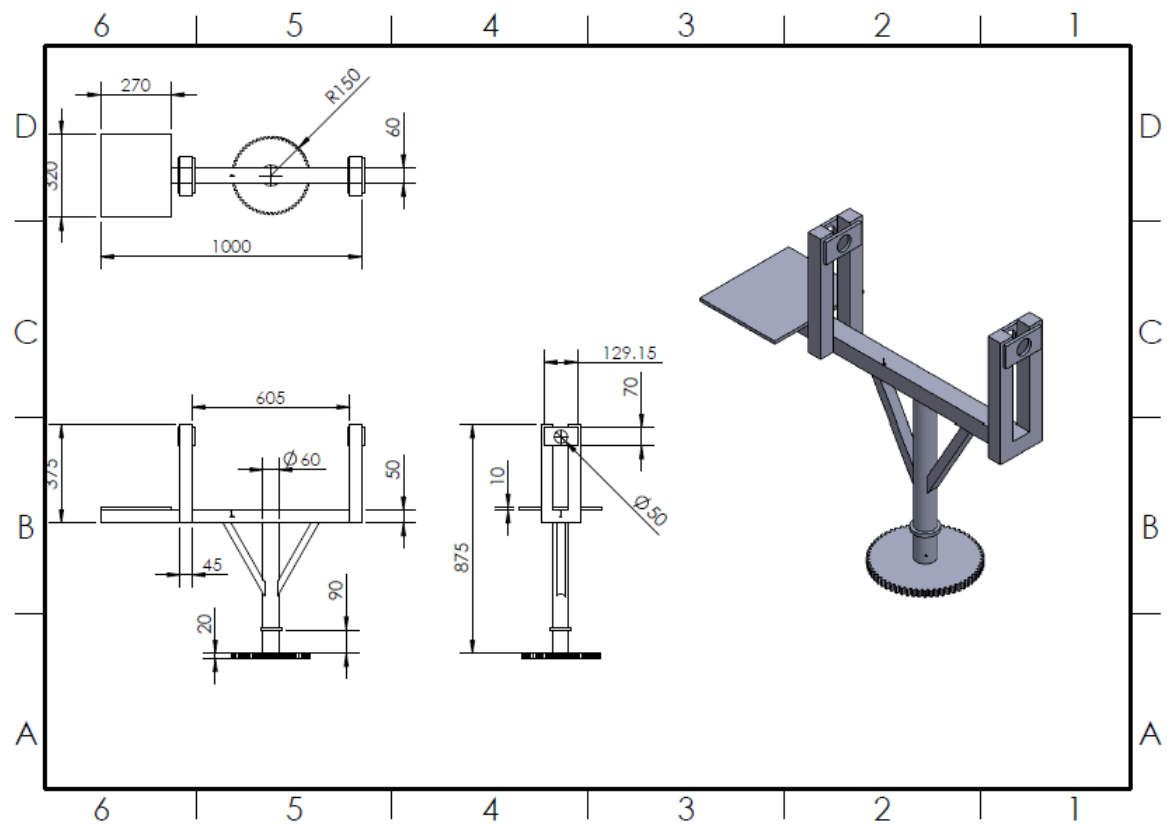


Figure 31: Fully dimensioned frame

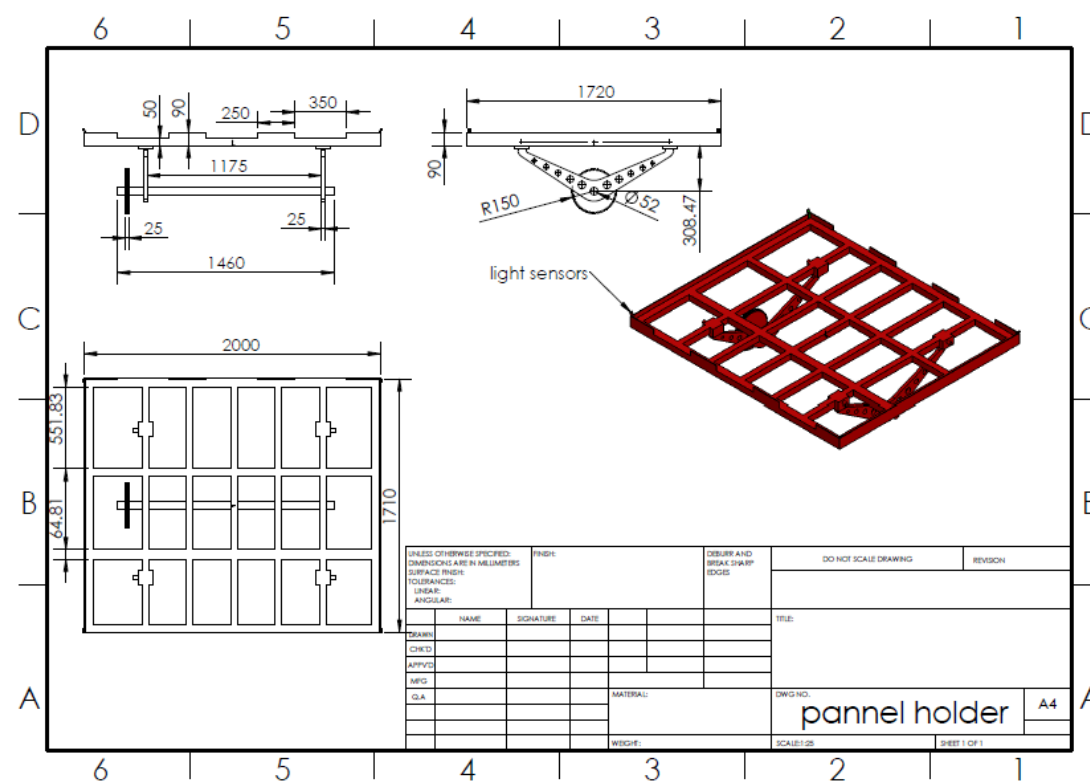


Figure 32: dimensioned panel holder

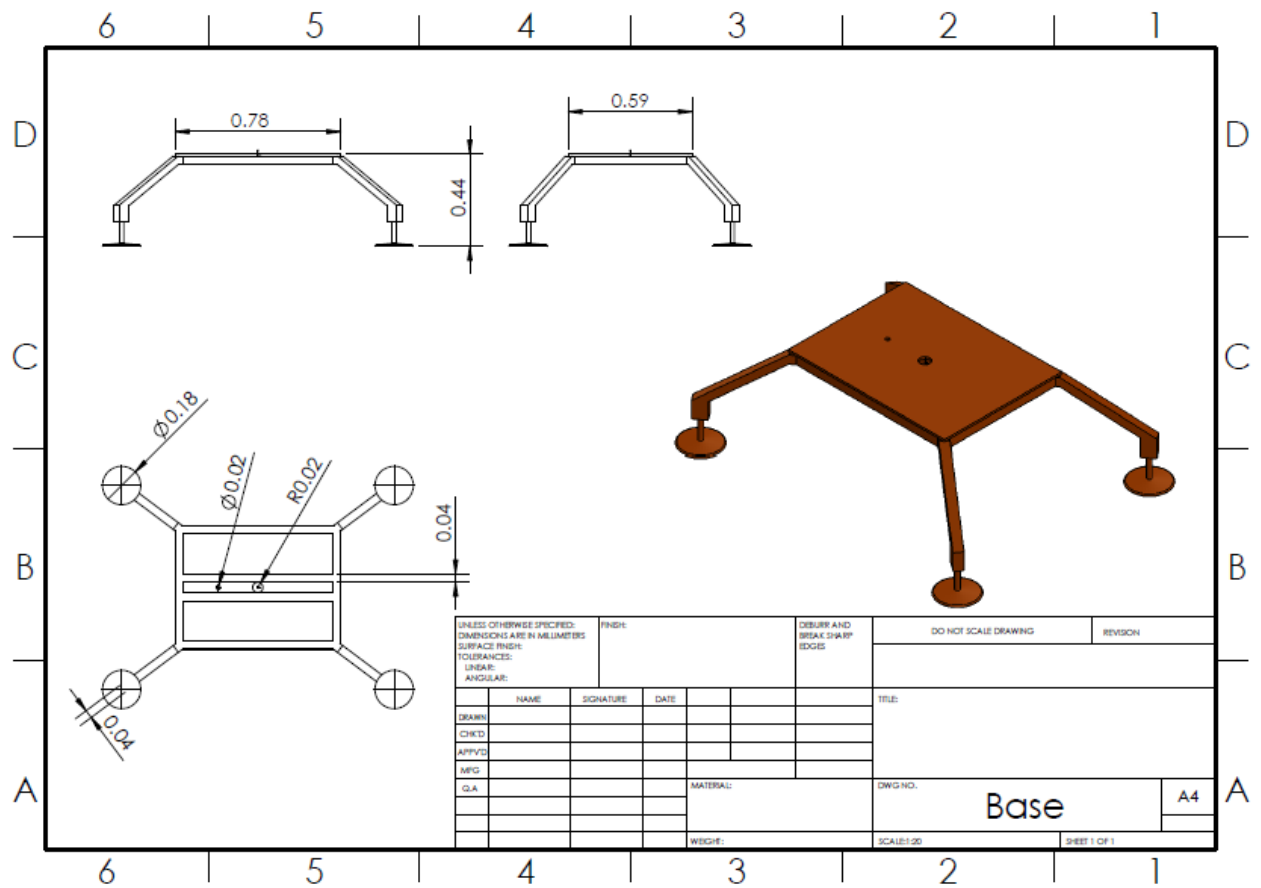


Figure 33: The base fully dimensioned