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DESIGN AND FABRICATION OF DUAL AXIS SOLAR SYSTEM TRACKER

MUHAMMAD AMIR SYAHIRAN BIN MUHAMMAD TARMINZI

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Engineering Technology in Manufacturing with Hons

Faculty of Engineering Technology
UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

Solar power is the energy from the sun that is converted into thermal or electrical energy. The uses of solar energy are now developing rapidly since it is the cleanest and renewable energy source available. This paper presents the design and fabrication of high-efficiency dual-axis solar tracking system. Moreover, the objectives of this paper is to make sure the designed dual-axis solar tracking system can move the solar panel to the direction of the light accurately. The project can be divided into two stages, which are the designing the structure of the solar tracker and the fabrication of the parts. In the design development, SolidWorks software is used to create the structure of the solar tracking system. To prove the structure is perfect for the solar tracking system, another software is used to test it. For the fabrication part, correct process is carefully chosen based on the machines and tools available in UMP. After the structure is completed, a solar panel, two linear actuators, sensors and batteries are assembled in the solar tracking system. The efficiency of the system has been tested and compared with static solar panel on several time intervals, and it shows the system react the best at the to-minutes intervals with consistent voltage generated. Therefore, the structure has been proven working for directing the solar panel towards the direction of light accurately so that it can capture maximum sunlight source for high efficiency solar harvesting applications.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

According to National Center of Policy Analysis, solar power is the fastest growing means of renewable energy production with grid connected solar capacity increasing on average by 60 % annually from 2004 to 2009 (D.Johnson-Hoyte *et al*, 2013). Unfortunately, solar energy only contributing a small part in energy work field. It is stated that the future of PV solar technologies looks promising considering favorable location and continued federal tax subsidies as well as state renewable standard protocol (S.J.Reichelstein and M.Yorston, 2012). According to paper, with the continued trend in decreasing cost of PV panels and government subsidies, PV Solar energy might become cost competitive in the next 10 years (subsidy-free), for commercial installations while for Utility-scale installations it will take longer. The latest solar energy production is by using the solar panel and solar tracker where the device is used to identify and track the light direction.

The goal of this project is to build a Dual-axis Smart Solar Tracking System which is basically a device onto which sensors had been used to track the accurate direction of the sun across the sky to ensure maximum amount of sunlight strikes on solar panel throughout the day. The tracking system is continuously finding the sunlight by navigating through the path ensuring the best sunlight is detected. Our team members are divided to three major specializations which are manufacturing for design chassis part, electrical for controller and energy for solar panel and determine the experimental location. The design of the solar tracker requires many components. The design, construction and test of it could be divided into five main parts, each with their main function. They are: 1. Design of tracker 2. Solar panel chosen, 3. Sensor and Sensor Controller, 4. Solar working mechanism with the sun, 5. Solar tracker efficiency.

Dual-Axis solar systems allow for precise control of the elevation and azimuth angle of the panel relative to the sun. The tracking system is reported to be more accurately potentially double the energy output of a fixed PV Solar system which is about 48.982% (A.Catarius and M.Christiner, 2010). Meanwhile, if it is compared to the single axis solar tracker, it is also proven that dual axis solar tracker will give more energy output since they can rotate on two axes due to its two degrees of freedom that act as axes of rotation. They are primary axis, the axis that is fixed with respect to the ground and secondary axis, which is the axis referenced to the primary axis. These axes are typically normal to one another. There are several common implementations of dual axis trackers. They are classified by the orientation of their primary axes with respect to the ground. Two common implementations are tip-tilt dual axis trackers (TTDAT) and azimuth-altitude dual axis trackers (AADAT). So, the dual axis solar tracker can produce 40% more power compared to the single axis solar tracker (M.Scanlon, 2010).

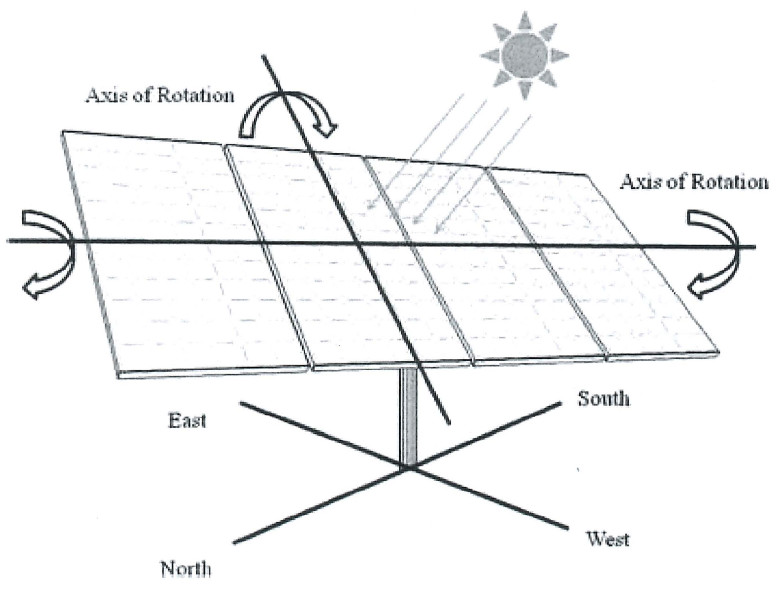


Figure 1.1: *Movement for dual-axis solar tracker*

The design of the solar tracking system is completed by using SolidWorks software, which is one of the friendliest designing tools. The design is used to help the process of fabrication where the measurement of each part is precisely done in the drawing. After the design process, the construction process of the solar tracker it is done with the aids of many machines and tools. For example, saw machine, grinder and welding machine. At the end, the solar tracking system is tested practically under the sunlight.

Compared to last year's, this project can ensure more precise direction since the solar panel is moved in two axes. Two linear actuators are used in order to move the solar panel in east-west and also north-south directions. With the used of these two linear actuator, it can increase the movement range of the solar panel. So, the solar panel are able to face any direction of the sunlight. Besides, with the aid of five sensors, it enhances the accuracy of the tracking system in order to trace the light intensity. By doing this, the solar tracking system are able to navigate to the best angle of exposure of light from the sun. the sensors constantly monitor the sunlight and tilt the panel towards the direction where the intensity of sunlight is maximum.

Figure 1.2*: Linear actuators of our project*

1.2 PROBLEM STATEMENT

Renewable energy sources become more popular and the demand of it keep increasing every year. The research of designing good solar tracker had been greatly developing and it is also supported by many institutes and governments. This solar tracker project is chosen because it encourages us to develop and explore more about this field and we had built our own solar tracking system. The previous project, uses the single axis solar tracker and it causes the solar panel tracking system not very accurate. So, we had decided to build a dual-axis solar tracker because it has higher degree of flexibility which also offer a wider range of motion. This factor becomes an advantage for the solar tracking system since its primary and secondary axes work together to allow these trackers to point the solar panels at specific points in the sky, allowing for a higher energy output on sunny days. It also has higher degree of accuracy in directional pointing. It is proven that dual axis solar tracker had an annual energy gain of 36.504% compared to single axis (A.Catarius and M.Christiner, 2010). By choosing the dual axis solar tracker, we face higher mechanical complexity, making it more likely for something to go wrong. The design is completed and it must be tested by using software which require deep knowledge of the software in order to create a very stable and strong structure. The fabrication also need a technological tools and machines to get an accurate measurement of the main parts which carry important role for this project. It also difficult to program compared to single axis solar tracker. By using the Arduino software, we are able to program the tracker correctly. Tracking also may cause shading problems. As the panels move during the course of the day, it is possible that, if the panels are located too close to one another, they may shade one another due to profile angle effects. As an example, if you have several panels in a row from east to west, there will be no shading during solar noon. But in the afternoon, panels could be shaded by their west neighboring panel if they are sufficiently close. This means that panels must be spaced sufficiently far to prevent shading in systems with tracking.

1.3 RESEARCH OBJECTIVES

There are three main objectives for our project:

- To build a smart solar tracker with dual-axis type using the suitable material.
- To make a strong and stable structure to support the solar panel.
- To allow the wide range of movement for the solar panel in order to track accurate direction of sunlight.

1.4 SIGNIFICANCE OF RESEARCH

- Can implement this solar tracker at a garden to detect the sunlight so that we can make the plants to get optimum amount of light.
- Can be implemented at home in electrical goods since we can convert the solar energy absorbed into electrical energy.

CHAPTER 2

LITERATURE REVIEW

2.1 SOLAR POWER

Solar power is the conversion of sunlight into electricity, either directly using photovoltaics (PV), or indirectly using concentrated solar power. Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Photovoltaic cells convert light into an electric current using the photovoltaic effect. Base on the research by the International Energy Agency projected in 2014, solar power will contribute about 16 and 11 percent during of the worldwide electricity consumption, and solar would be the world's largest source of electricity during 2050. The solar installations will widely be focusing in China and India (International Energy Agency, 2014).

Photovoltaics (PV) covers the conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon studied in physics, photochemistry, and electrochemistry. A typical photovoltaic system employs solar panels, each comprising a number of solar cells, which generate electrical power. One of the reason why the solar PV is used because it generates no pollution (J. M. Pearce, 2002). It was initially solely used as a source of electricity for small and medium-sized applications, from the calculator powered by a single solar cell to remote homes powered by an off-grid rooftop PV system. Other than its environmental friendly characteristics, solar PV is a cheap, low-carbon technology to harness renewable energy from the Sun.

2.1.1 HISTORY OF SOLAR POWER

Solar power was found since ancient Greeks and Romans when they saw that great benefit in what now refer to as passive solar design—the use of architecture to make use of the sun's capacity to light and heat indoor spaces. Romans advanced the art by covering south facing building openings with glass or mica to hold in the heat of the winter sun. Through calculated use of the sun's energy, Greeks and Romans offset the need to burn wood that was often in short supply.

Auguste Mouchout, inventor of the first active solar motor, questioned the widespread belief that the fossil fuels powering the Industrial Revolution in the 19th century would never run out. He developed a steam engine powered entirely by the sun. But its high costs coupled with the falling price of English coal doomed his invention to become a footnote in energy history. Nevertheless, solar energy continued to intrigue and attract European scientists through the 19th century. Scientists developed large cone-shaped collectors that could boil ammonia to perform work like locomotion and refrigeration. France and England briefly hoped that solar energy could power their growing operations in the sunny colonies of Africa and East Asia. In the United States, Swedish-born John Ericsson led efforts to harness solar power. He designed the "parabolic trough collector," a technology which functions more than a hundred years later on the same basic design. Ericsson is best known for having conceived the USS Monitor, the armored ship integral to the U.S. Civil War. Solar power could boast few major gains through the first half of the 20th century, though interest in a solar-powered civilization never completely disappeared. In fact, Albert Einstein was awarded the 1921 Nobel Prize in physics for his research on the photoelectric effect—a phenomenon central to the generation of electricity through solar cells.

Some 50 years' prior, William Grylls Adams had discovered that when light was shined upon selenium, the material shed electrons, thereby creating electricity. In 1953, Bell Laboratories (now AT&T labs) scientists Gerald Pearson, Daryl Chapin and Calvin Fuller developed the first silicon solar cell capable of generating a measurable electric current. The New York Times reported the discovery as "the beginning of a new era, leading eventually to the realization of harnessing the almost limitless energy of the sun for the uses of civilization."

In 1956, solar photovoltaic (PV) cells were far from economically practical. Electricity from solar cells ran about $300 per watt. For comparison, current market rates for a watt of solar

PV hover around $5. The "Space Race" of the 1950s and 60s gave modest opportunity for progress in solar, as satellites and crafts used solar paneling for electricity.

It was not until October 17, 1973 that solar leapt to prominence in energy research. The Arab Oil Embargo demonstrated the degree to which the Western economy depended upon a cheap and reliable flow of oil. As oil prices nearly doubled over night, leaders became desperate to find a means of reducing this dependence. In addition to increasing automobile fuel economy standards and diversifying energy sources, the U.S. government invested heavily in the solar electric cell that Bell Laboratories had produced with such promise in 1953. The hope in the 1970s was that through massive investment in subsidies and research, solar photovoltaic costs could drop precipitously and eventually becomes competitive with fossil fuels (L.Alexander, 2007).

2.1.2 TECHNOLOGIES IN SOLAR TRACKING

Solar energy is highly needed to support the electricity. Nowadays, solar panels play important role in storing the energy. Solar panels can operate without the use of solar tracking devices, but it is well documented that performance of the system is reduced without the use of trackers (H.Mousazadeh *et al*, 2009). This is due to the fact that the earth rotates on its axis and revolves around the sun, so the sun's position in the sky relative to the horizon changes over the course of the year. Therefore, a fixed collector will not be able to maintain a high array effective area with the sun's motion as trackers do (A.Catarius and M.Christiner, 2010). Solar trackers can be classified as passive and active device. The active device can be further divided into single and dual axis solar tracker.

The effectiveness of a solar tracker and PV technology in general, is directly correlated to the amount of sunlight that it is being exposed it. Its power output is depending on the amount of light that reaches the solar cell). PV technology is most efficient when it is greeted by a light source at a perfectly perpendicular angle, i.e. forming a 90^{o} angle. In order to accomplish this in a real-world situation, the PV panel must move with the sun to maintain this perpendicular angle (Mehleri, 2010).

Like most technology today, many types of solar tracking system are available varies in terms of prices, effectiveness, reliability, etc. The design options for a solar tracking system must be taken into careful consideration to ensure that the system is maximizing its output from tracking the sun. Even though solar tracking will inherently give a greater power output than a stationary PV panel, the option is not always ideal. Due to the increased cost for solar tracking technology versus stationary PV panels, solar tracking is not always the best option for a given application (D.Johnson-Hoyte *et al*, 2013). If a passive PV panel is used, we need to make sure that it is strategically placed facing the sun. The considerations to be taken regarding PV panel placement is that the panel must be placed in a spot where it will always have a clear line of sight (LOS) to the sun, and the panel must be positioned at an optimal angle facing the equator, depending on its latitude on earth. Stationary PV panels are a cheaper energy solution, but do not fully utilize the energy coming from the sun. So, it is one of the reason single and dual axis solar tracker are invented.

Figure 2.1*: Fix-mounted solar panel fixed on roof*

2.2 SUN'S POSITION

The position of the sun in the sky always change according to the rotation of the Earth. The position can be described by several angles. The angles are demonstrated in *Figure 2.2* below:

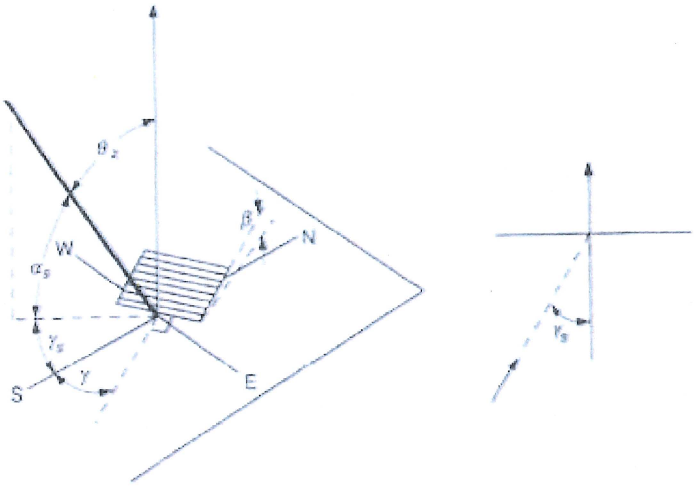


Figure 2.2: *Sun's position*

In the figure above, there is an inclined plane which shows the relative angles between the sun and a tilted surface. β is the slope of the plane from horizontal position. θ_z is the angle of incidence of direct radiation on a horizontal plane. It is the angle between vertical and the line to the sun and is called zenith angle. The angle between horizon and sun's rays is called solar altitude angle (α_s) which illustrates the height of the sun in the sky. Solar azimuth angle (γ_s) is the angle between the south and the horizontal projection of direct radiation. Surface azimuth angle (γ) is the angle between the south direction and the direction where the plane is facing. The solar position in the sky is shown for latitude of ±45° 0'. Solar altitude angle and azimuth angle are indicated in the plot by dates and times. As it can be seen, height of the sun reaches its minimum amount in December and maximum amount in June (J.A.Duffie and W.A.Beckman, 2013) as shown in *Figure 2.2*.

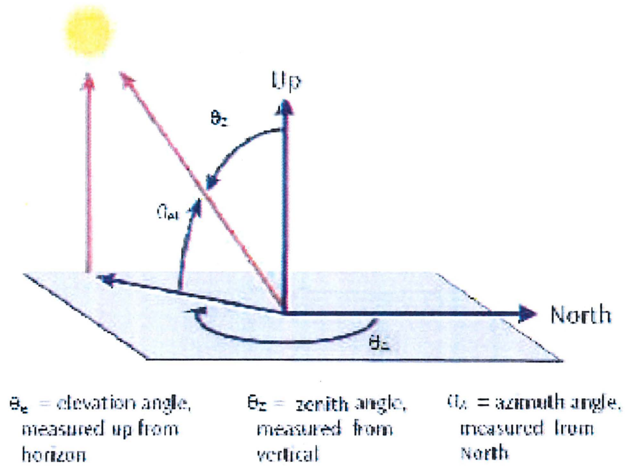


***Figure 2.3**: The position for elevation, zenith and azimuth angles*

2.2.1 ELEVATION ANGLE

The elevation angle (used interchangeably with altitude angle) is the angular height of the sun in the sky measured from the horizontal. The elevation angle is used interchangeably with altitude angle and is the angular height of the sun in the sky measured from the horizontal. Both altitude and elevation are used for description of the height in meters above the sea level. The elevation is 0° at sunrise and 90° when the sun is directly overhead. The angle of elevation varies throughout the day and also depends on latitude of the particular location and the day of the year.

2.2.2 ZENITH ANGLE

This is the angle between the sun and the vertical. It is similar to the angle of elevation but is measured from the vertical rather than from the horizontal. Therefore,

Zenith angle = 90^0 – Elevation angle (D.Cooke, 2011)

2.2.3 AZIMUTH ANGLE

An azimuth is an angular measurement in a spherical coordinate system. The vector from an observer (origin) to a point of interest is projected perpendicularly onto a reference plane. The angle between the projected vector and a reference vector on the reference plane is called the azimuth. For solar tracker, this is the compass direction from which the sunlight is coming. At solar noon, the sun is directly south in the northern hemisphere and directly north in the southern hemisphere. The azimuth angle varies throughout the day. At the equinoxes, the sun rises directly east and sets directly west regardless of the latitude. Therefore, the azimuth angles are 90^0 at sunrise and 270^0 at sunset (D.Cooke, 2011).

2.3 SOLAR TRACKING SYSTEM

Solar tracking system is a device for orienting a solar panel or concentrating a solar reflector or lens towards the sun. Concentrators, especially in solar cell applications, require a high degree of accuracy to ensure that the concentrated sunlight is directed precisely to the powered device. The solar tracking strategies usually include three types; closed-loop (feedback) control, open-loop (forward-loop) control and hybrid control (Z. Mi *et al*, 2016).

In an open-loop control mode, the movement of the solar tracker is controlled by pre-programmed code according to the calculated solar movement and position (e.g. geographic coordinates and the day and time of the year) without using feedback signals. The open-loop control mode possesses high reliability, since it is not affected by the local weather conditions. However, the open-loop control does not detect or correct any disturbances generated in either computing or mechanical processes, which usually occurs during the practical operation. To the contrary, a closed-loop control system utilizes optical sensors to detect the real-time position of the solar, give feedback to the controller and adjust the position of the solar panel accordingly. In that case, high tracking accuracy can be achieved when using the close-loop control mode (H.Mousazadeh *et al*, 2009). However, the drawback for using the closed-loop tracking strategy is that the optical sensor may misread solar position and cause tracking errors in special cases such as overcast (Alexandru C. and Pozna C., 2010). Therefore, in order to merge and enhance the advantages of both closed- and open-loop control strategies, the hybrid control strategy has been developed. For example, the hybrid solar tracking systems that can switch between closed-loop or open-loop solar tracking strategy automatically depends on the practical environmental conditions.

The solar tracking system can be divided into three types. They are fixed solar tracking system, single axis solar tracking system and dual axis solar tracking system.

2.3.1 FIXED SOLAR PANEL

Fixed solar tracker is commercially well known industrial rooftop solar project (kW) and solar water heater panels. It often flush-mounted on an appropriately facing pitched roof. They are easy to be manufactured since it just need low installation and maintenance cost. Besides, it is easier and cheaper to provision a sturdy mount; all mounts other than fixed flush-mounted panels must be carefully designed having regard to wind loading due to greater exposure. Fixed mounts are usually used in conjunction with non-concentrating systems, however an important class of non-tracking concentrating collectors, of particular value in the 3rd world, are portable solar cookers. These utilize relatively low levels of concentration, typically around 2 to 8 Suns and are manually aligned.

Even though a fixed flat-panel can be set to collect a high proportion of available noon-time energy, significant power is also available in the early mornings and late afternoon, when the misalignment with a fixed panel becomes excessive to collect a reasonable proportion of the available energy. For example, even when the Sun is only 10° above the horizon the available energy can be around half the noon-time energy levels (or even greater depending on latitude, season, and atmospheric conditions).

***Figure 2.4**: Solar panel being fix-mounted on ground by solar mounting structure*

2.3.2 PASSIVE SOLAR TRACKER

Passive solar trackers are trackers with a rotating motion created by thermal expansion. They contain two identical cylindrical tubes filled with a pressurized fluid or a shape memory alloy that work as an actuator for the rotation of the passive solar trackers. The pressurized fluid thermally boils and expands in the cylinder exposed to the sun and moves into the other that is shaded from the sun and condenses. This causes unbalanced forces that exert a thermal torque on the tracker towards a certain direction until equilibrium is restored and the actuators are balanced. One strong company, named Zomework had produced more than 17,000 passive tracking systems have been installed in different climates, all around the world. In this model electrical output of photovoltaic module increase 25% or more compared to module on fixed mounts. A 12-module tracking system delivers the same electric output as 15 modules mounted on fixed racks – a savings of three modules (N.J.Parmar *et al*, 2015). Zomework's products are very practical and with a universality of application that reduces the cost and simplifies the installation of solar systems.

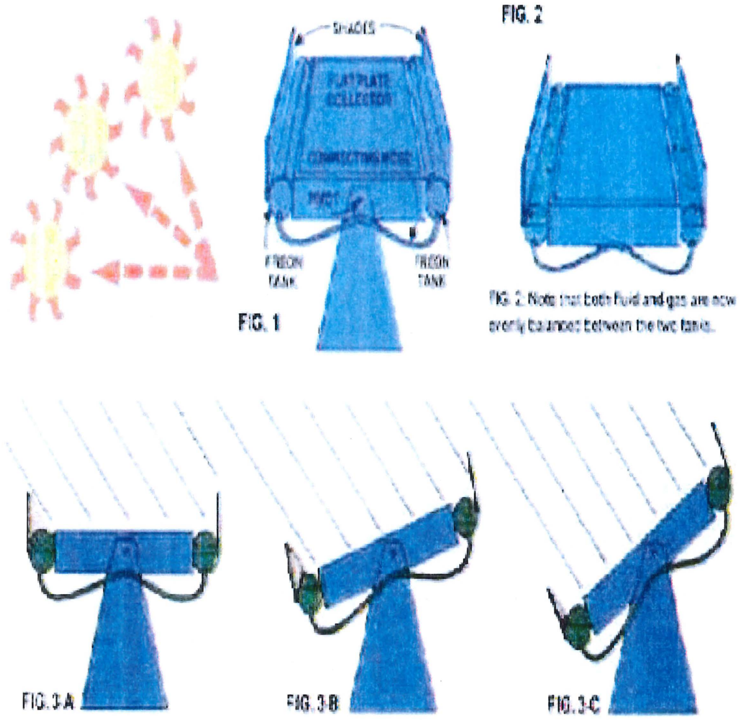


***Figure 2.5**: Mechanism for passive solar tracking system*

2.3.3 SINGLE AXIS SOLAR TRACKER

The single-axis solar tracking system analyzed in the paper consist of a PV panel rotating around a tilted shaft under the action of a Bidirectional-DC Motor controlled according to the real sun position estimated by means of two light intensity sensors (T.Tudorache *et al*, 2012). The light sensors consist of two LDR placed on either side of the panel separated by a black card box. Depending on the intensity of the sun rays one of the two LDR will be shadowed and the other will be illuminated.

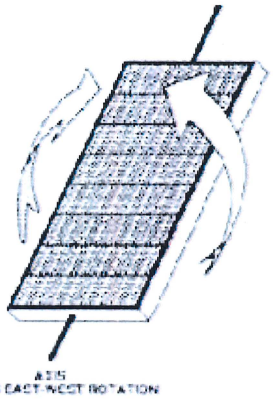


***Figure 2.6**: Principle of Single Axis Solar Tracking*

The LDR present in the side, in which the intensity of the sun rays is higher, will generate a stronger signal and the other will generate a weaker signal. The difference in the output voltage between the two LDR's will help in the movement of the PV panel in the direction in which the intensity of the sun rays is maximum (Deepthi.S. *et al*, 2013). To command the tracker, a microcontroller by giving pulse signal so that the motor can move the solar panel. The rotation of the motor either to rotate clockwise or anticlockwise is controlled by relay.

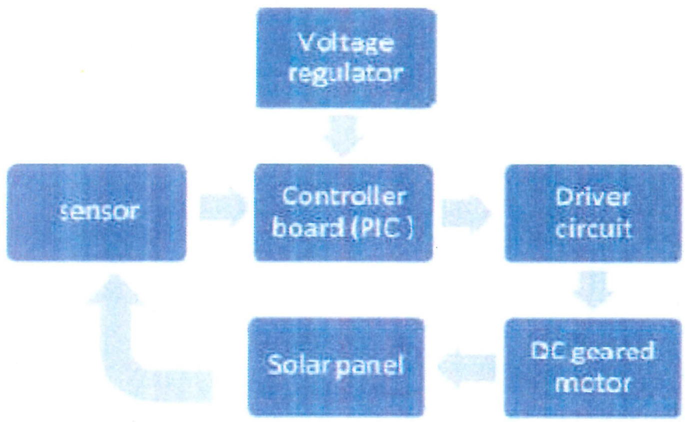


***Figure 2.7**: Block Diagram of Single Axis Tracker System*

Single axis solar tracking system has to be very reliable. This means that the system should be effective enough to track the sun across the sky and not track the reflection of the sun on a cloud (silver lining) and then falsely rotate all day. There has to be enough sunlight exposure; too many clouds will decrease its performance. The placement of the system is also very important. It works best in shade free geographic locations with low horizons.

Compared to the fix mount solar panel, this system is better in terms of the output. The average power values prove that the single-axis panel produces more power than that of the fixed mount. The power efficiency calculated for the singe-axis solar tracker is said to be 13% more than that of the fixed mount (Deepthi.S. *et al*, 2013).

2.3.4 DUAL-AXIS SOLAR TRACKER

Dual axis tracking system is invented to overcome the disadvantages in the single-axis tracking system since the single axis tracker only tracks the movement of sun from east to west. During cloudy days the efficiency of the single axis tracker is almost close to the fixed panel. In dual-axis tracking system the sun rays are captured to the maximum by tracking the movement of the sun in four different directions. The dual-axis solar tracker follows the angular height position of the sun in the sky in addition to following the sun's east-west movement. The dual-axis works in the same way as the single-axis but measures the horizontal as well as the vertical axis. The sensors will trigger one motor to tilt the tracker in sun's east - west direction and the other motor which is fixed the tracker is used to tilt the tracker in the sun's north-south direction.

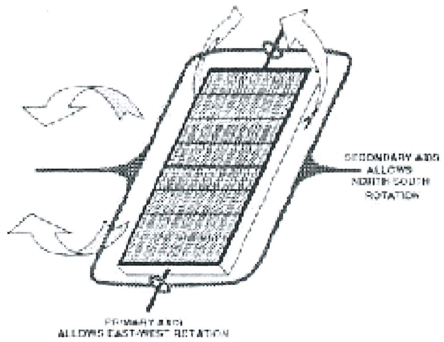


***Figure 2.8**: Mechanism for dual-axis solar tracking system*

The average power values prove that the dual-axis panel produces more power than that of the fixed mount. The power efficiency calculated for the singe-axis solar tracker is said to be 25% more than that of the fixed mount (Deepthi.S. et al, 2013). Trackers generate more electricity than their stationary counterparts due to increased direct exposure to solar rays. This increase can be as much as 10 to 25% depending on the geographic location of the tracking system.

Nowadays, dual axis solar tracker can be made very fast and the manufacturer made them easy to installed. Sometimes, the manufacturer will supply their customer with a single-pole design, comes equipped with a pre-mounted, programmed tracker controller for one quick installation. In addition, dual axis solar tracker is sturdy and reliable. It can be built with anodized aluminum and corrosion resistant galvanized steel. For example, DuraTrack DA uses a robust gear-driven design to maximize stability of the solar tracker. Lastly, dual axis solar tracking system is a low maintenance product. Simply lubricate the drive just once a year to continue harvesting maximum solar power far into the future.

***Figure 2.9**: Dual-axis solar tracking system*

The advantages of dual axis solar tracker are it has higher degree of flexibility that allowing for a higher energy output on sunny days by focus on more to the higher light of intensity. Besides that, it has higher degree of accuracy in directional pointing by using sensor with 4 direction north, south, east and west.

The disadvantages of dual-axis trackers include higher mechanical complexity and making it more likely for something to go wrong for example the coding for the system to move the solar panels. Moreover, it has lower lifespan and lower reliability and also unreliable performance in cloudy or overcast weather. Complex design like use more motors and sensors.

2.4 SOLAR PANEL

Solar panel can be described as a panel designed to absorb the sun's rays as a source of energy for generating electricity or heating. The solar panel is packaged with photovoltaic (PV) module, connecting assembly of typically 6×10 solar cells. Solar Photovoltaic panels constitute the solar array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications. Each module is rated by its DC output power under standard test conditions, and typically ranges from 100 to 365 watts. Silicon Crystalline Cells is made by using crystalline silicon solar cells, developed from the microelectronics technology industry. The silicon solar cell was first patented by a Russel Ohl, an American inventor on the payroll of Bell Laboratories in 1941 (M.I.Current, 2010). Solar panels found their first mainstream use in space satellites. Silicon crystalline technology are currently makes up 87% of PV market sales in 2011 and Crystalline silicon PV cells have laboratory energy conversion efficiencies as high as 25% for single-crystal cells and 20.4% for multi-crystalline. However, industrially produced solar modules currently achieve efficiencies ranging from 18%–24% cells (Energy.gov, 2015).

2.4.1 MONOCRYSTALLINE CELL

Monocrystalline cells are made using saw-cut from single cylindrical crystal of Silicon. Monocrystalline solar panels can produce with an efficiency of 22.5 %. In June 2010 they broke the world's record for commercially produced solar cells at 24.2% (SunPower, 2010). According to various researchers, it is not theoretically possible to convert more than 29 % of the light into energy using crystalline solar cells. Realistically, the limit for a PV panel is likely closer to 24 to 25 percent because of factors like heat, said Tom Werner, the CEO of SunPower, during a briefing with reporters in June 2010 (T.Werner, 2010).

Benefits of monocrystalline solar panels is high efficiency, as already mentioned, PV panels made from monocrystalline solar cells are able to convert the highest amount of solar energy into electricity of any type of flat solar panel. Consequently, Monocrystalline panels are a great choice for urban settings or where space is limited. As a developer of PV rooftop installations in Germany, buying or leasing roof space is a significant cost of the whole project and so you want to be able to produce as much electricity you can from this valuable resource. can be expected. The record lab cell efficiency is 25.6 % for mono-crystalline and 20.8 % for multi-crystalline silicon based technology. In the last 10 years, the efficiency of average commercial wafer-based silicon modules increased from about 12 % to 16 % (Freiburg, 2016). Moreover, benefits of monocrystalline cells are environmental concern, some thin film solar products use cadmium telluride (CdTe). Cadmium is a heavy metal that accumulates in plant and animal tissues. Cadmium is a 'probable carcinogen' in humans and animals. While cadmium telluride doesn't pose a threat while the panel is in service, disposal of this toxic waste when the product reaches the end of its life come at large cost and suitable facilities which are why firms like First Solar offer their own "end of life" recycling program to take care of disposing this material. Monocrystalline solar panels are not hazardous to the environment.

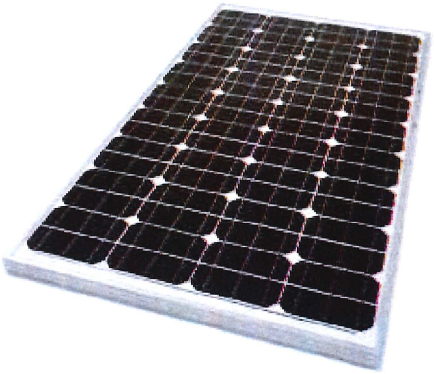


***Figure 2.10**: Monocrystalline solar panel*

2.4.2 POLYCRYSTALLINE CELL

Polycrystalline silicon, also called polysilicon or Poly-Si, is a high purity, polycrystalline form of silicon, used as a raw material by the solar photovoltaic and electronics industry. Polysilicon consists of small crystals, also known as crystallites, giving the material its typical metal flake effect. While polysilicon and multisilicon are often used as synonyms, multicrystalline usually refers to crystalls larger than 1 mm. Multicrystalline solar cells are the most common type of solar cells in the fast-growing PV market and consume most of the worldwide produced polysilicon. About 5 tons of polysilicon is required to manufacture 1 megawatt (MW) of conventional solar modules. The power output of single-crystalline and poly-crystalline modules of the same area is quite similar. Both types of crystalline silicon are very durable and have stable power output over time (D.C.Jordan and S.R.Kurtz, 2012).

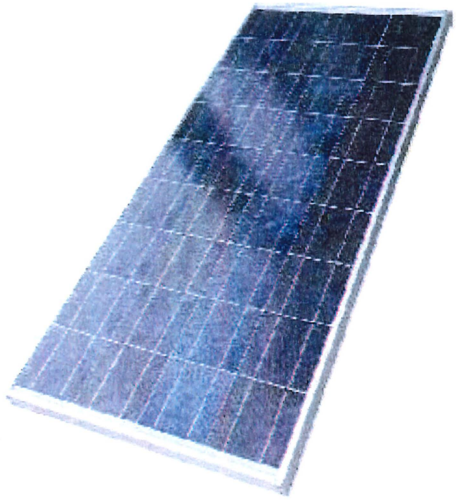


Figure 2.11: *Poly crystalline solar panel*

2.4.3 AMORPHOUS CELL

Amorphous silicon (a-Si) is the non-crystalline form of silicon used for solar cells and thin-film transistors in LCD displays and it is set as semiconductor material for a silicon solar cells, or thin-film silicon solar cells, it is deposited in thin films onto a variety of flexible substrates, such as glass, metal and plastic. Amorphous silicon cells generally feature low efficiency, but are one of the most environmentally friendly photovoltaic technologies, since they do not use any toxic heavy metals such as cadmium or lead.

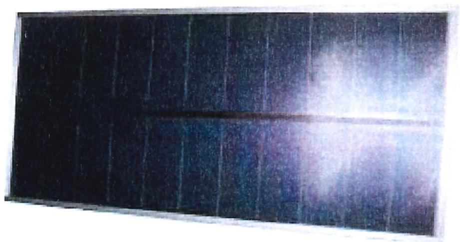


Figure 2.12: *Amorphous solar panel*

2.5 MOTOR

An electric motor is an electrical machine that converts electrical energy into mechanical energy. The reverse of this is the conversion of mechanical energy into electrical energy and is done by an electric generator. In normal motoring mode, most electric motors operate through the interaction between an electric motor's magnetic field and winding currents to generate force within the motor. In certain applications, such as in the transportation industry with traction motors, electric motors can operate in both motoring and generating or braking modes to also produce electrical energy from mechanical energy.

2.5.1 DC MOTOR BRUSHED

Another motor that can be used to actuate the panels are direct current motors. These motors are very basic and due to this makes them cheap compared to others. Some drawbacks to DC motors is that the brushes cause friction against the rotation of the rotor. It is also possible for the motor to create sparks from the brushes making and disconnecting on contact points which in turn can cause radio frequency interference. Another downside to these motors is that the brushes will eventually wear out and either the motor or the brushes will need to be replaced based on the cost of the repair. Another problem with using these motors is that they will need a mechanism, such as a worm gear, so that they hold their place. A motor that is able to make the panels hold their place is ideal so that the design can save energy my only having periodic movements instead of constant changes.

2.5.2 DC MOTOR BRUSHLESS

Brush-less DC motors can also be used to actuate the panels. Brushless motors have multiple advantages over brushed motors. One major advantage is their reliability, since there are no brushes used to alternate the current in the motor; there is less internal resistance for the motor to overcome. Also since there is less friction there will be less wear on the internal parts of the motor. Another positive for these motors is that since there it is brush-less there is no sparking from the commentator making contacts which in turn will lower the chance of electromagnetic interferences. Also due to the design of these motors, they are self-cooled by conduction. Since they are self-cooled they can be completely encapsulated to become more weather resistant. One of the biggest downfalls to brushless motors is there high cost. These motors normally require a more advanced motor controller to operate them. So not only will we have to spend more on the motor but also spend more on the controller.

2.5.3 STEPPER MOTORS

Steppers motors can be used to actuate the panel. The main reason to using a stepper motor is that they do not have a fluid rotation. Stepper motors rotate in by breaking up the rotation into a sequence of steps, such that they have the ability to stop at a certain point in the rotation. The motors interior is also designed with teeth on the magnets and on the rotor. These teeth can act as place holders when the one of the magnets is not charged. One of the best applications for stepper motors is their use in positioning systems since they can easily be controlled by a micro-controller. Stepper motors are also useful in that they need no feedback to operate. These motors also have a long life since the only wearing components are the bearings. They also have great low speed torque which is what we are aiming for. The motors also cannot be damaged by mechanical overloads. Some disadvantages for stepper motors is their low efficiency. They require a large amount of power to operate. Another downfall is that they have low accuracy with rotational speed. Finally, for their size and weight, they output power is comparatively low (Scott, 2010).

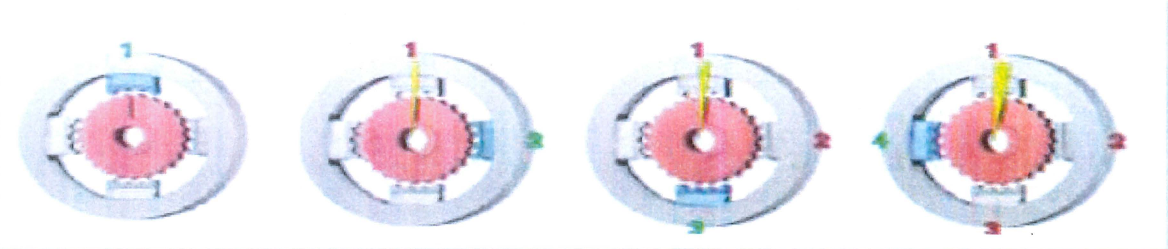


***Figure 2.13**: Working principle of PM stepper motor*

2.5.4 SERVO MOTORS

Servo motors are another potential candidate for the panel actuation. Servo motors act similarly to stepper motors but are generally smaller in size. Servo motors are mainly used in positioning systems on smaller scale applications. They have high output power compared to their size as well. These motors also stay cool compared to other motors. Another benefit that these motors offer is that they produce no vibration from operation. One major downfall for these motors is that the brush wear is extremely high. On average the brushes will last 2000 hours of operation before replacement parts will be needed. They also will require a bit more coding so that they are tuned and stabilized in a feedback loop. If by chance they motors are used in an overloaded situation it will damage the motor. These motors also output their peak torque at high speeds, which is the opposite of what we need.

Servo motors are also built such that they have a specific range that they can turn. This is done by a pulse modulated signal being sent to the motor. Also since these motors are built this way it is possible to use them as a lever or a pin pulling mechanism for our panel rotation. By using the servo motors to pull a pin and push it in, it can act as the main component that locks the panels into place.

2.5.5 LINEAR ACTUATOR

Linear actuators are most beneficial when used to push or pull an object in a linear direction. There are also three main different types of linear actuators namely, screw, wheel and axle, and cam. Screw actuators are good to use when one has to push and pull an object. Wheel and axle actuators are mostly used in pulling objects based on their design. Finally, cam actuators are useful when an object needs to be pushed in a specific direction. All of these designs can be used in conjunction with electro mechanical actuation (D.Gumbs *et al*, 2010). An actuator is a type of motor that is responsible for moving or controlling a mechanism or system. It is operated by a source of energy, typically electric current, hydraulic fluid pressure, or pneumatic pressure, and converts that energy into motion. An actuator is the mechanism by which a control system acts upon an environment. The control system can be simple, software-based, a human, or any other input. There are varieties of actuators and they are Mechanical actuators, Hydraulic actuators, Pneumatic actuators, Electro-mechanical, Linear motor etc. In our system we have used linear actuator because linear actuator creates motion in a straight line, in contrast to the circular motion of a conventional electric motor (T.Ahmed *et al,* 2014).

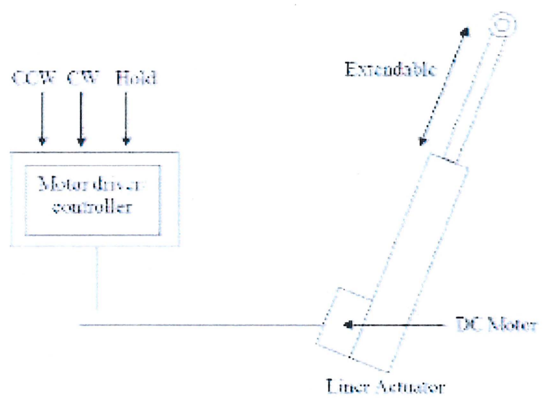


Figure 2.14: *The linear actuator system*

Actuator Type	Advantages	Disadvantages
Mechanical actuators	Cheap repeatable. no power source required. self-contained. identical behavior extending or retracting.	Manual operation only. No automation.|
Hydraulic actuators	Very high forces possible.	Can leak. requires position feedback for repeatability. External hydraulic pump required. Some designs good in compression only.
Linear motor	Simple design. Minimum of moving parts. High speeds possible. Self contained. Identical behavior extending or retracting.	Low to medium force.
Electro-mechanical	Cheap. Repeatable. Operation can be automated. Self-contained. Identical behavior extending or retracting. DC or stepping motors. Position feedback possible.	Many moving parts prone to wear
Pneumatic actuators	Strong, light, simple, fast.	Precise position control impossible except at full stops

Table 2.1: *Types and the characteristics of actuators*

2.5.6 COMPARISON BETWEEN MOTORS

DC Motor Brushed	
Advantages	Low Cost Availability
Disadvantages	Internal Friction From Brushes Commutator Can Cause Electromagnetic Interference Will Require Mechanism to Lock Panels In Place Brush and Commutator Wear
DC Motor Brushless	
Advantages	Less Internal Friction Reduced Electromagnetic Interference Less Internal Wear Self Cooling Can Be Built Enclosed
Disadvantages	Will Require Mechanism to Lock Panels in Place High Cost Requires More Advanced Motor Controller
Stepper Motors	
Advantages	Can Lock Into Place Without Using an External Mechanism Long Life High Low Speed Torque
Disadvantages	High Cost High Power Draw Low Accuracy with Rotational Speed Bulky
Servo Motors	
Advantages	Vibration Free High Output Power Compared to Size
Disadvantages	Requires More Coding Low Brush Life Max Torque is at High Speed Can be Damaged from Overload
Linear Actuators	
Advantages	Low Cost Repeatable Position Feedback is Possible
Disadvantages	Many Moving Parts, Prone to wear

Table 2.2: *Motor actuation comparison table*

2.6 LIGHT DEPENDENT RESISTOR (LDR)

The simplest optical sensor is a photon resistor or photocell which is a light sensitive resistor these are made of two types, cadmium sulfide (CdS) and gallium arsenide (GaAs). In this project, the solar tracking system uses five cadmium sulphide (CdS) photocells for sensing the light. The photocell is a passive component whose resistance is inversely proportional to the amount of light intensity directed towards it. The photocell to be used for the tracking system is based on light saturation resistance. The term light saturation means the further increasing the light intensity to the CdS cells will not decrease its resistance any further. Light intensity is measured in Lux, the illumination of sunlight is approximately 30000 lux (T.A.Papalias and M.Wong, 2007).

Light dependent resistors (LDR), also known as Photo resistors, are light sensitive devices most often used to indicate the presence or absence of light, or to measure the light intensity. In the dark, their resistance is very high, sometimes up to 1MΩ, but when the LDR sensor is exposed to light, the resistance drops dramatically, even down to a few ohms, depending on the light intensity. LDRs have a sensitivity that varies with the wavelength of the light applied and are nonlinear devices. They are used in many applications but are sometimes made obsolete by other devices such as photodiodes and phototransistors. There is table that show the differences of LDR output when presences of light and also absences of light.

Conditions	Resistance
Darkness	> 10 MΩ
60W bulb at 1m	2.4 kΩ
1 W bulb at 0.1 m	1.1 kΩ
Fluorescent lighting	275 Ω
Bright sunlight	10 Ω

Table 2.3: *Light intensity measurement*

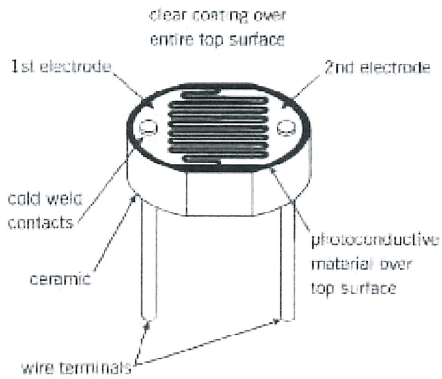


Figure 2.15: *LDR construction*

2.7 BATTERIES (LOAD)

One of the group's objectives is to find a way to power devices through recharging batteries. Without the proper selection of a battery, it is possible for the overall efficiency of the project to drastically be reduced. Since our motors will have the possibility to need more power than a micro-controller can supply it will be necessary to power the batteries remotely and 48 have a secondary motor controller control this process. As long as our budget remains the same with no surprises, we will be looking for a 12 Volt rechargeable battery to power the motors. We are looking at 12 Volts mainly because they are proving to be one of the standard voltages required to run the actuators we are looking to buy. Currently if our budget allows we will be looking at lithium-ion polymer batteries due to their lightweight attributes. We are leaning away from more traditional lead acid batteries because of they are bulky and heavy, which will be counterproductive in making the design mobile.

Even if the rest of the project has optimum efficiency, but yet improper batteries are selected, the batteries may only utilize 20% of the full power for which they are capable of producing. There are also many different types of rechargeable batteries to choose from, so we will analyze some of the pros and cons of each type. The reason we want to choose rechargeable batteries as opposed to just a particular device is that the longevity of the project. If we designed the project to just power a particular device that device may be one which isn't constantly used, or if the device were to break, the user would not be getting the most from the project. The state-of-charge of a battery is the percentage of its capacity available relative to the capacity when it is fully charged. By this definition, a fully charged battery has a state-of-charge of 100% and a battery with 20% of its capacity removed has a state-of-charge of 80 % (D.G.Vutetakis, 2001). The state-of-health of a battery is the percentage of its capacity available when fully charged relative to its rated capacity. By allowing the project to power rechargeable batteries however, batteries are something that is used in every household. By using batteries however, once a particular device's functionality has been used, it can always then be transferred towards a different device. As a matter of fact, the US Nation Electrical Manufactures Association has even declared that the US demand for rechargeable batteries is growing two times faster than the demand for just regular disposable batteries. In *Table 2.4*, a brief overview of some of the major components of most types of rechargeable batteries is displayed.

The first column refers to the name/type of battery. The voltage column is in reference to a nominal cell voltage. The next three columns are comprised of the energy density sections. Energy density is in reference to the energy/weight, where the weight has been varied 3 times. The power column refers to the power/ weight. The efficiency column refers to the charge and discharge efficiency values. The following column refers to the Watt times hour divided by the US dollar in order to determine the energy consumer price. The next discharge column is in reference to the self-discharge monthly rate, the natural progression. The next column refers to the number of cycles in the battery's lifetime. The final column gives a rough estimation of the value of the particular battery's lifetime.

Type	Voltage[a]	Energy density[b]			Power[c]	Effi.[d]	E/$[e]	Disch.[f]	Cycles[g]	Life[h]
	(V)	(MJ/kg)	(Wh/kg)	(Wh/L)	(W/kg)	(%)	(Wh/$)	(%/month)	(#)	(years)
Lead-acid	2.1	0.11-0.14	30-40	60-75	180	70%-92%	5-8	3%-4%	500-800	5-8 (car battery), 20 (stationary)
VRLA[i]	2.105									
Alkaline	1.5	0.31	85	250	50	99.9%	7.7	<0.3	100-1000	<5
Ni-iron	1.2	0.18	50		100	65%	5-7.3[6]	20%-40%		50+
Ni-cadmium	1.2	0.14-0.22	40-60	50-150	150	70%-90%	1.25-2.5[6]	20%	1500	
NiH2	1.5		75						20,000	15+
NiMH	1.2	0.11-0.29	30-80	140-300	250-1000	66%	2.75	30%	500-1000	
Ni-zinc	1.7	0.22	60	170	900		2-3.3		100-500	
Li ion	3.6	0.58	150-250	250-360	1800	80-90%	2.8-5[7]	5%-10%	1200	2-3
Li polymer	3.7	0.47-0.72	130-200	300	3000+		2.8-5.0		500~1000	2-3
$LiFePO_4$	3.25		80-120	170 [8]	1400		0.7-3.0		2000+[9]	
Li sulfur[10]	2.0	0.94-1.44[11]	400[12]	350					~100	
Li titanate	2.3		90		4000+	87-95%'	0.5-1.0[13]		9000+	20+
Thin film Li	?			350	959	?	?p[14]		40000	
ZnBr			75-85							
V redox	1.15-1.55		25-35[15]			80%[16]		20%[16]	14,000[17]	10(stationary)[16]
NaS			150			89%-92%				
Molten salt	2.58		70-110[18]	160[8]	150-220		4.54[19]		3000+	8+
Silver zinc (Ag-zinc)	1.86		130	240						

Table 2.4: *A table of all of the most commonly accepted rechargeable batteries on the market today*

2.7.1 LEAD ACID BATTERY

Most people today still use them quite significantly as a matter of fact, these are the batteries found in our cars. Using our device to charge a car battery is a very exciting thought. It also very cheap compare with lithium types of batteries. However, as a result of the project remaining in its initial stages, a daunting moves to test it in one's car itself, and is out of the question right now. These car batteries also have both positive and negative connotations to them. One of the negative aspects of using a car battery is the sheer size and weight (S.Bloomfied, 2016). Car batteries generally weigh about 30 lbs, so they are a considerable weight. Depending on how the load is positioned, whether it is mounted on the project or placed to the side of the project, it is also determined by the structural integrity of the frame itself. The life expectancy of these batteries is not the greatest, but also not the worst. The average lifespan of a car battery is about 5 to 8 years before the battery itself dies. There are also other factors that can help to prolong the battery's life as well. This can be seen through the way in which lead acid batteries can be charged or recharged. There are three significant steps in charging these batteries. The first step is known as the bulk charge state. In this initial state, the maximum amount of safe current is sent towards the battery to raise the voltage of the battery until it has reached 80% or so of its full capacity. From this point, absorption charge is implemented. At this charging state, the incoming charging voltage is still kept constant, but the current slowly dies down as the internal resistance of the battery takes effect. The final stage of battery charging then kicks in, once the batteries have attained the maximum charge, the charging voltage then drops but does not completely go away. The reason for keeping a small level of charge is so that the battery does not discharge, but during this stage, the gassing of the chemicals inside of the battery dies down and also helps to promote the life of the battery itself (D.Gumbs *et al*, 2010).

2.7.2 RECHARGEABLE ALKALINE BATTERY

Alkaline batteries are typically the type of batteries that come to mind whenever someone mentions the word battery. They are the most commonly used battery, typically found in AA, AAA, C, D and even some 9 volt cells as well. Typical AA alkaline batteries have a voltage value of 1.5 volts. With the rechargeable variety however, the standard voltage is 1.65 volts. This is the first positive difference between the regular vs. the rechargeable. In terms of efficiency, the rechargeable alkaline currently have lifetimes of about 80% of a typical disposable alkaline battery. This is not a bad efficiency, but it is not at the optimum level either. The typical lifetime of these types of rechargeable batteries is up to 50 times greater than the non-chargeable kind. This would greatly help waste and also lower the amount of harmful chemicals introduced into the world around us thanks to the improper as well as regular disposal of alkaline batteries, because there are no toxins found in this battery. In terms of pricing, if we were to get 2 AA equivalent batteries, they would range about 3.00 to about 3.60. All in all, these batteries are lacking when it comes to the recharge cycle numbers, about 50 to about 500 cycles. Another unfortunate characteristic about these batteries is how the capacity drops even after just a few releases of its charge. These graphs located in *Figure 2.16.* Show how the nickel cadmium batteries and the rechargeable alkaline batteries' lives can be compared to each other. It is clear to see from the figure that the nickel cadmium battery provides the best use over time, but the alkaline battery declines at a steady state making it very easy to predict the amount of charge still remaining in the battery itself. It is possible to see from the graphs how the alkaline battery acts in a more linear fashion while the NiCd battery although the general output is better than that of the alkaline, once it drops, the battery decreases at an exponential rate (D.Gumbs *et al*, 2010).

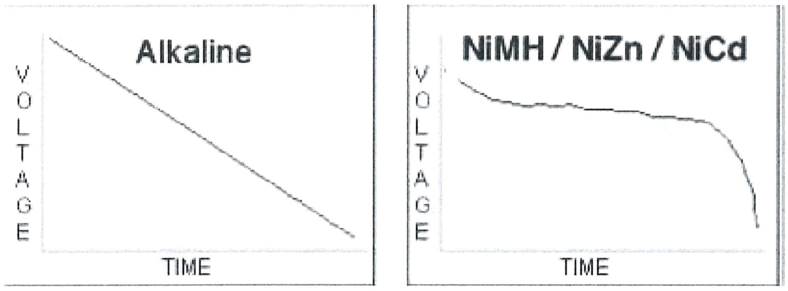


Figure 2.16: *Relationship between the lifetimes of each particular type of battery*

2.7.3 LITHIUM-ION BATTERY

Lithium- ion batteries are a very popular battery today amongst most professionals as well as college students. These are the typical batteries found in laptops. One positive reputation that the lithium ion battery share is that it is able to hold a charge for an extremely long period of time, with or without use. An example of this can be seen in laptop computers once again, we are able to charge them in the morning and if not used, they retain an excellent amount of power even if it is not used until some hours later. This is responsible because of an incredible energy to mass ratio found in this type of battery. These lithium ion batteries have an initial voltage value of 3.6 volts, the second highest ranked rechargeable battery on the chart in *Figure 2.17*. A negative aspect of this battery however is the high charge level and temperatures. These batteries to tend to overheat very quickly and also by creating such excessive heat, some efficiency is lost because the energy is turning into heat. The lithium-ion battery for which the preferred charge protocol for a high rate charge is to start the charge at a relatively high, usually constant current to a given voltage and then taper charging at a constant voltage to a given current cutoff. Exceeding the maximum voltage is a potential safety hazard and could cause irreversible damage to the battery. Charging to a lower voltage will reduce the capacity of the battery (D.Linden and T.B.Reddy, 2001). This excess heat also contributes to a much shorter battery life as well. Also from the way these batteries are constructed, these batteries tend to perform exceptionally well upon initial use. As time goes on however the resistance in these batteries internally rises so much that the battery actually begins to operate for smaller and smaller time periods. The cost for a new lithium ion battery is also extremely high, so this is definitely an important factor to consider (S.Bloomfied, 2016). The way to properly charge these types of batteries is also very similar to the method used in the lead acid batteries. Upon initial charge, these batteries are charging at the maximum allowed current until the voltage limit for each individual cell inside of the battery is reached. At this point, the batter then needs a maximum voltage value per cell until the current subsides 3% below the charge current. The batteries at this point are essentially charged and a periodic final charge is applied once every few hours to just top off the battery. The typical life time of lithium ion batteries are between 3 and 5 hours on average, and have an excellent voltage value associated with them as well. *Figure 2.17* shows the ratio between the cell capacity and discharge cycles of lithium ion batteries. From the *Figure 2.17* it is possible to tell by the time 400 cycles have been achieved for each half a cell, the battery no longer can be considered.

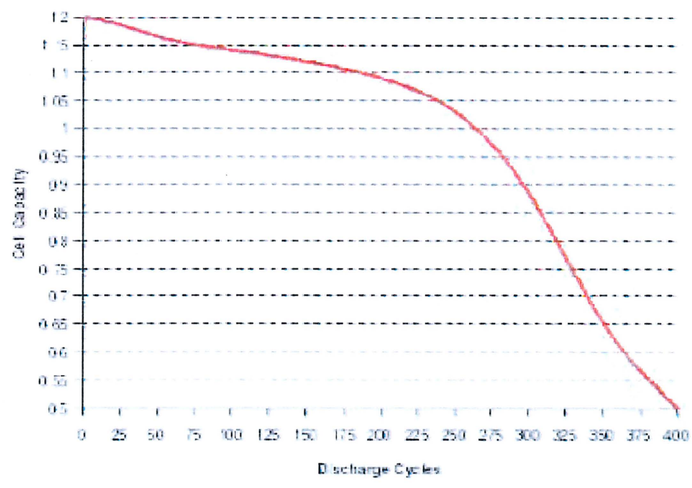


Figure 2.17: *Relationship between the cell capacity and number of discharge cycles for a lithium ion battery*

2.7.4 NICKEL-METAL HYDRIDE BATTERY

The nickel metal hydride battery is the second oldest type of common rechargeable battery. This battery is more accepted amongst consumers as well as industry. This battery which has a charge / discharge rate of about 30% is not really a frugal amount. As a matter of fact, when this battery is compared to that of the lithium ion battery, the energy density volume is extremely similar, if not the same. However, the self-discharge rate when comparing this battery to that of the lithium ion cell, is extremely higher. In terms of comparison towards the nickel cadmium battery, this battery does prove to be a better battery, but does not exceed that of the lithium ion. In terms of composition, this battery is very similar to the cadmium variety, but instead of using cadmium this battery has an effective sponge alloy. When compared to the nickel cadmium battery, this nickel metal hydride battery has been proven to have a much higher energy density, even as high as 40%. This density affects the run times and can also play a factor in the space needed by the battery. We also learned earlier that the cadmium chemical is also a strong anti-environmental friendly compound. The cadmium is considered toxic and there for must be handled and disposed of carefully. The nickel metal hydride battery is not as toxic as the cadmium so that is definitely an improvement when thinking in the green state of mind, much like what we are trying to achieve. This nickel metal variety also is not as limited as the cadmium battery when thinking in terms of the usage of the battery, the cell manufacturing of the battery, and the disposal like what was just previously stated. Another positive aspect about this battery when thinking of our consumers' needs is that as a result of this battery following so closely in the footsteps of its cadmium forefront, this battery is extremely easy to incorporate into devices which previously may have been used by the cadmium. The integration and practicality of this battery can truly be seen with this aspect. The overall operating temperature of these types of batteries is also very similar when compared to the cadmium style. In *Figure 2.18*, we are able to see the relationship between the discharge temperature and the amount of capacity available. There are optimum operating temperatures as this graph will display. There are also some other downfalls when analyzing this battery. This battery will actually start to break down and decompose during long uses of inactivity. This nickel metal hydride battery also had a very low nominal voltage value. The nominal voltage for this battery is only 1.2 volts, making this battery extremely inefficient when powering devices with a larger demand for voltage (D.Gumbs *et al*, 2010).

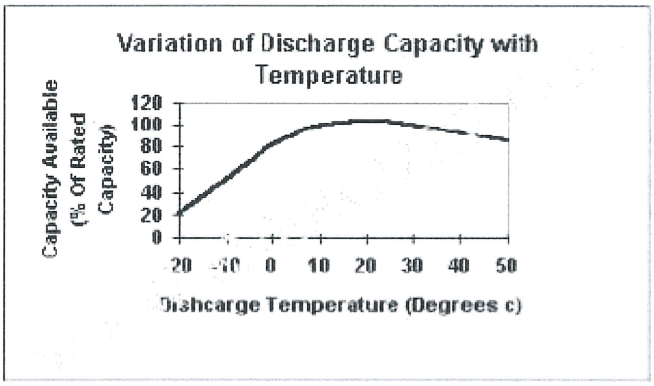


Figure 2.18: *The discharge temperature of the nickel metal hydride can be related to the amount of capacity available within the battery itself*

2.7.5 LITHIUM-ION POLYMER BATTERY

As the name suggests this type of battery is similar but yet different to the popular typical lithium ion battery. The way one could view this battery is an upgraded version of the commonly known lithium ion battery. Not only is this battery extremely thin, there are a few varieties in the cell composure of this battery which actually allows this battery to be more versatile than its predecessor. This battery can actually be molded to form any shape, something the typical lithium ion battery is able to achieve. This battery does promote a little higher nominal voltage, therefore making this battery the highest nominal commonly known rechargeable type of battery. The power ratio of this battery as a result of having a similar output, but having an extremely lighter material as its composure when comparing to the regular lithium ion, is more than double of its predecessor. In terms of charging, the method used to charge this battery is identical to the regular lithium ion battery as well (D.Gumbs *et al*, 2010).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter explains the methods and techniques that had been used throughout this semester to accomplish the objectives stated in Chapter 1. In addition, this chapter also discusses the process flow of the project which is about the designing the structure of the dual axis solar tracker and the fabrication process to build the part of the solar tracker. The steps and explanation for software and hardware development with the electrical circuit diagrams also included in this chapter.

3.2 PLANNING FOR SENIOR DESIGN PROJECT

Each steps starting from designing and fabricating this project are carefully planned and approved by supervisors so that the criteria needed to build a complete solar tracker can be meet. *Figure 3.1* shows the flowchart of the project.

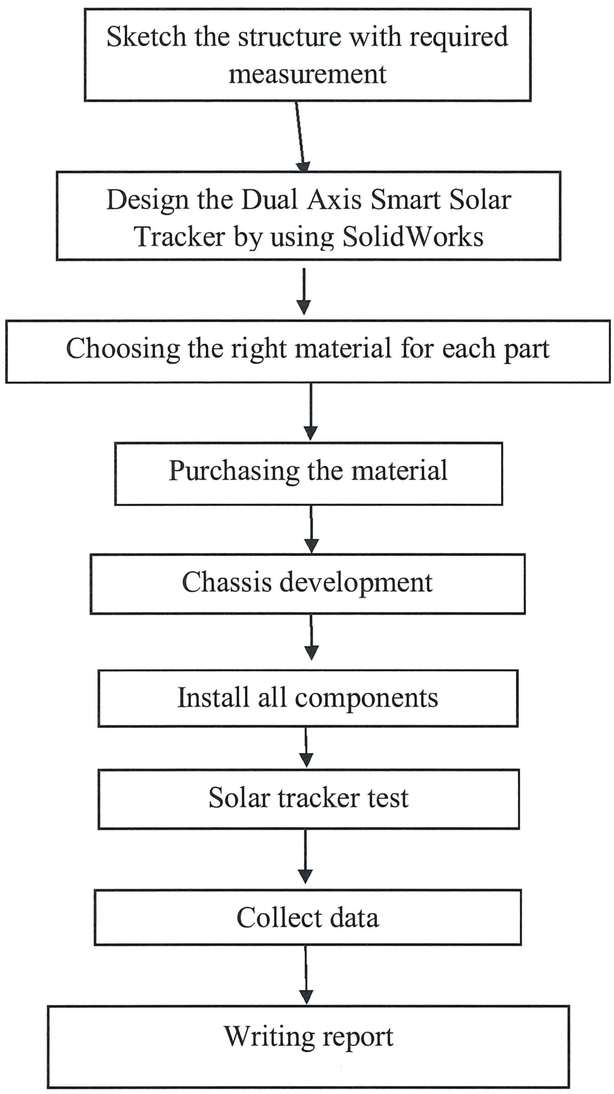


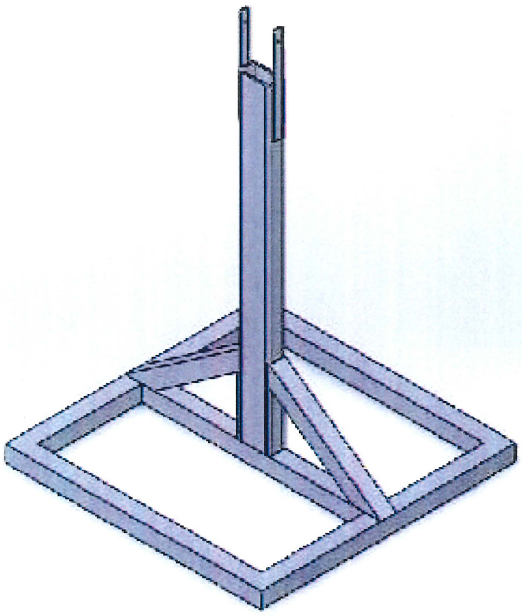
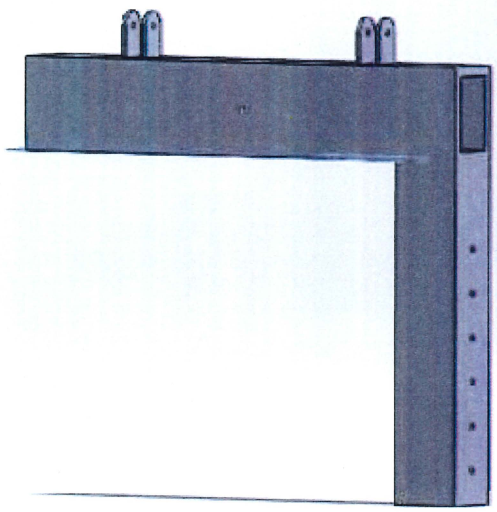
Figure 3.1: *Planning for senior design project*

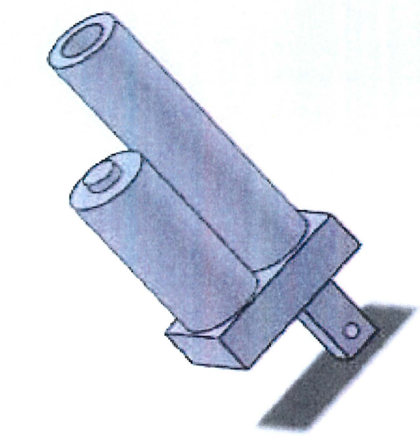
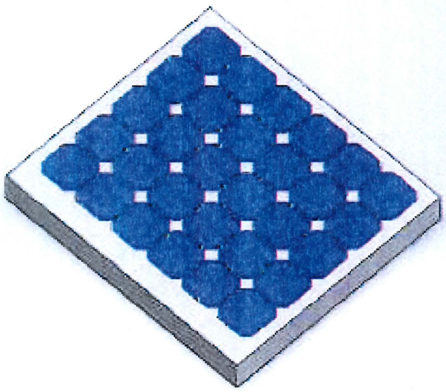
The design part is done during last semester and before the semester end, the material for the structure are decided before the semester ends. Early this semester, the purchasing had been done and the waiting time to receive the materials takes about a month. After that the construction and chassis development take part. Then, solar panel was mounted to the chassis and electrical part such as sensor, microcontroller, solar charge controller and battery were installed. The solar tracker is then tested after all the components are ready. Finally, we proceed with report writing.

3.3 DESIGNING STRUCTURE OF DUAL AXIS SOLAR TRACKER

Every product need to have a complete design with exact measurement before it can be fabricated. The design plays a fundamental role in this project. So, before starts the design process, a few criteria should be take note. The information is gathered by doing some discussion with supervisor and also among team members. Firstly, the information regarding the components needed in the solar tracker are decided so that the design can be made to make sure that all of the component can be installed without errors. After that, we also survey available solar tracker in the market in order to gain some idea on the structure of the solar tracker. The process continued by inserting measurement on the sketches.

The engineering design process was a methodical series of steps that engineers use in creating functional products and processes. The process is highly iterative, parts of the process often need to be repeated many times before another can be entered - though the part(s) that get iterated and the number of such cycles in any given project may vary. The design part for this project is done by two software, which are SolidWorks and NX10. SolidWorks (stylized as SOLIDWORKS) is a solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) computer program that runs on Microsoft Windows. The design for each part are done and shown below:

Component	Features
	• Main support for the solar tracker • The base made from mild steel with dimension 800mm x 800mm • The upper part is made of mild steel of 1000mm
	• The part where it connects the stand with the linear actuator • It also connected to the upper part which hold the solar panel

	• Linear actuator which controls the movement of the solar tracker either to the north or south and east or west
	• Solar panel which will face perpendicularly to the direction of the sunlight

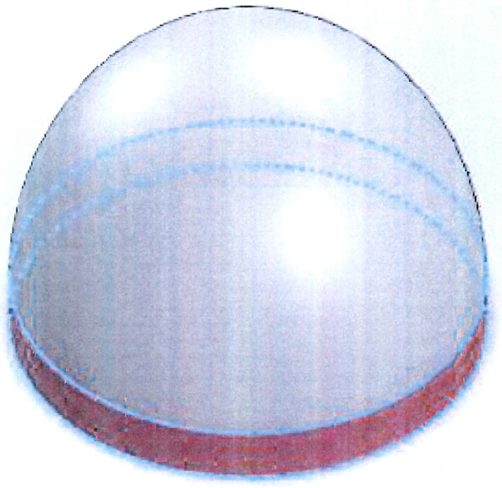
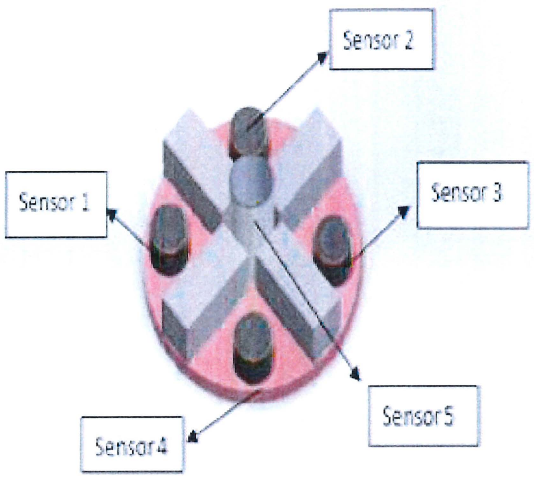
 	• Sensor's holder which place all the sensors in place • Contains 5 sensors which one of them is in a tube • The sensors will track the direction of the sunlight and send instruction to the microcontroller

***Table 3.1**: Design of dual axis solar tracker using SolidWorks software*

Figure 3.2: *Finished design A: Front view, B: Back view, C: Side view and D: Isometric view*

3.4 MATERIAL SELECTION

Choosing the right materials is one of the key that lead to the success for our project. Material selection is known as a core step in the process of designing any physical object. In the context of product design, the main goal of material selection is to minimize cost while meeting product performance goals (G.E.Dieter, 1997). Systematic selection of the best material for a given application begins with properties and costs of candidate materials. For our project, we had to choose materials that cost within the budget set by the faculty. Our team also survey the available materials in the store that we can used so that we can avoid from ordering from outside since it can cause a lot of time and money. After doing some study, mild steel is chosen as the primary material for the structure. This is because it had met the criteria needed for the project.

Figure 3.3: *2-inch x 2-inch mild steel*

3.4.1 PROPERTIES OF MILD STEEL

One of the reason why mild steel offers a good balance of toughness, strength and ductility. It is very important to have a strong structure to avoid any failure in the project especially for our solar tracker since it involve quite heavy loads and motion. Mild steel is an excellent material that filled in strength-to-weight characteristics. It is used for the base and main support for our project to make the structure stronger and more stable. The properties of mild steel are shown in table below.

Properties	Value
Modulus of Elasticity	200 – 250 MPa
Yield Strength	250 – 395 MPa
Tensile Strength	345 – 580 MPa
Elongation	26% – 47%
Hardness	107.5 – 172.5 HV
Density	7800 – 7900 kgm^{-3}

***Table 3.2**: Properties of mild steel*

Next, mild steel is chosen because it can be easily weld. Since the solar tracker design is complex and consist of many parts, it is a must to use the material that can be joined easily. Mild carbon steel can be instantly welded by all the conventional welding processes. Low carbon welding electrodes are to be used in the welding procedure, and post-heating and preheating are not necessary. Pre-heating can be performed for sections over 50 mm. Post-weld stress relieving also has its own beneficial aspects like the pre-heating process. Also, electricity can flow through mild steel easily without impacting its structural integrity. Mild steel is a variant of hard steels, which makes it much less brittle and enhances its flexibility.

Mild steel is the most common form of steel as its price is relatively low while it provides material properties that are acceptable for many applications. Low carbon steel contains approximately 0.05–0.15% carbon and mild steel contains 0.16–0.30% carbon (J.Gupta, 2009) which makes it magnetize well. Since it's relatively inexpensive, mild steel is useful for most projects requiring huge amounts of steel. So, mild steel is strongly recommended to build the solar tracker for our project since it is one of the cheapest metal. Besides, it is available in the store. We can cut our budget and can use the money for other purposes. Most everyday products made from steel contain some mild steel material. Since it has a weak resistance to corrosion, mild steel must be painted or sealed to keep it from rusting. Putting a coat of grease or oil on mild steel also helps to protect it from corrosion.

3.4.2 COMPARING MILD STEELS TO OTHER MATERIALS

In order to support our decision choosing the mild steel as our main material to build the solar tracker, we had done some comparison of materials between the mild steel, Aluminium and stainless steel. The results are shown in the *Table 3.3* below:

Types of material	Mild Steel	Stainless Steel (316)	Aluminium 6061
Density (g/cm³)	7.85	7.70	2.70
Tensile strength (MPa)	440	505	124
Shear strength/ modulus (GPa)	58 - 62	74	26
Modulus of elasticity (GPa)	200	190 - 205	68.9

***Table 3.3**: Comparison between mild steel, stainless steel and Aluminium*

After further study, it is believed that the mild steel is the best material compared to stainless steel and Aluminium. Mild steel is chosen because of their medium strength, formability, weldability, and low cost comparing to Aluminium. Furthermore, it is very cheap and easily welded compared to stainless steel. *Table 3.4* shows the advantages and disadvantages of using mild steel.

Advantages	Disadvantages
The least expensive of all steel types.	Low corrosion resistance.
Easy to be weld and high ductility.	Cannot be better made by heat.

Table 3.4: *The advantages and disadvantages of using mild steel*

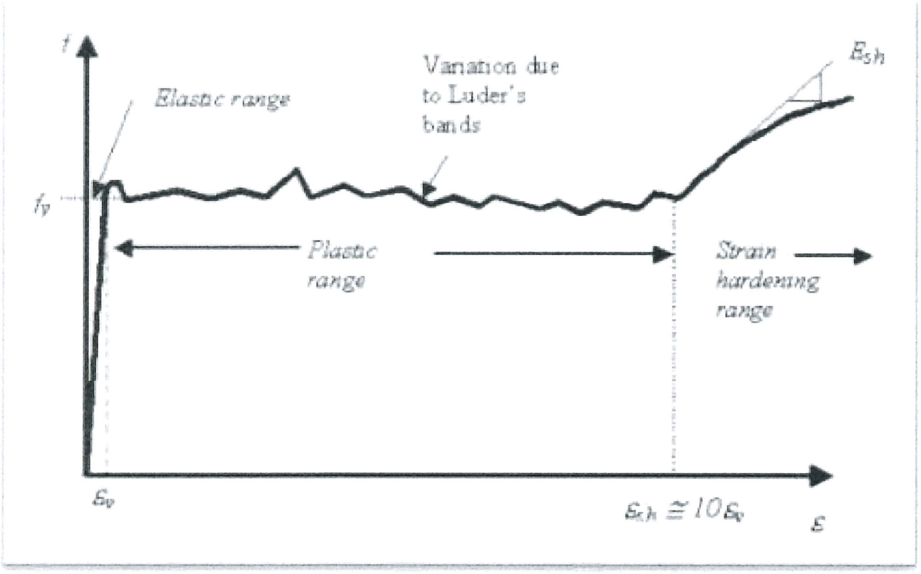


Figure 3.4: *Stress strain curve for mild steel*

<u>Applications of Mild/Low Carbon Steel:</u>

• It is used in bending, crimping and swaging processes.

• Carburized parts that include worms, gears, pins, dowels, non-critical components of tool and die sets, tool holders, pinions, machine parts, ratchets, dowels and chain pins use mild/low carbon steel.

• It is widely used for fixtures, mounting plates and spacers.

• It is suitably used in applications that do not need high strength of alloy steels and high carbon.

- It provides high surface hardness and a soft core to parts that include worms, dogs, pins, liners, machinery parts, special bolts, ratchets, chain pins, oil tool slips, tie rods, anchor pins, studs etc.
- It is used to improve drilling, machining, threading and punching processes.
- It is used to prevent cracking in severe bends.

3.5 FABRICATION

Metal fabrication is the building of metal structures by cutting, joining, assembling and finishing processes. In our project, it involves the construction of machines and structures from various component. The solar tracker is built by referring engineering drawings done in previous step. These value added processes including welding, cutting, forming and machining are done in the workshop. The fabrication starts with shop drawings including precise measurements then move to the fabrication stage and finally to the installation of the final project.

3.5.1 CUTTING PROCESS

The first thing that was going to build is the base of the solar tracker. The criteria of the base are high strength, wide enough and easy for machining. At first, we decided to use mild steel plate as planned during the designing stage, but the material is too heavy and costly. So we decided to use hollow mild steel of 2-inch x 2-inch since it is suitable for the frame part. Its hollow characteristic makes the machining process easier. The hollow steel is used to reduce the weight of the unit compared to the steel plate.

The process starts with measuring the mild steel according to measurement in the engineering drawing by using measuring tapes. Then, before cutting it, it is marked using faithful double end scriber and engineer square. The use of engineer square is essential to make sure the mild steel is 90^0 when it is cut. The measurement is double checked to avoid any mistakes.

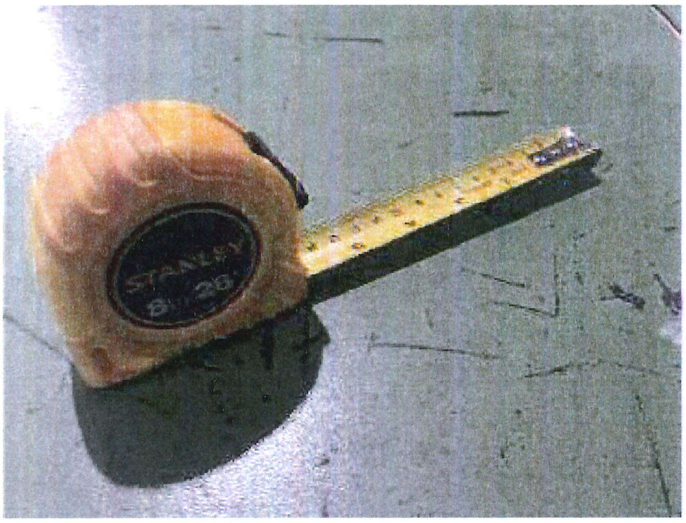


***Figure 3.5**: Measuring tape*

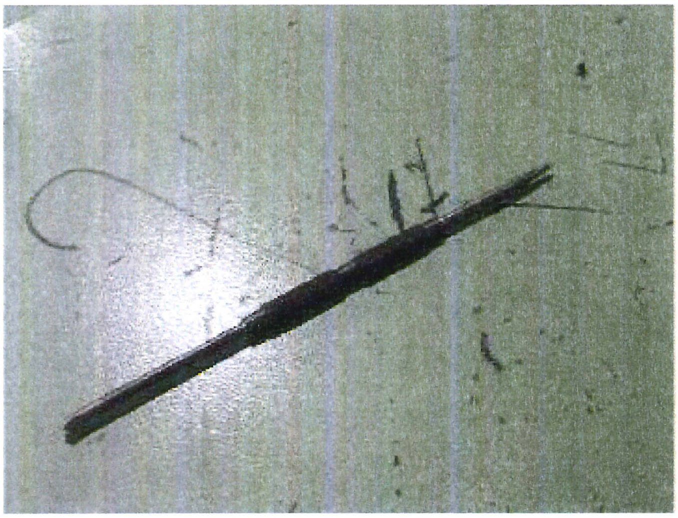


***Figure 3.6**: Faithful double end scriber and engineer square*

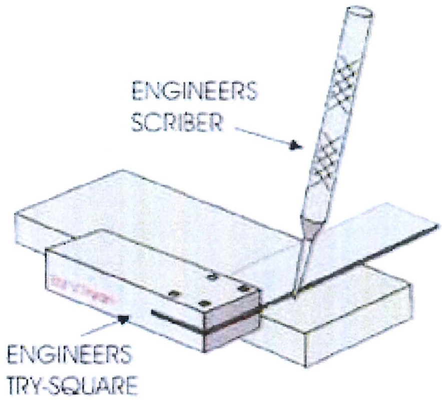


***Figure 3.7**: Illustration how to use scriber and engineer square*

The material has to be cut into desired size. This is done with a variety of tools. For our project, we had use Bosh cutting machine. Its minimum maintenance and easy to install makes our work easier. The grinding disc is 355mm diameter with cutting speed about 3500rpm are one of the reason we chose the machine. We only need to apply a little force to cut the high strength hollow mild steel.

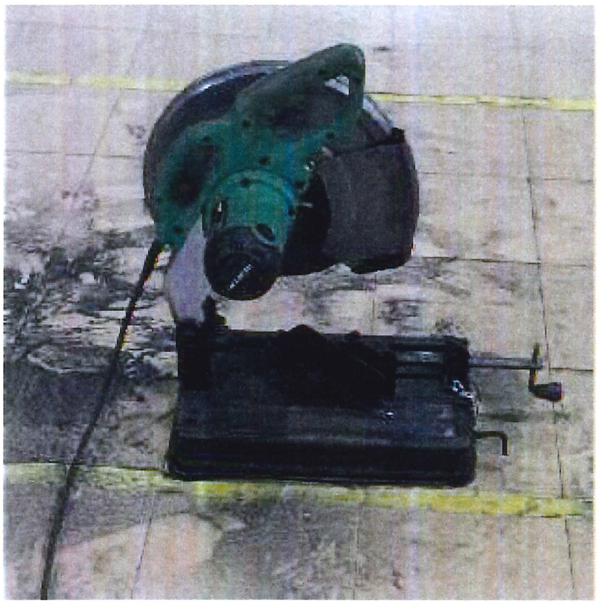


***Figure 3.8**: Bosh cutting machine*

3.5.2 WELDING PROCESS

Welding is the main focus of our solar tracker project. Welding is a fabrication process that joins materials, usually metals or thermoplastics, by causing fusion, which is distinct from lower temperature metal-joining techniques such as brazing and soldering, which do not melt the base metal. In addition to melting the base metal, a filler material is typically added to the joint to form a pool of molten material (the weld pool) that cools to form a joint that is usually stronger than the base material. Pressure may also be used in conjunction with heat, or by itself, to produce a weld.

There are many types of welding process. The one that we used is the gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding, which an electric arc forms between a consumable wire electrode and the workpiece metal, which heats the workpiece metal, causing them to melt and join. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations.

The reason why we use MIG welding steels because it provided faster welding time compared to other welding processes. Besides, the process is more versatility compared to others and as a result, it became a highly used industrial process. Today, GMAW is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation.

***Figure 3.9**: MIG welding machine*

3.5.3 JOINING PROCESS

After welding all the mild steel, then, we need to join the base with the upper part of the solar tracker which will makes the solar tracker move in two axes. The joining process is done by using the bolt and nut which will hold the solar panel holder, upper part of the solar tracker with the base. We also use the same concept to assemble the linear actuator to the body of solar tracker. At first, we need to weld bracket at the part that we want to join. The brackets will become the holder or the place where we can place the nuts and bolts.

***Figure 3.10**: The figure shows how the linear actuator is assembled*

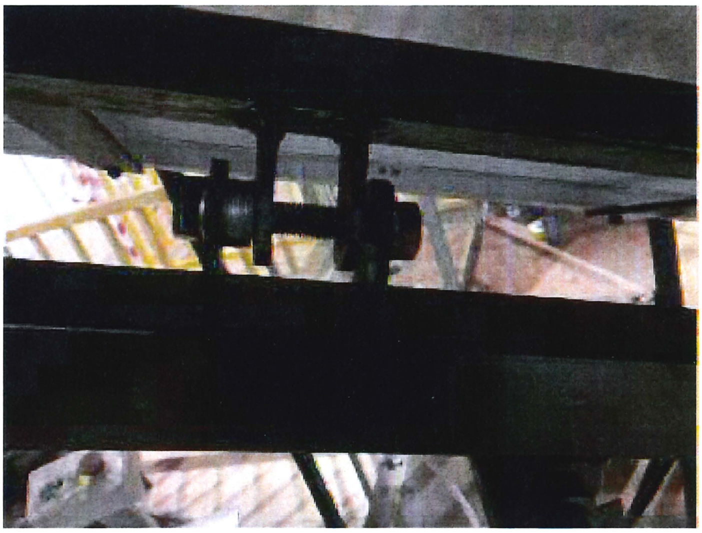


***Figure 3.11**: The figure shows how the base part is joined to the upper part by using brackets*

Then, after the hinges are weld, we can assemble the part that are need to join by using nut and bolt as shown in *Figure 3.11* above. A nut is a type of fastener with a threaded hole. Nuts are almost always used in conjunction with a mating bolt to fasten two or more parts together. The two partners are kept together by a combination of their threads' friction, a slight stretching of the bolt, and compression of the parts to be held together. Nut are important in our project to make sure the solar tracker rotates in two axes which are the north-south direction and east-west direction. In applications where vibration or rotation may work a nut loose, various locking mechanisms may be employed: lock washers, jam nuts, specialist adhesive thread-locking fluid. In this project we had use the washers and grease to avoid this problem.

The most common shape is hexagonal, for similar reasons as the bolt head - 6 sides give a good granularity of angles for a tool to approach from (good in tight spots), but more (and smaller) corners would be vulnerable to being rounded off. It takes only 1/6th of a rotation to obtain the next side of the hexagon and grip is optimal. However, polygons with more than 6 sides do not give the requisite grip and polygons with fewer than 6 sides take more time to be given a complete rotation. Other specialized shapes exist for certain needs, such as wingnuts for finger adjustment and captive nuts (e.g. cage nuts) for inaccessible areas.

Figure 3.12: *The base of linear actuator is fixed to a plate using bolt and nut*

The *Figure 3.12* shows how the linear actuator is fixed to the solar tracker. A plate is placed at the base so in order to weld the bracket. This is because the base of the linear actuator is made of Aluminium which is not suitable for welding. So, a plate is fixed at the base by using bolt and nut.

3.5.4 FINISHING PROCESS

Surface finishing is a broad range of industrial processes that alter the surface of a manufactured item to achieve a certain property. Finishing processes may be employed to improve appearance, adhesion or wettability, solderability, corrosion resistance, tarnish resistance, chemical resistance, wear resistance, hardness, modify electrical conductivity, remove burrs and other surface flaws, and control the surface friction. In limited cases some of these techniques can be used to restore original dimensions to salvage or repair an item. An unfinished surface is often called mill finish. Surface finishing processes can be categorized by how they affect the workpiece:

- Removing or reshaping finishing
- Adding or altering finishing

For our project, we had use the spraying method as the finishing. But first, the rust is removed from the mild steel by using bowl-type wire wheel wire brush. The process need to be carefully handled so that the rust is removed completely. Later, the fabrication process continued with spraying.

***Figure 3.13**: Bowl-type wire wheel wire brush used to remove rust*

***Figure 3.14**: Tools to remove welding wear*

Figure 3.15: *Spraying*

3.6 FINAL PRODUCT

Figure 3.16: *Final product*

3.7 COST ANALYSIS

Product	Price (RM)	Quantity	Total(RM)
100W Monocrystalline Solar Panel	599.00	1	599.00
Arduino Uno	37.00	1	37.00
LDR Sensors	2.00	5	10.00
Solar charge controller	90.00	1	90.00
Box	10.00	1	10.00
Spiral wire wrap	10.00	1	10.00
Pcb stand	1.00	12	12.00
5amp terminal blocks	3.00	1	3.00
4-Relay module	24.00	1	24.00
Resistor	0.50	5	2.50
Capacitor	0.50	2	1.00
Voltage regulator	1.00	1	1.00
12V, 12 inch stroke (100kg) linear actuator	218.00	1	218.00
12V, 6 inch stroke (150kg) linear actuator	255.00	1	255.00
Mild Steel Plate (Length x Height x Thickness) - 1100mm x 100mm x 2mm	130.00/meter	1	160.00
Mild Steel Square Hollow Tube (2” x 2” x 1mm) - Length = 2400mm	25.00/meter	1	60.00
Mild Steel Square Hollow Tube (2” x 2” x 1mm) - Length = 5000mm	20.00/meter	1	100.00
Silicon	7.00	1	7.00
Tire	8.00	4	32.00
Spray	7.00	1	7.00
Bracket	1.00	16	16.00
		Overall Cost	1654.50

***Table 3.5**: Cost Analysis*

3.8 GANTT CHART

Project activities	Weeks	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Verify the titles	Plan															
	Action															
Verify the supervisor	Plan															
	Action															
Discuss about the title with supervisor	Plan															
	Action															
Literature and theoretical study	Plan															
	Action															
Complete the proposal for project	Plan															
	Action															
Verify the panels	Plan															
	Action															
Submission of proposal	Plan															
	Action															
Proposal presentation	Plan															
	Action															
Complete the final report	Plan															
	Action															
Final report submission	Plan															
	Action															

Project activities	Weeks	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Hardware design	Plan															
	Action															
Construction of hardware	Plan															
	Action															
Collection of data by testing	Plan															
	Action															
Modification and evaluation	Plan															
	Action															
Complete the chapter 4	Plan															
	Action															
Complete the chapter 5	Plan															
	Action															

3.9 ETHICAL CONSIDERATION

Safety becomes the primary concern during the fabrication process in the workshop and laboratory. One should wear a suitable attire to do work such as wears goggle to protect the eyes and safety shoes is needed as to avoid injuries. Gloves are also a must when handling tools and machine. Next, for the data collections, the solar tracker should be tested directly under the sunlight and it must be at an open space so that better result can be obtained. Since the solar panel is very sensitive to the shading, it is better to make the solar tracker a little bit higher so that there will be no shading problems may be occurred.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 PROJECT OUTCOMES

At the end of this project, testing had been held to ensure its functioning as stated in the objectives. After the first trial, the solar tracker did not rotate at wide range. This is due to the unexpected length of the linear actuator. The linear actuator is slightly longer than the designed that had been made. So, a few ideas are generated and it is decided to add a metal plate to increase the solar tracker rotation range. The electrical part is also being adjusted after the sensor movement problem is detected. After adjustment is done, the solar tracker is able to operate correctly according to its program. The solar tracking system are able to detect the direction light accurately and the movement of solar tracker is very smooth. The reading of the sunlight intensity is obtained and a few analysis is done.

4.2 DESIGN ANALYSIS

The design is then analyzed by doing simulation in NX10 software. NX, formerly known as NX Unigraphics or usually just UG, is an advanced high-end CAD/CAM/CAE software package originally developed by Unigraphics, but since 2007 by Siemens PLM Software. It can be used among other tasks, for:

- Design (parametric and direct solid/surface modelling)
- Engineering analysis (static; dynamic; electro-magnetic; thermal, using the finite element method; and fluid, using the finite volume method).

- Manufacturing finished design by using included machining modules.

Simulation is done on the base part which is the main support for the solar tracker. A strong base is an important key to the structure. The base must be widely enough so that the body of the solar tracker is stable. From the design in the SolidWorks, the base part is 800mm x 800mm.

4.2.1 LOAD CALCULATION

The load main load that had been count is the solar panel and its holder which is made by ourselves, which are 9kg and 3 kg. so, the total load had been assigned is 12kg.

Force Formula:

$F = ma$

Where; F = Force

m = Mass

a = Gravitational acceleration

$F \quad = 12k \quad \times 9.81$

$= 117.72$ N

4.2.2 STRESS AND DEFORMATION TEST

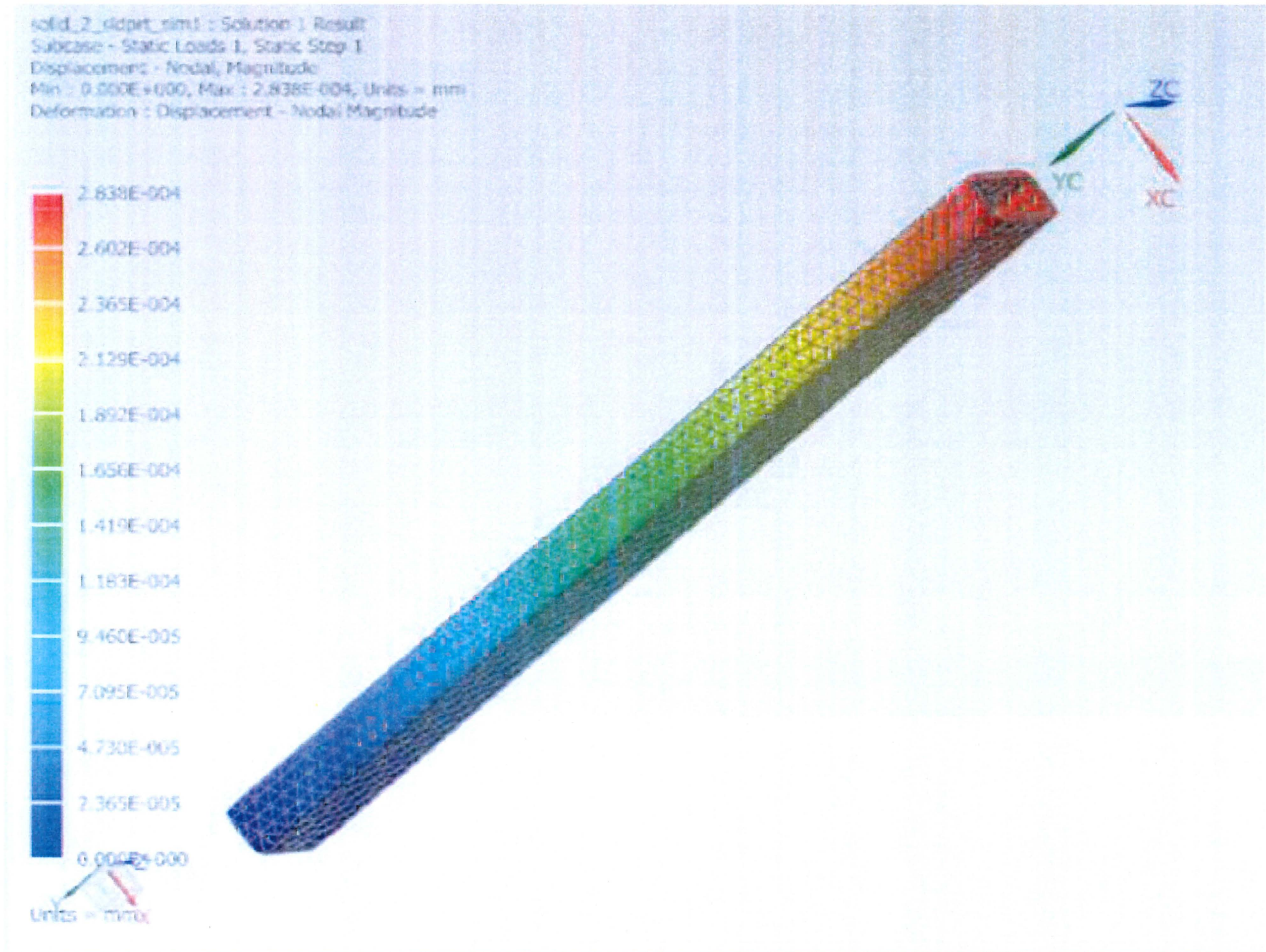


***Figure 4.1**: Simulation results on the main support*

From the *Figure 4.1,* it shows that the main support is strong enough to resist the force from the load. The red zone shows the maximum pressure exerted by the main support and the blue zone at the bottom shows the minimum pressure caused by the load. It can be concluded that the structure of the solar tracker is very strong and there will not be any deformation occur.

4.3 SOLAR OUTPUT

Time	Voltage (V)
9.00 am	13.50
10.00 am	13.53
11.00 am	14.71
12.00 pm	16.25
1.00 pm	16.68
2.00 pm	16.90
3.00 pm	16.70
4.00 pm	15.57
5.00 pm	15.00

Table 4.1: *Solar voltage output of PV panel in Fixed Mode for Sunny day*

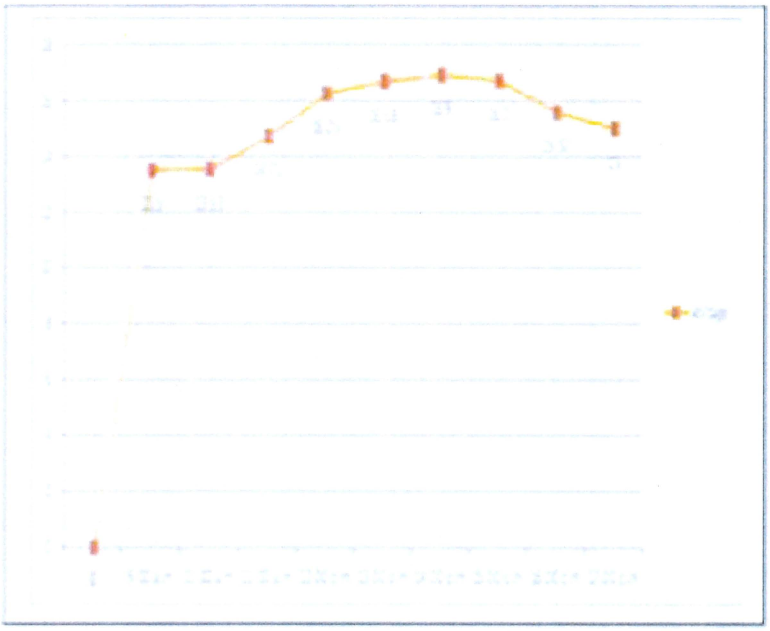


Figure 4.2*: Solar voltage output by time of the day in Fixed Mode for sunny day*

Time	Voltage (V)
9.00 am	13.50
10.00 am	14.85
11.00 am	16.69
12.00 pm	17.89
1.00 pm	18.33
2.00 pm	18.70
3.00 pm	18.67
4.00 pm	18.10
5.00 pm	17.92

Table 4.2: *Solar voltage output of PV panel in Tracking Mode for Sunny day*

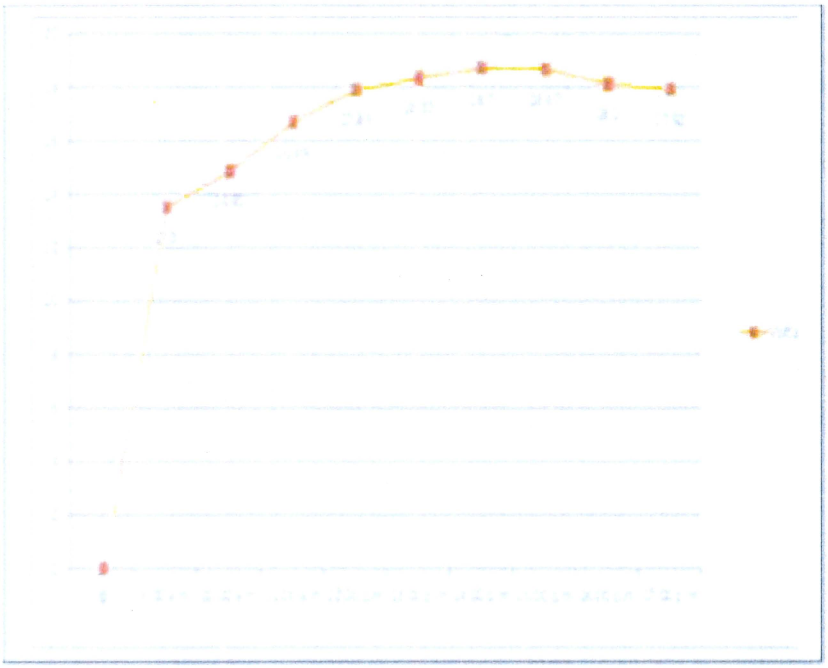


Figure 4.3*: Solar voltage output by time of the day in Tracking Mode for sunny day*

Time	Fixed Mode (Voltage, V)	Tracking Mode (Voltage, V)
9.00 am	13.50	13.50
10.00 am	13.53	14.85
11.00 am	14.71	16.69
12.00 pm	16.25	17.89
1.00 pm	16.68	18.33
2.00 pm	16.90	18.70
3.00 pm	16.70	18.67
4.00 pm	15.57	18.10
5.00 pm	15.00	17.92

Table 4.3: *Comparison of solar voltage output of PV panel in Fixed Mode and Tracking Mode for Sunny day*

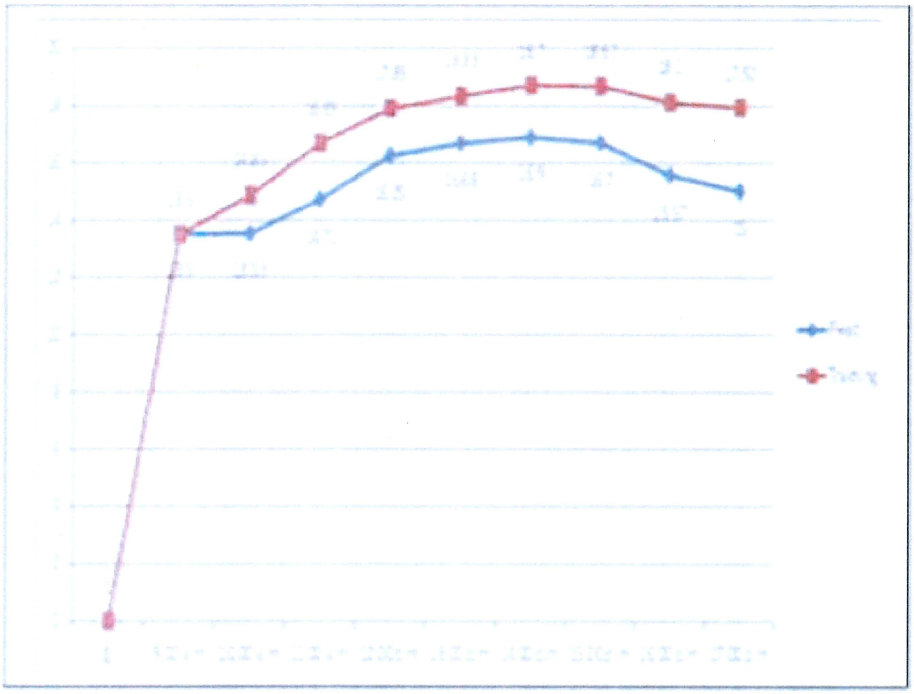


Figure 4.4*: Graph of comparison solar voltages output in Fixed Mode and Tracking Mode for Sunny day*

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The analysis of the structure and motion of the solar tracker shows that some factors that need to be considered to build an efficient solar tracker. The team is able to build a smart solar tracker by using suitable material. The main goal of choosing a correct material is to minimize cost while meeting product performance goals. Mild steel had been chosen as the best material for the solar tracker based on its properties that meet the project requirements. The mild steel had enough strength to make the structure of the solar tracker strong and stable since it can withstand high stress and it also has high flexibility. One of the important criteria that made mild steel as the material for the project is due to weldability. Next, the solar tracker also moves in a wide range since it has two axis of rotation. With the advantages of the two axis of rotation, it enables the solar panel to track the direction of the light accurately. After many testing on the structure and the solar tracking system, a lot of improvements are made to make sure the results for this project is precise.

5.2 RECOMMENDATIONS

For this project, it is recommended to test it in the real environment so that we can know the condition for the solar tracker when it faced the sunny or cloudy condition. It is important to know the reaction and properties of the structure of the solar tracker when it is reacted to the weather around it so that we can avoid any unwanted possibilities such as the expanding or contracting of the steel due to temperature changes. It is also recommended to test the solar tracker in real weather so that we can know the range of the movement of the solar tacker. Next, it is better to add some safety precautions to the solar tracker. For example, in order to implement it in the real environment, we need to shield some parts of the solar tracker which is sensitive to the rain. Light Dependent Resistor (LDR) must be protected from rain because it can cause failure in its function. So, we need to build a protector to cover it but make sure that the cover is transparent so that the LDR can still tracking the light even though it is raining.

As for the results, comparing the power output is better rather than comparing the voltage. The power can be calculated by the formula, P = I x V. In industries, the use of dual axis solar tracker is not implemented. This is because the cost of building the dual axis is so high and but its efficiency is not too differing from the single axis. That is why the industries do not want to use the dual axis solar tracker. So, it is recommended to build a very low cost dual axis solar tracker so that it can be practically implemented in large scale industries.

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APPENDICES

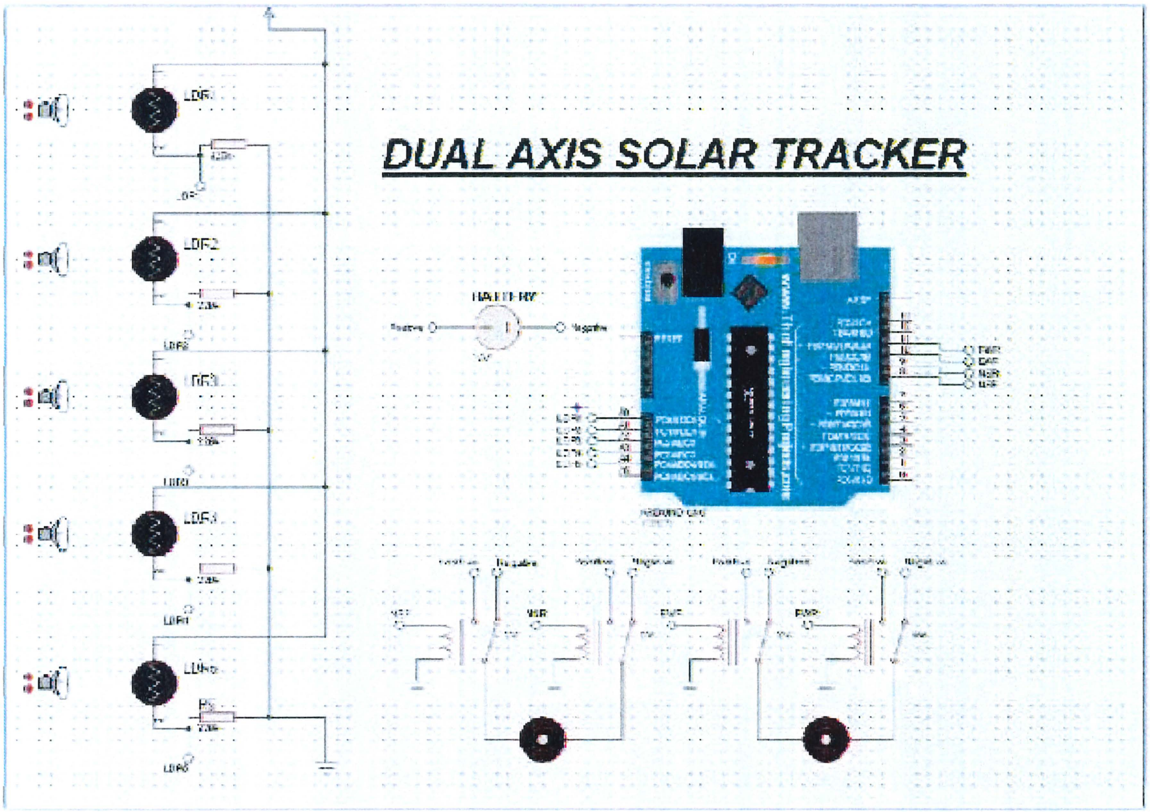
APPENDIX A

SAMPLE APPENDIX 1

```
int Ldr1 = A0; //LDR 1
int Ldr2 = A1; //LDR 2
int Ldr3 = A2; //LDR 3
int Ldr4 = A3; //LDR 4
int Ldr5 = A4; //LDR 5
int mtrNSF = 8; //north-south motor push
int mtrNSR = 9; //north-south motor pull
int mtrEWF = 10; //east-west motor push
int mtrEWR = 11; //east-west motor pull
int mtrOFF = 12;
int sensorValue1 = 0;
int sensorValue2 = 0;
int sensorValue3 = 0;
int sensorValue4 = 0;
int sensorValue5 = 0;
void setup()
{
// put your setup code here, to run once:
pinMode(mtrNSF,OUTPUT); //north-south motor as output
pinMode(mtrNSR,OUTPUT); //north-south motor as output
pinMode(mtrEWF,OUTPUT); //east-west motor as output
pinMode(mtrEWR,OUTPUT); //east-west motor as output
pinMode(mtrOFF,OUTPUT);
pinMode(Ldr1,INPUT); // LDR 1 as input
pinMode(Ldr2,INPUT); // LDR 2 as input
pinMode(Ldr3,INPUT); // LDR 3 as input
pinMode(Ldr4,INPUT); // LDR 4 as input
pinMode(Ldr5,INPUT); // LDR 5 as input
Serial.begin(9600); //sets serial port for communication
}
void loop()
{
// put your main code here, to run repeatedly:
sensorValue1 = analogRead(Ldr1);
sensorValue2 = analogRead(Ldr2);
sensorValue3 = analogRead(Ldr3);
sensorValue4 = analogRead(Ldr4);
sensorValue5 = analogRead(Ldr5);
Serial.print("LDR1 value=");
Serial.print(sensorValue1);
Serial.print("\t LDR2 value=");
Serial.print(sensorValue2);
Serial.print("\t LDR3 value=");
Serial.print(sensorValue3);
Serial.print("\t LDR4 value=");
Serial.print(sensorValue4);
```

```
Serial.print("\t LDR5 value=");
Serial.println(sensorValue5);
{
if(sensorValue1>sensorValue2)
{
digitalWrite(mtrNSF,HIGH);
digitalWrite(mtrNSR,LOW);
}
else if(sensorValue2>sensorValue1)
{
 digitalWrite(mtrNSR,HIGH);
digitalWrite(mtrNSF,LOW);
}
 else if(sensorValue1==sensorValue2)
{
digitalWrite(mtrNSR,LOW);
digitalWrite(mtrNSF,LOW);
}
else
{}
}
{
if(sensorValue3>sensorValue4)
{
digitalWrite(mtrEWF,HIGH);
digitalWrite(mtrEWR,LOW);
}
else if(sensorValue4>sensorValue3)
{
digitalWrite(mtrEWR,HIGH);
digitalWrite(mtrEWF,LOW);
}
else if(sensorValue4==sensorValue3)
{
digitalWrite(mtrEWR,LOW);
digitalWrite(mtrEWF,LOW);
}
else
{}
}
{
if
((sensorValue5>sensorValue1)&&(sensorValue5>sensorValue2)&&(sensorValue5>sensorValue3)&&(sensor
Value5>sensorValue4))
{
digitalWrite(mtrOFF,HIGH);
digitalWrite(mtrNSR,LOW);
digitalWrite(mtrNSF,LOW);
digitalWrite(mtrEWR,LOW);
digitalWrite(mtrEWF,LOW);
```

```
}
else
{
digitalWrite(mtrOFF,LOW);
}
}
}
```



APPENDIX B

SAMPLE APPENDIX 2