# Solar Tracking

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# Final Project Report

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# ABSTRACT

Solar energy is fast becoming a very important means of renewable energy resource. With solar tracking, it will become possible to generate more energy since the solar panel can maintain a perpendicular profile to the rays of the sun. Even though the initial cost of setting up the tracking system is considerably high, there are cheaper options that have been proposed over time. This project discuses the design and construction of a prototype for solar tracking system that has a dual axis of freedom.

The control circuit is based on an ArduinoMega2560 microcontroller. It was programmed to detect sun's position before actuating the servo to position the solar panel. The solar panel is positioned where it is able to receive maximum light. As compared to other motors, the servo motors are able to maintain their torque at high speed. They are also more efficient with efficiencies in the range of 80-90%. Servos can supply roughly twice their rated torque for short periods. They are also quiet and do not vibrate or suffer resonance issues. Performance and characteristics of solar panels are analyzed experimentally.

Silicon solar cells produced an efficiency of 20% for the first time in 1985. Whereas there has been a steady increase in the efficiency of solar panels, the level is still not at its best. Most panels still operate at less than 40%. As a result, most people are forced to either purchase a number of panels to meet their energy demands or purchase single systems with large outputs. There are types of solar cells with relatively higher efficiencies but they tend to be very costly.

One of the ways to increase the efficiency of solar panels while reducing costs is to use tracking. Through tracking, there will be increased exposure of the panel to the sun, making it have increased power output. The trackers can either be dual or single axis trackers. Dual trackers are more efficient because they track sunlight from both axes.

A single tracking system was used. It is cheaper, less complex and still achieves the required efficiency. In terms of costs and whether or not the system is supposed to be implemented by those that use solar panels, the system is viable. The increase in power is considerable and therefore worth the small increase in cost. Maintenance costs are not likely to be high.

# INTRODUCTION

## General background

Solar energy is clean and available in abundance. Solar technologies use the sun for provision of heat, light and electricity. These are for industrial and domestic applications. With the alarming rate of depletion of depletion of major conventional energy sources like petroleum, coal and natural gas, coupled with environmental caused by the process of harnessing these energy sources, it has become an urgent necessity to invest in renewable energy sources that can power the future sufficiently. The energy potential of the sun is immense. Despite the unlimited resource however, harvesting it presents a challenge because of the limited efficiency of the array cells.

The best efficiency of the majority of commercially available solar cells ranges between 10 and 20 percent. This shows that there is still room for improvement. This project seeks to identify a way of improving efficiency of solar panels. Solar tracking is used. The tracking mechanism moves and positions the solar array such that it is positioned for maximum power output. Other ways include identifying sources of losses and finding ways to mitigate them.

When it comes to the development of any nation, energy is the main driving factor. There is an enormous quantity of energy that gets extracted, distributed, converted and consumed every single day in the global society. Fossil fuels account for around 85 percent of energy that is produced. Fossil fuel resources are limited and using them is known to cause global warming because of emission of greenhouse gases. There is a growing need for energy from such sources as solar, wind, ocean tidal waves and geothermal for the provision of sustainable and power.

Solar panels directly convert radiation from the sun into electrical energy. The panels are mainly manufactured from semiconductor materials, notably silicon. Their efficiency is 24.5% on the higher side. Three ways of increasing the efficiency of the solar panels are through increase of cell efficiency, maximizing the power output and the use of a tracking system.

Maximum power point tracking (MPPT) is the process of maximizing the power output from the solar panel by keeping its operation on the knee point of P-V characteristics. MPPT technology will only offer maximum power which can be received from stationary arrays of solar panels at any given time. The technology cannot however increase generation of power when the sun is not aligned with the system.

Solar tracking is a system that is mechanized to track the position of the sun to increase power output by between 30% and 60% than systems that are stationary. It is a more cost effective solution than the purchase of solar panels.

There are various types of trackers that can be used for increase in the amount of energy that can be obtained by solar panels. Dual axis trackers are among the most efficient, though this comes with increased complexity. Dual trackers track sunlight from box axes. They are the best option for places where the position of the sun keeps changing during the year at different seasons. Single axis trackers are a better option for places around the equator where there is no significant change in the apparent position of the sun.

The level to which the efficiency is improved will depend on the efficiency of the tracking system and the weather. Very efficient trackers will offer more efficiency because they are able to track the sun with more precision. There will be bigger increase in efficiency in cases where the weather is sunny and thus favorable for the tracking system.

**Problem statement**

A solar tracker is used in various systems for the improvement of harnessing of solar radiation. The problem that is posed is the implementation of a system which is capable of enhancing production of power by 30-40%. The control circuit is implemented by the microcontroller. The control circuit then positions the motor that is used to orient the solar panel optimally.

**Project justification**

The project was undertaken to ensure the rays of the sun are falling perpendicularly on the solar panel to give it maximum solar energy. This is harnessed into electrical power. Maximum energy is obtained between 1200hrs and 1400hrs, with the peak being around midday. At this time, the sun is directly overhead. At the same time, the least energy will be required to move the panel, something that will further increase efficiency of the system. The project was designed to address the challenge of low power, accurate and economical microcontroller based tracking system which is implemented within the allocated time and with the available resources. It is supposed to track the sun's movement in the sky. In order to save power, it is supposed to sleep during the night by getting back into an horizontal position. There is implementation of an algorithm that solves the motor control that is then written into C- program on Arduino IDE.

**Objectives**

The project was carried out to satisfy two main objectives:

- Design a system that tracks the solar UV light for solar panels.
- Prove that the tracking indeed increases the efficiency considerably. The range of increase in efficiency is expected to be between 30 and 40 percent.

**Scope of the project**

The solar project was implemented using a servo motor. The choice was informed by the fact that the motor is fast, can sustain high torque, has precise rotation within limited angle and does not produce any noise. There is the embedded software section where the ArduinoMega 2560 is programmed using the C language before the chip removed from the Arduino board. The Arduino IDE was used for the coding. Goa has coordinates of $15.28^0$N, $74.167^0$E and therefore the position of the sun will not vary in a significant way during the year. In the tropics, the sun position varies considerably during certain seasons. The position of the sun is calculated using the astronomical equations at every 15 minutes of the day. The procedure is repeated throughout the day.

## LITERATURE REVIEW

### Introduction

A solar tracker is a device used for orienting a photovoltaic array solar panel or for concentrating solar reflector or lens toward the sun. The position of the sun in the sky is varied both with seasons and time of day as the sun moves across the sky. Solar powered equipment work best when they are pointed at the sun. Therefore, a solar tracker increases how efficient such equipment are over any fixed position at the cost of additional complexity to the system. There are different types of trackers.

Extraction of usable electricity from the sun became possible with the discovery of the photoelectric mechanism and subsequent development of the solar cell. The solar cell is a semiconductor material which converts visible light into direct current. Through the use of solar arrays, a series of solar cells electrically connected, there is generation of a DC voltage that can be used on a load. There is an increased use of solar arrays as their efficiencies become higher. They are especially popular in remote areas where there is no connection to the grid.

Photovoltaic energy is that which is obtained from the sun. A photovoltaic cell, commonly known as a solar cell, is the technology used for conversion of solar directly into electrical power. The photovoltaic cell is a non mechanical device made of silicon alloy.

Figure : Solar Cell

The photovoltaic cell is the basic building block of a photovoltaic system. The individual cells can vary from 0.5 inches to 4 inches across. One cell can however produce only 1 or 2 watts that is not enough for most appliances. Performance of a photovoltaic array depends on sunlight. Climatic conditions like clouds and fog significantly affect the amount of solar energy that is received by the array and therefore its performance. Most of the PV modules are between 10 and 20 percent efficient.

**The Earth: Rotation and Revolution**

The earth is a planet of the sun and revolves around it. Besides that, it also rotates around its own axis. There are thus two motions of the earth, rotation and revolution. The earth rotates on its axis from west to east. The axis of the earth is an imaginary line that passes through the northern and southern poles of the earth. The earth completes its rotation in 24 hours. This motion is responsible for occurrence of day and night. The solar day is a time period of 24 hours and the duration of a sidereal is 23 hours and 56 minutes. The difference of 4 minutes is because of the fact that the earth's position keeps changing with reference to the sun.

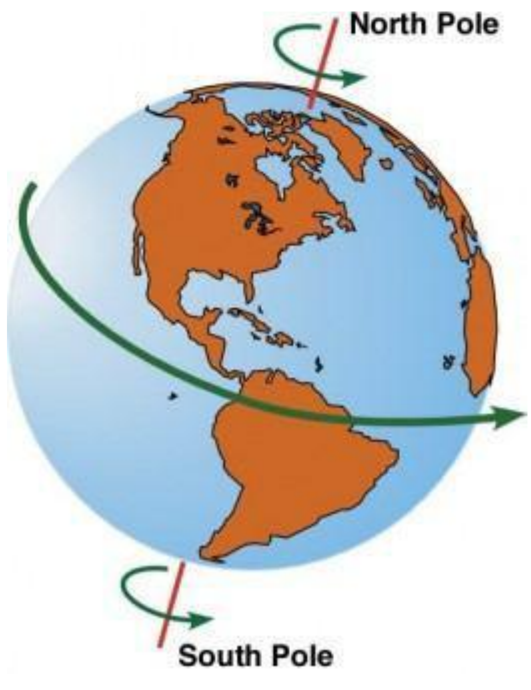



Figure : Earth's rotation

The movement of the earth round the sun is known as revolution. It also happens from west to east and takes a period of 365 days. The orbit of the earth is elliptical. Because of this the distance between the earth and the sun keeps changing. The apparent annual track of the sun via the fixed stars in the celestial sphere is known as the ecliptic. The earth's axis makes an angle of 66.5 degrees to the ecliptic plane. Because of this, the earth attains four critical positions with reference to the sun.

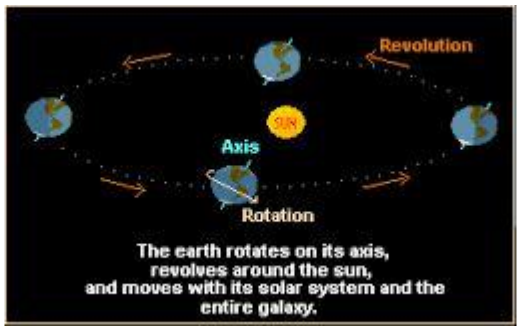



Figure : Revolution and rotation

**Solar Irradiation: Sunlight and the Solar Constant**

The sun delivers energy by means of electromagnetic radiation. There is solar fusion that results from the intense temperature and pressure at the core of the sun. Protons get converted into helium atoms at 600 million tons per second. Because the output of the process has lower energy than the protons which began, fusion gives rise to lots of energy in form of gamma rays that are absorbed by particles in the sun and re-emitted.

The total power of the sun can be estimated by the law of Stefan and Boltzmann.

$$P=4pir^2\ \epsilon\lambda T^4$$

T is the temperature that is about 5800K, r is the radius of the sun which is 695800 km and **λ** is the Boltzmann constant which is $1.3806488 \times 10^{-23}\ m^2\ kg\ s^{-2}\ K^{-1}$. The emissivity of the surface is denoted by **ϵ.** Because of Einstein's famous law $E=mc^2$ about millions of tons of matter are converted to energy each second. The solar energy that is irradiated to the earth is $5.10^{24}$ Joules per year. This is 10000 times the present worldwide energy consumption per year.

Solar radiation from the sun is received in three ways: direct, diffuse and reflected.

Direct radiation**:** is also referred to as beam radiation and is the solar radiation which travels on a straight line from the sun to the surface of the earth.

Diffuse radiation: is the description of the sunlight which has been scattered by particles and molecules in the atmosphere but still manage to reach the earth’s surface. Diffuse radiation has no definite direction, unlike direct versions.

Reflected radiation: describes sunlight which has been reflected off from non-atmospheric surfaces like the ground.

**Sunlight**

Photometry enables us to determine the amount of light given off by the Sun in terms of brightness perceived by the human eye. In photometry, a luminosity function is used for the radiant power at each wavelength to give a different weight to a particular wavelength that models human brightness sensitivity. Photometric measurements began as early as the end of the $18^{th}$ century resulting in many different units of measurement, some of which cannot even be converted owing to the relative meaning of brightness. However, the luminous flux (or lux) is commonly used and is the measure of the perceived power of light. Its unit, the lumen, is concisely defined as the luminous flux of light produced by a light source that emits one candela of luminous intensity over a solid angle of one steradian. The candela is the SI unit of luminous intensity and it is the power emitted by a light source in a particular direction, weighted by a luminosity function whereas a steradian is the SI unit for a solid angle; the two-dimensional angle in three-dimensional space that an object subtends at a point.

One lux is equivalent to one lumen per square metre;

$1\ \mathrm{lx} = 1\mathrm{lm} \cdot \mathrm{m} = 1\ \mathrm{cd} \cdot \mathrm{sr} \cdot \mathrm{m}$ **(1)**

i.e. a flux of 10 lumen, concentrated over an area of 1 square metre, lights up that area with illuninance of 10 lux.

Sunlight ranges between 400 lux and approximately 130000 lux, as summarized in the table below.

**Elevation angle**

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 degrees at sunrise and 90 degrees 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.

**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, the zenith angle = 90 degrees – elevation angle.

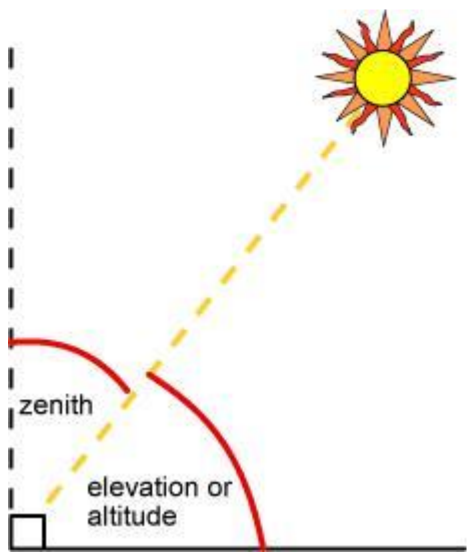



Figure : angle of elevation and zenith angle

**Azimuth angle**

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 degrees at sunrise and 270 degrees at sunset.

**Types of solar trackers and tracking technologies**

There are various categories of modern solar tracking technologies;

**Active tracker**

Active trackers make use of motors and gear trains for direction of the tracker as commanded by the controller responding to the solar direction. The position of the sun is monitored throughout the day. When the tracker is subjected to darkness, it either sleeps or stops depending on the design. This is done using sensors that are sensitive to light such as LDRs. Their voltage output is put into a microcontroller that then drives actuators to adjust the position of the solar panel.

**Passive solar tracking**

Passive trackers use a low boiling point compressed gas fluid driven to one side or the other to cause the tracker to move in response to an imbalance. Because it is a non precision orientation it is not suitable for some types of concentrating photovoltaic collectors but works just fine for common PV panel types. These have viscous dampers that prevent excessive motion in response to gusts of wind.

**Chronological solar tracking**

A chronological tracker counteracts the rotation of the earth by turning at the same speed as the earth relative to the sun around an axis that is parallel to the earth’s. To achieve this, a simple rotation mechanism is devised which enables the system to rotate throughout the day in a predefined manner without considering whether the sun is there or not. The system turns at a constant speed of one revolution per day or 15 degrees per hour. Chronological trackers are very simple but potentially very accurate.

**Single axis trackers**

Single axis trackers have one degree of freedom that act as the axis of rotation. The axis of rotation of single axis trackers is aligned along the meridian of the true North. With advanced tracking algorithms, it is possible to align them in any cardinal direction. Common implementations of single axis trackers include horizontal single axis trackers (HSAT), horizontal single axis tracker with tilted modules (HTSAT), vertical single axis trackers (VSAT), tilted single axis trackers (TSAT) and polar aligned single axis trackers (PSAT) [8].

**Dual axis trackers**

Dual axis trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to each other. The primary axis is the one that is fixed with respect to the ground. The secondary axis is the one referenced to the primary axis. There are various common implementations of dual trackers. Their classification is based on orientation of their primary axes with respect to the ground.

**Fixed and tracking collectors**

Solar energy can be harnessed using either fixed or movable collectors.

**Fixed collectors**

Fixed collectors are mounted on places that have maximum sunlight and are at relatively good angle in relation to the sun. These include rooftops. The main aim is to expose the panel for maximum hours in a day without the need for tracking technologies. There is therefore a considerable reduction in the cost of maintenance and installation. Most collectors are of the fixed type. When using these collectors, it is important to know the position of the sun at various seasons and times of the year so that there is optimum orientation of the collector when it is being installed. This gives maximum solar energy through the year.

The sun chart for Goa is shown below.

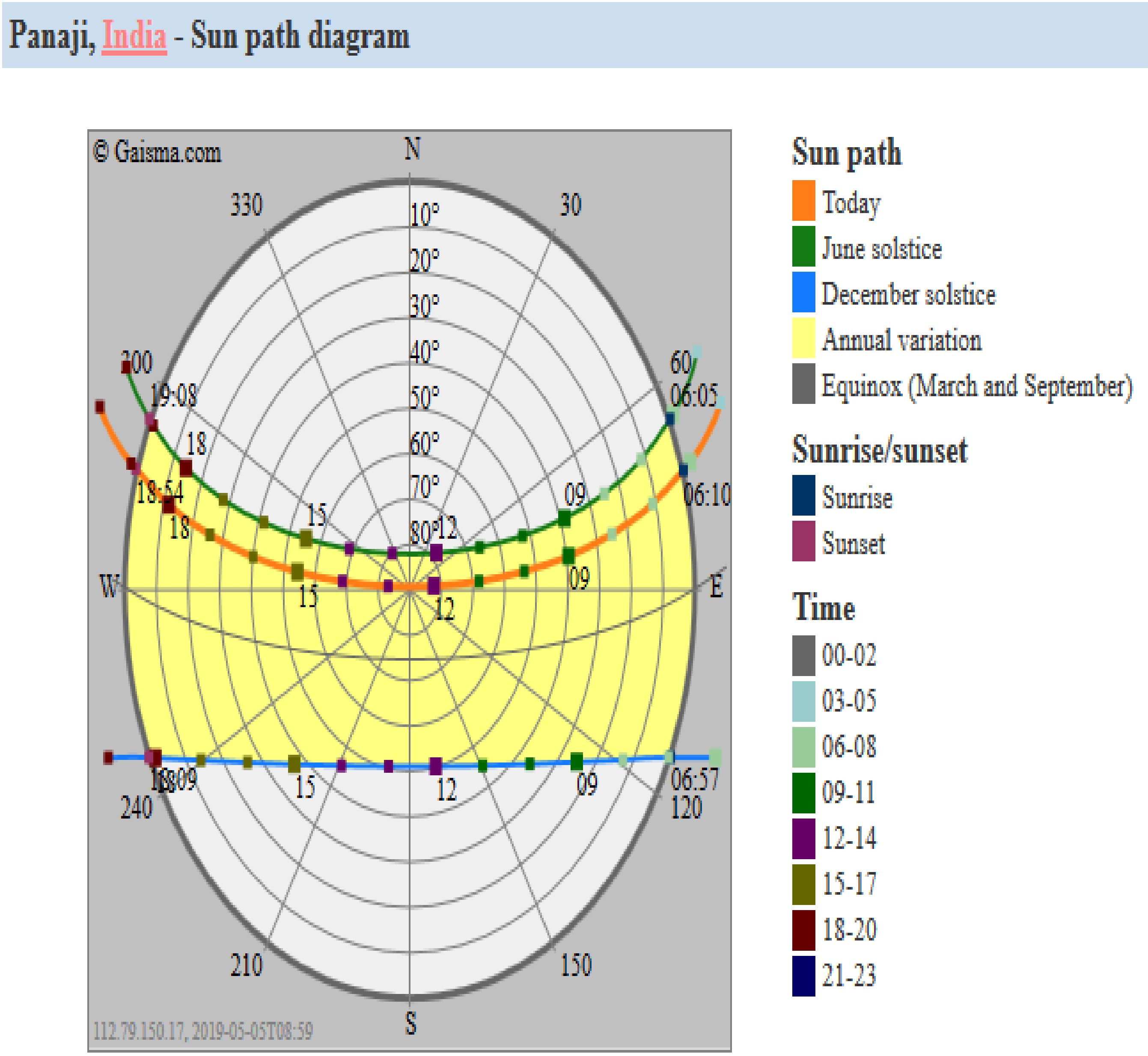



Figure : Sun path diagram for Goa

Through the use of the chart, it is possible to ascertain the position of the sun at different times and seasons so that the panel can be fixed for maximum output. Fixed trackers are cheaper in tropical countries like Kenya. For countries beyond +10 degrees North and -10 degrees South of the equator, there is need for serious tracking. This is because the position of the midday sun varies significantly.

The chart shows that the position of the sun is highest between 1200h and 1400h. For the periods outside this range, the collectors are obliquely oriented to the sun and therefore only a fraction reaches the surface of absorption.

**Effect of light intensity**

Change of the light intensity incident on a solar cell changes all the parameters, including the open circuit voltage, short circuit current, the fill factor, efficiency and impact of series and shunt resistances. Therefore, the increase or decrease has a proportional effect on the amount of power output from the panel.

**Efficiency of solar panels**

The efficiency is the parameter most commonly used to compare performance of one solar cells to another. It is the ratio of energy output from the solar panel to input energy from the sun. in addition to reflecting on the performance of solar cells, it will depend on the spectrum and intensity of the incident sunlight and the temperature of the solar cell. As a result, conditions under which efficiency is to be measured must be controlled carefully to compare performance of the various devices.

The efficiency of solar cells is determined as the fraction of incident power that is converted to electricity. It is defined as:

$$P_{max} = V_{OC} I_{SC} FF$$

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}}$$

where $V_{oc}$ is the open-circuit voltage;

$I_{sc}$ is the short-circuit current

FF is the fill factor

ŋ is the efficiency.

The input power for efficiency calculations is 1 $kW/m^2$ or 100 $mW/cm^2$. Thus the input power for a $100 \times 100$ $mm^2$ cell is 10 W.

**Benefits and demerits of solar energy**

There are several benefits that solar energy has and which make it favorable for many uses.

**Benefits**

- Solar energy is a clean and renewable energy source.
- Once a solar panel is installed, the energy is produced at reduced costs.
- Whereas the reserves of oil of the world are estimated to be depleted in future, solar energy will last forever.
- It is pollution free.
- Solar cells are free of any noise. On the other hand, various machines used for pumping oil or for power generation are noisy.
- Once solar cells have been installed and running, minimal maintenance is required. Some solar panels have no moving parts, making them to last even longer with no maintenance.
- On average, it is possible to have a high return on investment because of the free energy solar panels produce.
- Solar energy can be used in very remote areas where extension of the electricity power grid is costly.

**Disadvantages of solar power**

- Solar panels can be costly to install resulting in a time lag of many years for savings on energy bills to match initial investments.
- Generation of electricity from solar is dependent on the country's exposure to sunlight. This means some countries are slightly disadvantaged.
- Solar power stations do not match the power output of conventional power stations of similar size. Furthermore, they may be expensive to build.
- Solar power is used for charging large batteries so that solar powered devices can be used in the night. The batteries used can be large and heavy, taking up plenty of space and needing frequent replacement.

Because merits are more than the demerits, the use of solar power is considered as a clean and viable source of energy. The various limitations can be reduced through various ways.

## DESIGN AND IMPLEMENTATION

**Calculating sun's position**

First, the fractional year (γ) is calculated, in radians

$$\gamma = \frac{2\pi}{365} * (\text{day\_of\_year} - 1 + \frac{hour - 12}{24})$$

(For leap years, use 366 instead of 365 in the denominator.)

From γ, we can estimate the equation of time (in minutes) and the solar declination angle (in radians).

$$Eqtime = 229.18*(0.000075 + 0.001868\cos(\gamma) - 0.032077\sin(\gamma) - 0.014615\cos(2\gamma) - 0.040849\sin(2\gamma))$$

$$Decl = 0.006918 – 0.399912\cos(\gamma) + 0.070257\sin(\gamma) - 0.006758\cos(2\gamma) + 0.000907\sin(2\gamma) - 0.002697\cos(3\gamma) + 0.00148\sin(3\gamma)$$

Next, the true solar time is calculated in the following two equations. First the time offset is found, in minutes, and then the true solar time, in minutes.

$$time\_offset = eqtime+4*longitude–60*timezone$$

where eqtime is in minutes, longitude is in degrees(positive to the east of the Prime Meridian), timezone is in hours from UTC (U.S. Mountain Standard Time = –7 hours).

$$tst= hr*60 + mn+ sc/60 + time\_offset$$

where hr is the hour (0 -23), mnis the minute (0 -59), sc is the second (0 -59).

The solar hour angle, in degrees, is:

*ha= (tst/ 4) –180*

The solar zenith angle (ϕ) can then be found from the hour angle (ha), latitude (lat) and solar declination (decl) using the following equation:

cos(ϕ)= sin(lat)sin(decl) + cost(lat)cos(decl)cos(ha)

And the solar azimuth (θ, degrees clockwise from north) is found from:

$$\cos(180-\theta) = -\frac{\sin(lat)\cos(\phi)-\sin(decl)}{\cos(lat)\sin(\phi)}$$

**Sunrise/Sunset Calculations**

For the special case of sunrise or sunset, the zenith is set to 90.833° (the approximate correction for atmospheric refraction at sunrise and sunset, and the size of the solar disk), and the hour angle becomes:

$$ha = \pm arccos\left\{\frac{\cos(90.833)}{\cos(lat)\cos(decl)} - \tan(lat)\tan(decl)\right\}$$

where the positive number corresponds to sunrise, negative to sunset. Then the UTC time of sunrise (or sunset) in minutes is:

*sunrise= 720 – 4*(longitude+ha)–eqtime*

where longitude and hour angle are in degrees and the equation of time is in minutes.

Solar noon for a given location is found from the longitude (in degrees, positive to the east of the Prime Meridian) and the equation of time (in minutes):

*snoon = 720 –4*longitude– eqtime*

**Servo motor**

Servo motors are used for various applications. They are normally small in size and have good energy efficiency. The servo circuitry is built inside the motor unit and comes with a positionable shaft that is fitted with a gear. The motor is controlled with an electric signal that determines the amount of shaft movement.

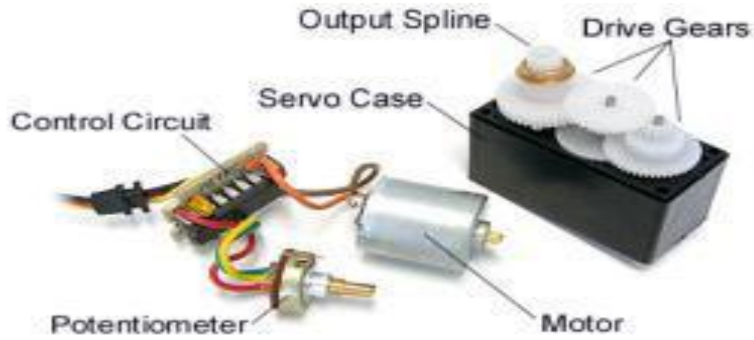



Figure : servo motor inside features

**Components of the servo motor**

Inside the servo there are three main components; a small DC motor, a potentiometer and a control circuit. Gears are used to attach the motor to the control wheel. As the motor rotates, the resistance of the potentiometer changes so the control circuit can precisely regulate the amount of movement there is and the required direction.

When the shaft of the motor is at the desired position, power supply to the motor is stopped. If the shaft is not at the right position, the motor is turned in the right direction. The desired position is sent through electrical pulses via the signal wire. The speed of the motor is proportional to the difference between the actual position and the position that is desired. Therefore, if the motor is close to the desired position, it turns slowly. Otherwise, it turns fast. This is known as proportional control.

**How the servo is controlled**

Servos are sent through sending electrical pulses of variable width, or pulse width modulation (PWM), through the control wire. There is a minimum pulse, maximum pulse and a repetition rate. Servos can usually turn only 90 degrees in either direction for a total of 180 degrees movement. The neutral position of the motor is defined as that where the servo has the same amount of potential rotation in both the clockwise and counter-clockwise direction. The PWM sent to the motor determines the position of the shaft, and based on the duration of the pulse sent through the control wire the rotor will turn to the position that is desired.

The servo motor expects to see a pulse after every 20 milliseconds and the length of the pulse will determine how far the motor will turn. For instance, a 1.5ms pulse makes the motor to turn in the 90 degrees position. If the pulse was shorter than 1.5ms, it will move to 0 degrees and a longer pulse moves it to 180 degrees. This is shown below.

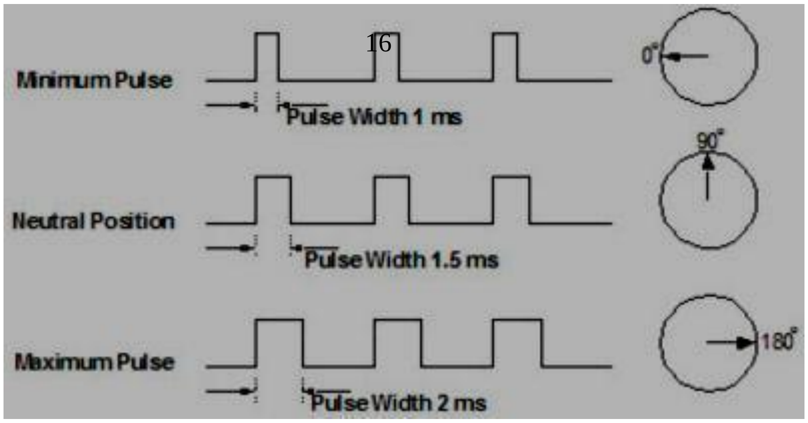



Figure : variable pulse width control servo position

For applications where there is requirement of high torque, servos are preferable. They will also maintain the torque at high speeds, up to 90% of the rated torque is available from servos at high speeds. Their efficiencies are between 80 to 90%.

A servo is able to supply approximately twice their rated torque for short periods of time, offering enough capacity to draw from when needed. In addition, they are quiet, are available in AC and DC, and do not suffer from vibrations.

**Advantages and disadvantages of servo motors**

For applications where high speed and high torque are required, servo motors are the better option. While stepper motors peak at around 2000 RPM, servos are available at much faster speeds. Servo motors also maintain torque at high speed, up to 90% of the rated torque is available from servos at high speeds. They have an efficiency of about 80-90% and supply roughly twice their rated torque for short periods. Furthermore, they do not vibrate or suffer from resonance issues.

Servo motors are more expensive than other types of motors. Servos require gear boxes, especially for lower operation speeds. The requirement for a gear box and position encoder makes the designs more mechanically complex. Maintenance requirements will also increase.

**Crystal**

Crystal oscillators are electronic oscillator circuits that use inverse piezoelectric effect. With this effect, when electric field is applied across certain materials they will produce mechanical deformation. Therefore a crystal uses mechanical resonance of a vibrating crystal of piezoelectric material so that there is creation of an electric signal with precise frequency. They have high stability, are low cost and quality factor which makes them superior over such resonators as LC circuits, ceramic resonators and turning forks.

The crystal action can be represented by an equivalent electrical resonant circuit.

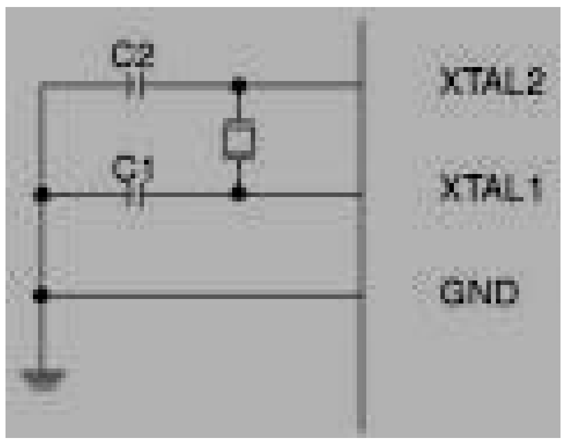



Figure : circuit diagram of a crystal

The optimal values of the capacitors depend on whether a quartz crystal or ceramic resonator is being used. It will also depend on application-specific requirements on start-up time and frequency tolerance. Crystal oscillators are not built into ICs because they cannot be easily fabricated with IC processes and the size is physically larger than IC circuits.

The internal oscillators of microcontrollers are RC oscillators. The reason why crystal oscillators are used is because the quality factor is on the order of 100000 while that of RC oscillators is on the order of 100. Therefore, the crystal oscillator has lower phase noise and lower variation in output frequency.

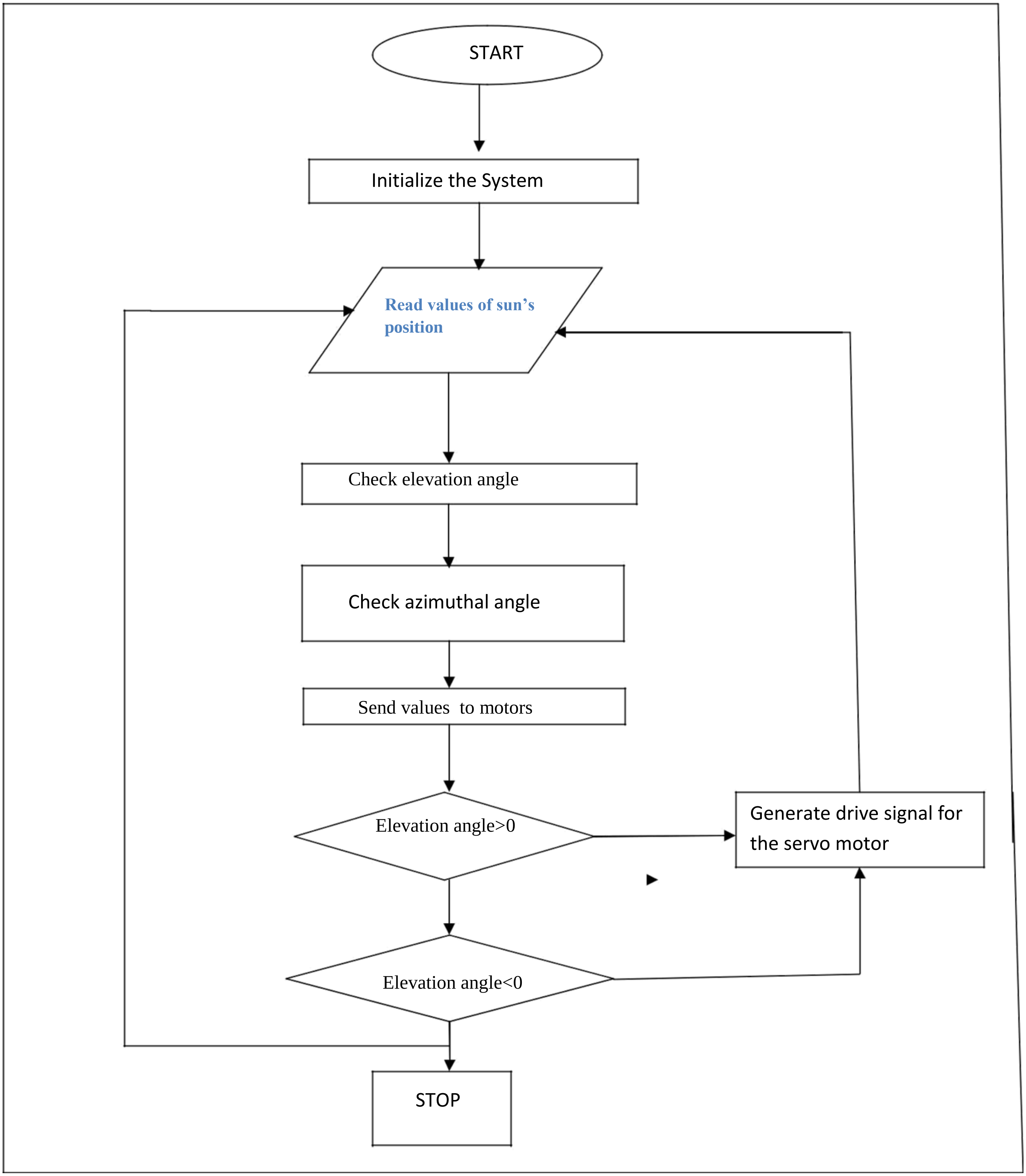



Figure : A Simplified Flow Chart of the Assembly

## RESULTS, SIMULATIONS AND ANALYSIS

### Results

The results were obtained for different days. Getting results from different days was helpful in that it made it possible to compare the various values gotten from different weather conditions. The values obtained were recorded and used to draw graphs to show the relations.

Table 4.1: Results for clear Morning and Sunny Afternoon for 2 consecutive days

| TIME | UNTRACKED VOLTAGE 1ST DAY | TRACKED VOLTAGE 1ST DAY | UNTRACKED VOLTAGE 2nd DAY | TRACKED VOLTAGE 2nd DAY |
|---|---|---|---|---|
| 6:00 | 0.9 | 1.4. | 0.5 | 1.2 |
| 7:00 | 1.5 | 2.2 | 1.6 | 2.2 |
| 8:00 | 2.6 | 2.9 | 2.4 | 2.6 |
| 9:00 | 2.7 | 3.1 | 2.6 | 2.9 |
| 10:00 | 2.8 | 3.6 | 3.0 | 3.5 |
| 11:00 | 3.0 | 3.8 | 3.3 | 3.8 |
| 12:00 | 3.1 | 3.8 | 3.7 | 3.9 |
| 14:00 | 2.9 | 3.9 | 3.7 | 3.9 |
| 16:00 | 2.8 | 3.8 | 2.5 | 3.1 |
| 17:00 | 2.5 | 3.0 | 1.9 | 2.4 |
| 18:00 | 2.3 | 2.7 | 0.1 | 1.0 |

*All readings are in volts across 100ohm resistance

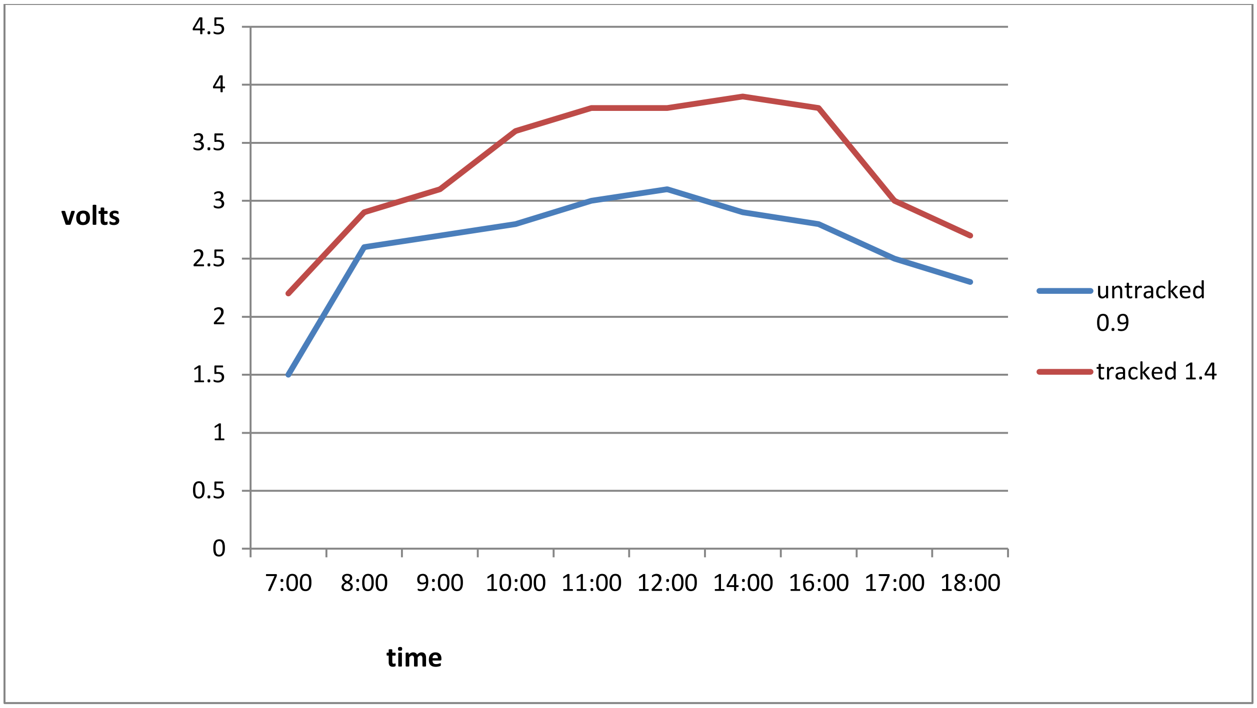



Figure : Graph of results obtained on 1st day

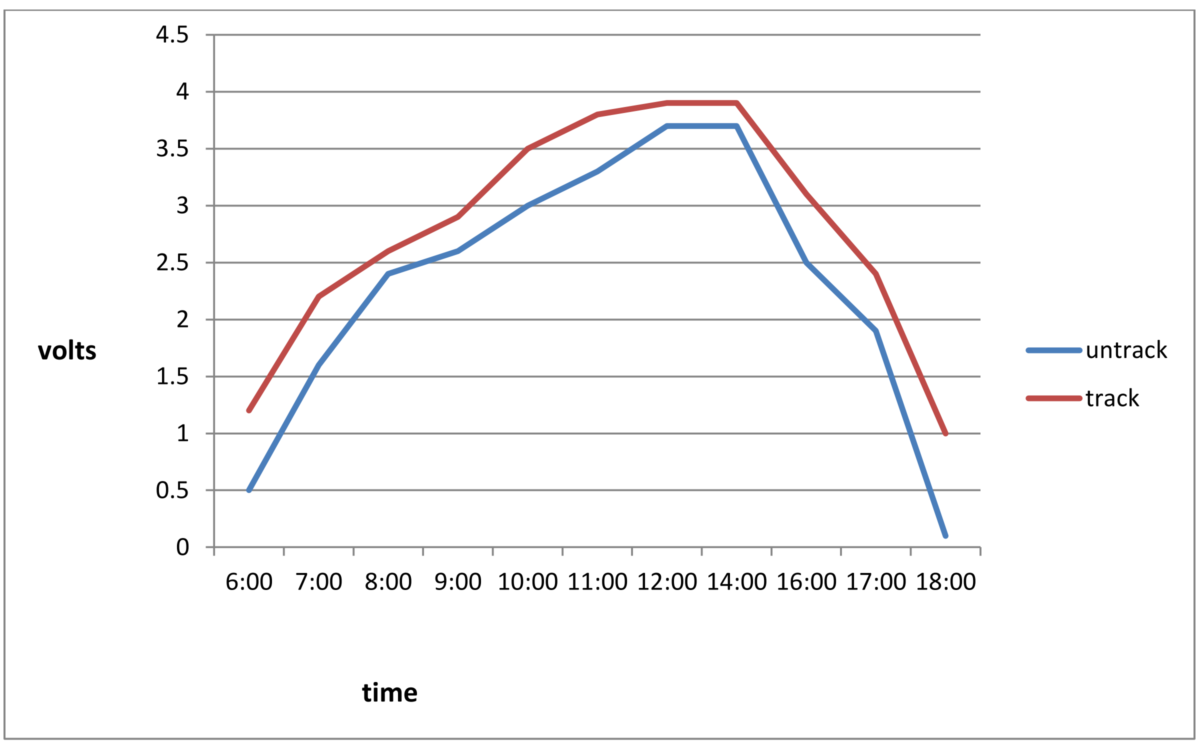



Figure : Graph of results obtained on 2nd day

Table

| TIME | AVERAGE UNTRACKED VOLTAGE | AVERAGE UNTRACKED POWER (mW) | AVERAGE TRACKED VOLTAGE | AVERAGE TRACKED POWER(mW) |
|---|---|---|---|---|
| 6:00 | 0.7 | 4.9 | 1.3 | 16.9 |
| 7:00 | 1.5 | 24.0 | 2.2 | 484 |
| 8:00 | 2.5 | 62.5 | 2.7 | 75.6 |
| 9:00 | 2.6 | 70.2 | 3.0 | 90.0 |
| 10:00 | 2.9 | 84.1 | 3.5 | 126.0 |
| 11:00 | 3.1 | 99.2 | 3.8 | 144.4 |
| 12:00 | 3.4 | 115.6 | 3.8 | 148.2 |
| 14:00 | 3.3 | 108.9 | 3.9 | 152.1 |
| 16:00 | 2.6 | 70.2 | 3.4 | 119.0 |
| 17:00 | 2.2 | 48.4 | 2.7 | 72.9 |
| 18:00 | 1.2 | 14.4 | 1.8 | 34.2 |

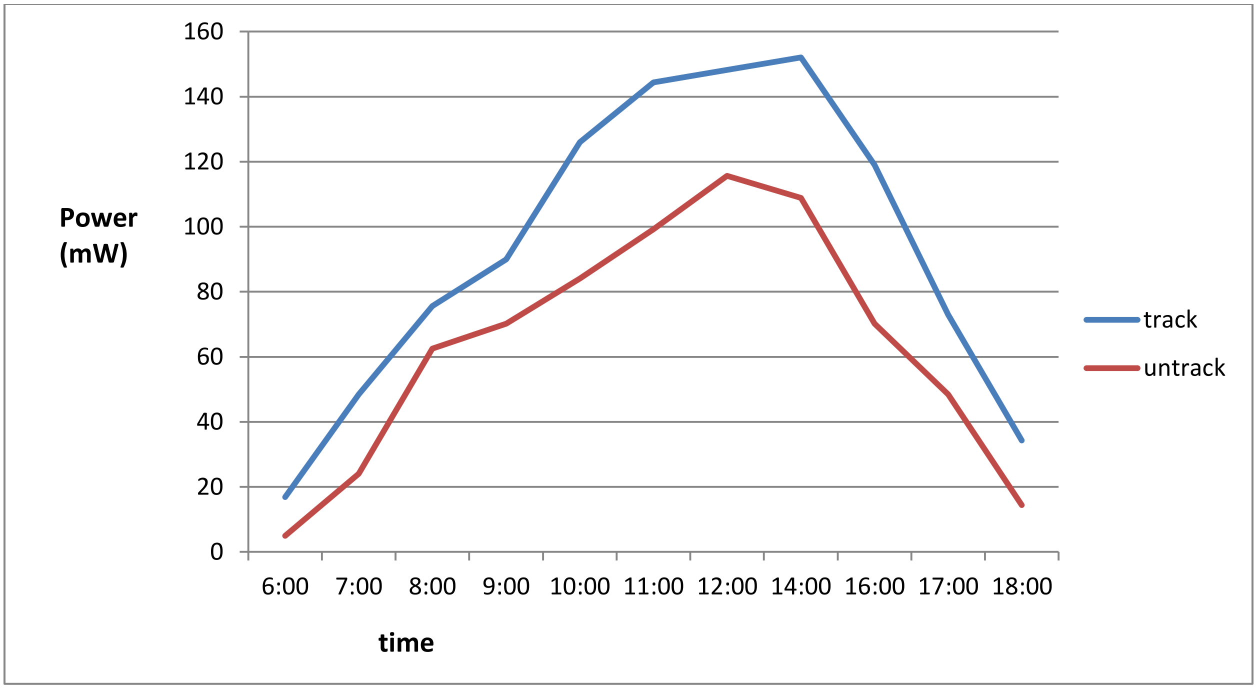



Figure 4.2: Graph of average power

Equation for tracked power:
$y = 0.0386x^4 - 1.3764x^3 + 10.744x^2 - 1.3759x + 12.389$

Equation for tracked power:
$y = 0.0291x^4 - 0.9633x^3 + 6.5077x^2 + 8.0138x - 7.9167$

Therefore the efficiency has been increased by 40%.

**Analysis**

From the curves, it can be seen that the maximum sunlight occurs at around midday, with maximum values obtained between 1200 hours and 1400 hours. In the morning and late evening, intensity of sunlight diminishes and the values obtained are less that those obtained during the day. After sunset, the tracking system is switched off to save energy. It is switched back on in the morning as at that time elevation angle becomes negative.

Days with the least cloud cover are the ones that have the most light intensity and therefore the output of the solar panel will be highest. For cloudy days, the values obtained for the tracking system and the fixed system do not differ too much because the intensity of light is more or less constant. Any differences are minimal. The tracking system is most efficient when it is sunny. It will be able to harness most of the solar power which will be converted into energy.

In terms of the power output of the solar panels for tracking and fixed systems, it is evident that the tracking system will have increased power output. This is because the power generated by solar panels is dependent on the intensity of light. The more the light intensity the more the power that will be generated by the solar panel.

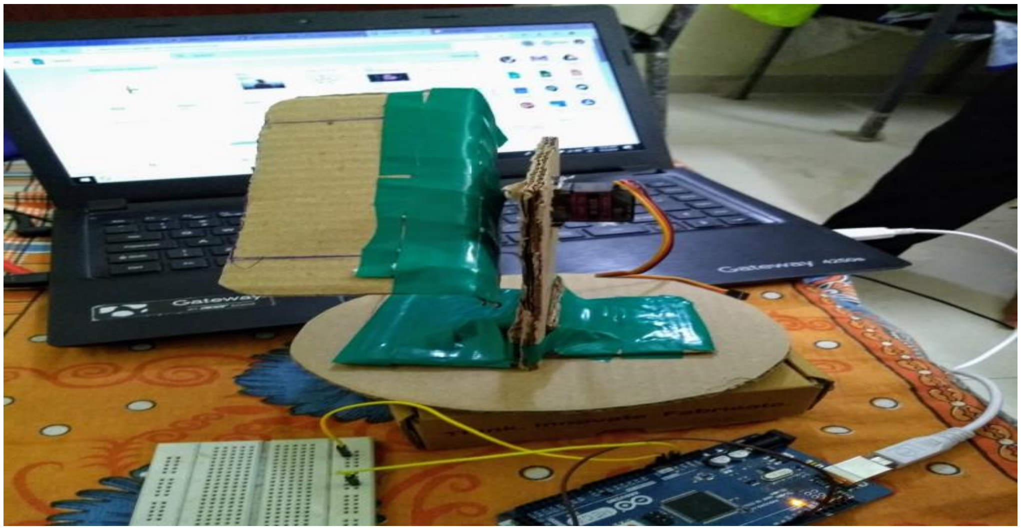
The increase in efficiency can be calculated. However, it is important to note that there will be moments when the increase in power output for the tracking system in comparison with the fixed system is minimal, notably on cloudy days. This is expected because there will not be much difference in the intensity of sunlight for the two systems. Similarly, on a very hot day at midday, both systems have almost the same output because the sun is perpendicularly above. As such, both systems receive almost the same amount of irradiation.

# CONCLUSION

## Conclusion

A solar panel that tracks the sun was designed and implemented. The required program was written that specified the various actions required for the project to work. As a result, tracking was achieved. The system designed was a dual axis tracker. While dual axis trackers are more efficient in tracking the sun, the additional circuitry and complexity was not required in this case. This is because Goa lies along the equator and therefore there are no significant changes in the apparent position of the sun during the various seasons. Dual trackers are most suitable in regions where there is a change in the position of the sun.

This project was implemented with minimum resources. The circuitry was kept simple, while ensuring efficiency is not affected.



# REFERENCES

[1] A.K. Saxena and V. Dutta, “A versatile microprocessor based controller for solar tracking,” in Proc. IEEE, 1990..

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[3] S. J. Hamilton, “Sun-tracking solar cell array system,” University of Queensland Department of Computer Science and Electrical Engineering, Bachelors Thesis, 1999.

[4] M. F. Khan and R. L. Ali, “Automatic sun tracking system,” 2005.

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[6] James Meeus, “Astronomical Algorithms”, 1991.

# APPENDIXES

## Appendix One: Code used in the microcontroller

```
#include<Servo.h>
#define DEG_TO_RAD 0.01745329
#define PI 3.141592654
#define TWOPI 6.28318531
Servo servo_test;
Servo servo_test2;
int lhour,lminute;
int zoneh=5,zonem=30;
int month=12,day=21,year=2019;
float Lon=72.87*DEG_TO_RAD,
Lat=19.08*DEG_TO_RAD;
float elev,azimuth;
void calc()
{
  int hour=lhour-zoneh,minute=lminute-
zonem,second=0,zone=0;
  float
T,JD_frac,L0,M,e,C,L_true,f,R,GrHrAngle,Obl,RA,Decl
,HrAngle;
  long JD_whole,JDx;
  // Changes may be required in for… loop to get
complete
  // daylight coverage in time zones farther west.
  JD_whole=JulianDate(year,month,day);
  JD_frac=(hour+minute/60.+second/3600.)/24.-.5;
  T=JD_whole-2451545;
  T=(T+JD_frac)/36525.;
  L0=DEG_TO_RAD*fmod(280.46645+36000.76983*T
,360);
  M=DEG_TO_RAD*fmod(357.5291+35999.0503*T,36
0);
  e=0.016708617-0.000042037*T;
  C=DEG_TO_RAD*((1.9146-
0.004847*T)*sin(M)+(0.019993-
0.000101*T)*sin(2*M)+0.00029*sin(3*M));
```

```
  f=M+C;
Obl=DEG_TO_RAD*(23+26/60.+21.448/3600.-
46.815/3600*T);
  JDx=JD_whole-2451545;
  GrHrAngle=280.46061837+(360*JDx)%360+.9856473
6629*JDx+360.98564736629*JD_frac;
  GrHrAngle=fmod(GrHrAngle,360.);
  L_true=fmod(C+L0,TWOPI);
  R=1.000001018*(1-e*e)/(1+e*cos(f));
  RA=atan2(sin(L_true)*cos(Obl),cos(L_true));
  Decl=asin(sin(Obl)*sin(L_true));
  HrAngle=DEG_TO_RAD*GrHrAngle+Lon-RA;
  elev=asin(sin(Lat)*sin(Decl)+cos(Lat)*(cos(Decl)*cos(
HrAngle)));
  // Azimuth measured eastward from north.
  azimuth=PI+atan2(sin(HrAngle),cos(HrAngle)*sin(Lat)
-tan(Decl)*cos(Lat));
}
void setup()
{
  servo_test.attach(9);
  servo_test2.attach(10);
  Serial.begin(9600);
  Serial.print("Longitude and latitude ");
  Serial.print(Lon/DEG_TO_RAD,3);
  Serial.print(" ");
  Serial.println(Lat/DEG_TO_RAD,3);
  Serial.println("year,month,day,local
hour,minute,second,elevation,azimuth");
}
int h=0;
int m=0;
void samay()
{
  delay(100);
  // delay(900000);//15 min delay
  m=m+15;
  if(m==60)
  {
    h++;
```

```
   m=0;
  }
  if(h==24)
  {
    h=0;

    delay(10000000);
  }
}

float elevd=0.0,
  azimuthd=0.0;
int motor_elev=0,
  motor_azi=0;
void loop()
{
  samay();
  lhour=h;
  lminute=m;
  calc();
  elevd=elev/DEG_TO_RAD;
  azimuthd=azimuth/DEG_TO_RAD;
  motor_elev=int(elevd);
  motor_azi=int(azimuthd);

  if(motor_elev<0)
  {
    servo_test.write(0);
    servo_test2.write(0);
  }
  if(motor_elev<180 && motor_elev>0)
  {
    print_data();
    if(motor_azi>170 && motor_azi<180)
    {
      motor_azi=170;

      Serial.print("\n\tChanged to 170");
    }
    else if(motor_azi>180)
```

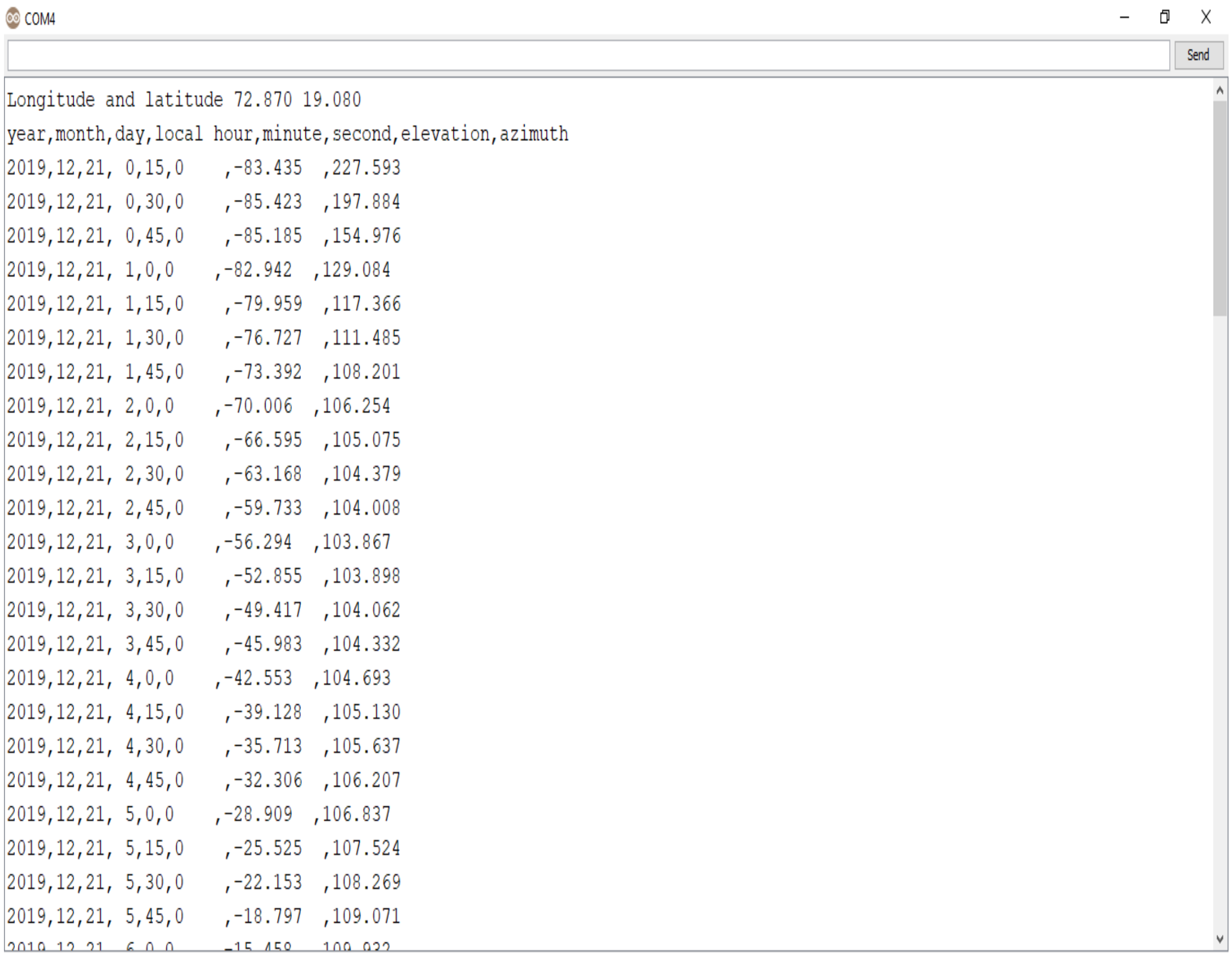
```
{
   Serial.print("\n\tChanged ");
   Serial.print(motor_azi);
   Serial.print(" ");
   Serial.print(motor_azi-180);
   Serial.print(" ");
   Serial.print(motor_elev);
   Serial.print(" ");
   Serial.print(180-motor_elev);
   Serial.print(" ");

   motor_azi=motor_azi-180;
   motor_elev=180-motor_elev;
  }

  motor_elev=motor_elev-20;
  if(motor_elev>=-20 && motor_elev<=150)
   servo_test.write(motor_elev);
  else
  {
   Serial.print("\n\nERROR: OUT OF RANGE
ELEV=");
   Serial.print(motor_elev);
   Serial.print("\n");
  }
  motor_azi=motor_azi-20;
  if(motor_azi>=-20 && motor_azi<=150)
   servo_test2.write(motor_azi);
  else
  {
   Serial.print("\n\nERROR: OUT OF RANGE AZI=");
   Serial.print(motor_azi);
   Serial.print("\n");
  }
  delay(500);
 }
}
void print_data()
{
 Serial.println();
```

```
  Serial.print(year);
  Serial.print(",");
  Serial.print(month);
  Serial.print(",");
  Serial.print(day);
  Serial.print(", ");
  Serial.print(lhour);
  Serial.print(",");
  Serial.print(lminute);
  Serial.print(",");
  Serial.print(0);
  Serial.print("    ,");
  Serial.print(elev/DEG_TO_RAD,3);
  Serial.print("  ,");
  Serial.print(azimuth/DEG_TO_RAD,3);
  Serial.print("   ,melev=");
  Serial.print(motor_elev);
  Serial.print("  ,mazi=");
  Serial.print(motor_azi);
}
long JulianDate(int year, int month, int day)
{
  long JD_whole;
  int A,B;
  if (month<=2)
  {
    year--;
    month+=12;
  }
  A=year/100;
  B=2-A+A/4;
  JD_whole=(long)(365.25*(year+4716))+(int)(30.6001*
(month+1))+day+B-1524;
  return JD_whole;
}
```

**Appendix : Screenshot of some of the readings obtained**



```
COM4
Send
Longitude and latitude 72.870 19.080
year,month,day,local hour,minute,second,elevation,azimuth
2019,12,21, 0,15,0    ,-83.435  ,227.593
2019,12,21, 0,30,0    ,-85.423  ,197.884
2019,12,21, 0,45,0    ,-85.185  ,154.976
2019,12,21, 1,0,0    ,-82.942  ,129.084
2019,12,21, 1,15,0    ,-79.959  ,117.366
2019,12,21, 1,30,0    ,-76.727  ,111.485
2019,12,21, 1,45,0    ,-73.392  ,108.201
2019,12,21, 2,0,0    ,-70.006  ,106.254
2019,12,21, 2,15,0    ,-66.595  ,105.075
2019,12,21, 2,30,0    ,-63.168  ,104.379
2019,12,21, 2,45,0    ,-59.733  ,104.008
2019,12,21, 3,0,0    ,-56.294  ,103.867
2019,12,21, 3,15,0    ,-52.855  ,103.898
2019,12,21, 3,30,0    ,-49.417  ,104.062
2019,12,21, 3,45,0    ,-45.983  ,104.332
2019,12,21, 4,0,0    ,-42.553  ,104.693
2019,12,21, 4,15,0    ,-39.128  ,105.130
2019,12,21, 4,30,0    ,-35.713  ,105.637
2019,12,21, 4,45,0    ,-32.306  ,106.207
2019,12,21, 5,0,0    ,-28.909  ,106.837
2019,12,21, 5,15,0    ,-25.525  ,107.524
2019,12,21, 5,30,0    ,-22.153  ,108.269
2019,12,21, 5,45,0    ,-18.797  ,109.071
```