DESIGN AND FABRICATION OF AN AUTOMATED DUAL AXIS SOLAR TRACKER

BY

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(MEE/13/1165)

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Department of Mechatronics Engineering

Faculty of Engineering

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DECLARATION

I hereby declare that the project work entitled Design and Fabrication of Automated Dual Axis Solar Tracker submitted to Mechatronics Engineering Department Oye Ekiti, is a record of an original work done by me under the supervision of Dr. Obaji M.O a lecturer in Mechatronics Engineering, and this project work is submitted in partial fulfillment for the requirements of the award of the degree of Bachelor of Engineering in Mechatronics Engineering. This project report has not been submitted to any other institution for the award of degree.

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APPROVAL

THIS PROJECT REPORT HAS BEEN APPROVED FOR ACCEPTANCE BY THE MECHATRONICS ENGINEERING DEPARTMENT, FEDERAL UNIVERSITY OYE-EKITI, EKITI STATE AND MEETS THE REGULATIONS GOVERNING THE AWARD OF BACHELOR OF ENGINEERING OF FUOYE.

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DEDICATION

I dedicate this project to God Almighty, the author and the finisher, the beginning and the end. He was by me all way. I also dedicate this project the family of Mr. and Mrs. Mathias Ugwuja.

List of Abbreviation

UNDP - United Nations Development Programme

EJ - Exajoules

PV - Photovoltaics

TW - Terawatts

HSAT - Horizontal Single Axis Trackers

HTSAT - Horizontal Single Axis Tracker with Tilted Modules

VSAT - Vertical Single Axis Trackers

TSAT - Tilted Single Axis Trackers

PSAT - Polar Aligned Single Axis Trackers

TTDAT - Tip-Tilt Dual Axis Trackers

AADAT - Azimuth-Altitude Dual Axis Trackers

CPU - Central processing unit

RAM - Random Access Memory

ROM - Read Only Memory

CMOS – Complementary Metal Oxide

RISC – Reduces Instruction Set Computer

MIPS – Millions Instructions Per Second

ADC – Analog-to-Digital Converter

AVCC – Analog Positive voltage,

AREF – Reference Voltage

GND – Ground

PDIP - Plastic Dual In-Line Package

GPS – Global Positioning System

AC – Alternating current

DC – Direct Current

CdS - Cadmium sulfide

GaAs - Gallium arsenide

LDR – Light Dependent Resistor

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ABSTRACT

This project is based on the need for alternate source of energy to reduce dependency on fossil fuels as source of energy. Existing projects and papers related to this project were either designed using weather reports to know the sun path for a particular period of time mostly throughout the year and the solar tracker is designed to follow this path throughout to improve the efficiency of the solar panel as the solar tracker is programmed to position itself where the sun should be based on the sun position according to the sun path diagram. This is limited in efficiency by cloud cover, seasons and times as it only takes into account the sun path. Some other projects have been carried out using two light sensors placed side by side and separated by an opaque material designed to move either vertically or horizontally and not both. This is also limited in efficiency by its motion in one axis. Based on the aforementioned this project is an improvement of the one axis motion solar tracker, it is an automated dual axis solar tracker designed using light sensors and a microcontroller which receive input from the light sensors, telling the microcontroller the intensity of sunlight in each quadrant positioned at the corners of the solar collector surface, the microcontroller manipulates this data according to the program it was designed to follow and turn therefore turns the solar panel to face the direction with the highest intensity. Series of tests were carried out for a period of one week and the result of the tests showed an increase in the output of the solar panels ranging from 25% to 30% when compared the output from a fixed solar collector installation.

CHAPTER ONE

1.1 INTRODUCTION

The sun is an important source of renewable energy that is anticipated to become the world's largest source of electricity by 2050, with solar photovoltaics and concentrated solar power contributing 16 and 11 percent to the global overall consumption, respectively.

The large magnitude of solar energy available makes it a highly appealing source of electricity. The United Nations Development Programme (UNDP) in its 2000 World Energy Assessment found that the annual potential of solar energy was 1,575–49,837 exajoules (EJ). This is several times larger than the total world energy consumption, which was 559.8 EJ in 2012.

In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits with the following global advantages; It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating global warming, and keep fossil fuel prices lower than otherwise.

The solar energy present near the surface of the planet differs from the amount solar energy that could be used by humans because factors such as geography, time variation, cloud cover, and also the land available to humans limit the amount of solar energy that we can acquire.

Geography affects solar energy potential because areas that are closer to the equator have a greater amount of solar radiation. However, the use of photovoltaics that can follow the position of the sun can significantly increase the solar energy potential in areas that are farther from the equator. Time variation affects the potential of solar energy because during the nighttime there is little solar radiation on the surface of the Earth for solar panels to absorb. This limits the amount of energy that solar panels can absorb in one day. Cloud cover can affect the potential of solar panels because clouds block incoming light from the sun and reduce the light available for solar cells.

The solar tracker is a device that keeps solar panels, parabolic troughs, fresnel reflectors, mirrors or lenses in an optimum position perpendicular to the solar radiation used to minimize the angle of incidence between the incoming sunlight and a photovoltaic panel. This increases the amount of energy produced from a fixed amount of installed power generation. The first tracker was introduced by Finster in 1962, a completely mechanical system, a year later; Saavedra presented a mechanism with an automatic electronic control, which was used to orient an Eppley pyrheliometer.

Solar trackers increase the amount of energy output per module at a cost of mechanical complexity and need for little maintenance. They sense the direction of the Sun through the use of sensors and tilt or rotate the system as needed for maximum exposure to solar energy throughout the day. Alternatively, fixed systems hold the solar modules stationary as the sun moves across the sky. For fixed systems the angles are set at a particular position. Most of these fixed systems are set on roof tops and poles above ground.

Solar trackers therefore increase the amount of energy produced from a fixed amount of installed power generating capacity. Two components of sunlight include the "direct beam" and the "diffuse sunlight", the direct beam carry about 90% of the solar energy while the diffuse beam carries the remainder of the solar energy. The diffuse beam resides in the blue sky on a clear day and increases on cloudy days proportionately. Since the amount of the solar energy largely dwells in the direct beam, to maximize solar panels it therefore requires that the solar panels be visible to the sun for as long as possible throughout the day. The fixed solar system are set to maximally collect so much energy during the noon time, thereby losing out on the solar energy that could be collected during the morning and early evening.

Solar collection devices can be classified as either passive or active depending on the way they capture, convert and distribute sunlight and enable solar energy to be harnessed at different capacities around the world, mostly depending on distance from the equator.

Active solar techniques use photovoltaics, concentrated solar power, solar thermal collectors, pumps, and fans to convert sunlight into useful outputs.

Passive trackers use a low boiling point compressed gas fluid that is driven to one side or the other (by solar heat creating gas pressure) to cause the tracker to move in response to an imbalance. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. As this is a non-precision orientation it is unsuitable for certain types of concentrating photovoltaic collectors but works fine for common photovoltaics (PV) panel types.

1.2 BACKGROUND STUDY

There is a great and growing need for renewable energy, in particular green energy. In years to come we will want a source of energy that will leave future generations with a sustainable energy source. A few good reasons to improve our green energy market are because not only do we want to have renewable energy for future generations, but we also want to have a sustainable energy market in future. Green energy has shown sustainable growth in past years, where oil has obviously not. In order to power our homes, businesses, and most aspects of our daily lives we require electricity, which requires massive power plants and spending billions of dollars to run them. But what if we could avoid all the resources that are used generating this energy, and replace them with green energy that could provide power directly to the consumers like businesses, the military or even private homes.

The sun is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air.

The Earth receives 174,000 terawatts (TW) of incoming solar radiation (insolation) at the upper atmosphere (Smil, 1991). Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses (Natural forcing of the climate system, 2007). The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined (Energy conversion of photosynthetic organism, 2008).

Being dependent on other countries, especially as one of the top consumer of fossil fuels, would have a negative impact on our country in the future; this is when these resources would have depleted far beyond sustaining a growing economy like ours.

On the economic side, considering solar technologies for investment in Nigeria would be shape this country to be more self-sustaining in future. On the environmental side, when it comes to burning these fossil fuels, it is known to produce large amounts of carbon dioxide.

Talking about the true benefits of solar power, some argue that it is not cost effective enough to be worthwhile. On the other hand reports have shown that costs have gone down for something like installments at home, and that the payoff for installing them would be even greater. The cost per watt has been estimated at $4.85/Watt, which is said to be a 50% increase since 5 years earlier. Although the cost for at home installation is said to cost around $5,000, the life of solar panels is said to be incredibly long, and only lose around half a percent of their maximum power each year. This makes them a great technology to invest in and continue to develop, so that in future they can produce even more power. Like this many countries have started to make this move toward green energy and energy independence; this is because they know it is the energy of the future.

The effectiveness of a solar tracker and PV technology in general, is directly correlated to the amount of sunlight that it is being exposed to; its power output is dependent on the amount of light that reaches the solar cell. PV technology is most efficient when it has a clear line of sight with a light source at a perfectly perpendicular angle, i.e. forming a 90 degree 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, *et al.* 2010).

Like most technology today, a large collection of solar tracking systems exist, ranging in price, 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. If key aspects of the application needs were to be neglected, the solar tracker could actual under-perform a well-positioned stationary PV panel.

Solar tracking obviously addresses these issues by actively following the sun in the sky. A standard PV panel will observe about 20-35% efficiency under ideal conditions, while solar tracking has been known to potentially double that with 50-60% efficiency under ideal conditions (Mousazadeh,et al 2009). Solar trackers can be categorized into the following: single or dual axis trackers. Single axis trackers singularly follow the Sun's East-West (or even North-South) movement, while the two-axis trackers follow the Sun's exact movement, no matter what direction. Tracking is usually carried out considering a single axis at a time, by using two photoresistors as sensors. These sensors are strategically placed next to one another and have a divider/tilted mount of some sort to create a voltage difference. This voltage difference is then used to determine which way the panel needs to turn to face the sun perpendicularly.

The first type of active solar collecting is single axis tracking. This will result in a greater power output than stationary PV panels, but is also more costly to design and implement. Single axis solar trackers can either have a horizontal or a vertical axis. The horizontal type is used in regions near the equator where the sun gets very high at noon, thus not having to adjust to vertical changes so much as horizontal changes.

The vertical type is used in high latitudes where the sun does not get very high, but summer days can be very long. Conversely, utilizing the fact that vertical movement does not have to be compensated for as much as horizontal movement.

The second type of active solar collecting is dual axis tracking. This results in a much greater power output than a stationary PV panel, but is also the most costly and most complicated to design. Dual axis solar trackers have both a horizontal and a vertical axis and thus they can track the sun's apparent motion virtually anywhere in the sky no matter where it is positioned on earth (Roth, *et al* 2005).

1.3 PROBLEM STATEMENT

The earth rotates about its axis through 360 degrees per day, but from the perspective of any fixed location the visible portion is 180 degrees during an average 1/2 day period (This occurs more in the dry and harmattan season; less, in the rainy season). A solar panel in a fixed orientation between the dawn and sunset extremes will see a motion of 75 degrees to either side, and thus will lose 75% of the energy in the morning and evening. Rotating the panels to the east and west can help recapture those losses. A tracker rotating in the east–west direction is known as a single-axis tracker.

The Sun also moves through 46 degrees north and south during a year. The same set of panels set at the midpoint between the two local extremes will thus see the Sun move 23 degrees on either side, causing losses of 8.3% A tracker that accounts for both the daily and seasonal motions is known as a dual-axis tracker. Generally speaking, the losses due to seasonal angle changes are complicated by changes in the length of the day, increasing collection in the summer in northern or southern latitudes. This biases collection toward the summer, so if the panels are tilted closer to the average summer angles, the total yearly losses are reduced compared to a system tilted at the spring/fall solstice angle (which is the same as the site's latitude).

Our common every day solar cells run at an efficiency of 18-20%, meaning they convert 18-20% of the solar energy they receive into electricity. This doesn't quite meet our power needs. To bring in enough power we either need to improve the efficiency of our panels or find ways of getting more from our current solar panels. Most of the panels we see as we go about our everyday activity is in a fixed position, most likely facing south at a 45 degree angle. This approach is extremely simple and meets the need of most small application; it isn't producing as much energy as would be sufficient enough for connection to the grid.

The single simplest way of getting more energy out of a solar panel is to have it track the sun. In fact solar panels that track the sun create around 30% more energy per day than a fixed panel.

1.4 SCOPE OF STUDY

i. The following aspects are to be considered in this study, these include
ii. The economics of manufacturing a dual axis solar tracker.
iii. Comparison between a dual axis solar tracker and a fixed solar tracker as commonly found in Nigeria.
iv. Power consumption per room depending on selected number of appliances compared to the efficiency of the solar tracker's output.
v. How a change in solar panel would affect the size of servo motors to be used in the design based on the general weight of the prototype.
vi. The economic relevance of the solar trackers to increase the efficiency of the solar panels there by creating an alternative power source that could be large enough to be connected to the grid.

1.5 SIGNIFICANCE OF STUDY

This project is significant in showing the relevance of solar tracking to the sun as a renewable energy source, its efficiency, how economic it can be in terms of cost and meeting and satisfying the power consumption demands of the costumers.

1.6 AIMS

To design and fabricate an automated dual axis solar tracker

1.7 OBJECTIVES

The objectives are:

i. To design the system using AutoCAD
ii. Fabricate a model of the system frame using Acrylic plastic
iii. Design the circuitry using microcontroller, 12kg.cm servo motor

CHAPTER TWO

2.1 LITERATURE REVIEW

Solar energy is radiant light and heat from the Sun. It is a very large, inexhaustible source of energy. Solar energy affords great potential for conversion into electric power, able to ensure an important part of the electrical energy needs of the planet. It is an important source of renewable energy and the large magnitude of solar energy available makes it a highly appealing source of electricity. In 2000, the United Nations Development Programme, UN Department of Economic and Social Affairs, and World Energy Council published an estimate of the potential solar energy that could be used by humans each year that took into account factors such as insolation, cloud cover, and the land that is usable by humans. The estimate found that solar energy has a global potential of 1,575–49,837 EJ per year (Energy and the challenge of sustainability, 2000) . This is several times larger than the total world energy consumption, which was 559.8 EJ in 2012 (2014 Key World Energy Statistics, 2015) (Energy and the challenge of sustainability, 2000).

In 2011, the International Energy Agency said that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhance sustainability, reduce pollution, lower the costs of mitigating global warming, and keep fossil fuel prices lower than otherwise. These advantages are global. The Earth receives 174,000 terawatts (TW) of incoming solar radiation (insolation) at the upper atmosphere (Smil, 1991). Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. Solar radiation is absorbed by the Earth's land surface, oceans which cover about 71% of the globe and atmosphere.

The potential solar energy that could be used by humans differs from the amount of solar energy present near the surface of the planet because factors such as geography, time variation, cloud cover, and the land available to humans limit the amount of solar energy that we can acquire.

In 2002, this was more energy in one hour than the world used in one year (Nature journal, 2008) (Powering the Planet: Chemical challenges in solar energy utilization, 2008). Photosynthesis captures approximately 3,000 EJ per year in biomass (Energy conversion of photosynthetic organism, 2008).The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined (Exergy flow chart, 2008).

Nigeria is a tropical country and as such receives sunlight every day. This sunlight carries soar energy which radiates Electromagnetic waves. Sunlight is composed of photon energy. Solar energy is converted into electricity by photoelectric effect. Pone of the numerous application of photoelectric effect is the solar cells.

Table 2.1 showing the relationship between frequency, wavelength and photon energy of electromagnetic waves

S/N	Electromagnetic Waves	Frequency	Wavelength	Photon Energy
1	Gamma rays	High frequency	Short wavelength	High photon energy
2	X-rays	↑	↓	↑
3	Ultra-violet rays	↑	↓	↑
4	Infrared rays	↑	↓	↑
5	Microwaves	↑	↓	↑
6	Radio waves	Low frequency	Long wavelength	Low photon energy

Photon energy $hf = \frac{hc}{\lambda}$

N photon energy = nhf

$$\text{Intensity of light} = I = \frac{no\ of\ photon\ energy\ per\ second}{A} = \frac{\frac{E_{total}}{t}}{Area} = \frac{nhf}{t} x \frac{1}{A}$$

Therefore more photons means higher intensity

Frequency of photon energy required for photoelectric energy effect to take place (to free electron from a metal surface) is called threshold frequency (f_o)

Incident photon energy $E = hf_o + 0$ where KE = 0

$$Threshold\ photon\ energy \equiv work\ function\ ie\ hf_0 = \phi$$

Work function (ϕ) is the minimum amount of energy required to release electron from the metal surface.

Example higher frequency like $f > f_o$

For ultra-violent light with high frequency $E_{UV} = hf_o + K.E$

$$hf_O = \phi + K.E$$

2.2 SOLAR CELLS

Solar cells are devices designed to absorb the sun's rays as a source of energy and converting it for generating electricity or heating. Each module is rated by its DC output power under standard test conditions (STC), and typically ranges from 100 to 365 watts. In this project the solar panels used are four (4) 12v 160mA 2W.

A solar panel works by allowing photons, or particles of light, to knock electrons free from atoms, generating a flow of electricity. Solar panels actually comprise many, smaller units called photovoltaic cells. (Photovoltaic simply means they convert sunlight into electricity.) Many cells linked together make up a solar panel. Metal conductive plates on the sides of the cell collect the electrons and transfer them to wires. At that point, the electrons can flow like any other source of electricity.

In most African countries the use of solar power is basically to augment the poor electrical power supply from the power grid where local towns cannot boast of power supply of at least 5 hours in every 24 hours. In Nigeria the most common application of solar panels is street lightning, supply of power to peripherals electrical components, charge inverter batteries, solar water heating systems in homes and hotels.

2.2.1 Efficiency of a Solar Cell

The efficiency is the parameter most commonly used to compare performance of one solar cell 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 and can be calculated from the formula

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

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

Where V_{oc} = the open-circuit voltage;

I_{sc} = the short-circuit current

FF = the fill factor

η = the efficiency.

2.3 Harnessing Solar Energy

Solar power is the conversion of sunlight into electricity, either directly using photovoltaics (PV), or indirectly using concentrated solar power (CSP). CSP systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. PV converts light into electric current using the photoelectric effect. Solar power is anticipated to become the world's largest source of electricity by 2050, with solar photovoltaics and concentrated solar power contributing 16 and 11 percent to the global overall consumption, respectively. (Here comes the sun Chile greenlight enormous 400-megawatts solar project, 2013)

The effective collection area of a flat-panel solar collector varies with the cosine of the misalignment of the panel with the Sun. Sunlight has two components, the "direct beam" that carries about 90% of the solar energy, and the "diffuse sunlight" that carries the remainder - the diffuse portion is the blue sky on a clear day and increases proportionately on cloudy days. As the majority of the energy is in the direct beam, maximizing collection requires the Sun to be visible to the panels as long as possible. The energy contributed by the direct beam drops off with the cosine of the angle between the incoming light and the panel. In addition, the reflectance (averaged across all polarizations) is approximately constant for angles of incidence up to around 50°, beyond which reflectance degrades rapidly (Nader, 2011).

2.3.1 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 (David, 2011).

2.3.2 Modes of Flat Panel Solar Energy Reception: Fixed and Tracking

2.3.2.1 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. Fixed collectors are a cheaper energy solution, but do not fully utilize the energy coming from the sun, due to the fact that the earth is rotating on a tilted axis and takes an elliptical path around the sun. 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 most common of the fixed panel system is the Roof-mounted solar power systems consist of solar modules held in place by racks or frames attached to roof-based mounting supports (Shingleton, 2012). Roof-based mounting supports include:

Pole mounts, which are attached directly to the roof structure and may use additional rails for attaching the module racking or frames.

Ballasted footing mounts, such as concrete or steel bases that use weight to secure the panel system in position and do not require through penetration. This mounting method allows for decommissioning or relocation of solar panel systems with no adverse effect on the roof structure.

2.3.2.2 Tracking Collectors

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 afternoons (David, 2011) 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).

Solar trackers increase the amount of energy produced per solar at a cost of mechanical complexity and need for maintenance. They sense the direction of the Sun and tilt or rotate the modules as needed for maximum exposure to the light. Alternatively, fixed racks hold modules stationary as the sun moves across the sky. The fixed rack sets the angle at which the module is held. Tilt angles equivalent to an installation's latitude are common. Most of these fixed racks are set on poles above ground (Mousazadeh, 2009) (optimum Tilt of Solar Panel, 2014).Panels that face West or East may provide slightly lower energy, but evens out the supply, and may provide more power during peak demand (energy/solarpower, 2014).

Thus the primary benefit of a tracking system is to collect solar energy for the longest period of the day, and with the most accurate alignment as the Sun's position shifts with the seasons.

In addition, the greater the level of concentration employed, the more important accurate tracking becomes, because the proportion of energy derived from direct radiation is higher, and the region where that concentrated energy is focused becomes smaller.

Geography affects solar energy potential because areas that are closer to the equator have a greater amount of solar radiation. However, the use of photovoltaics that can follow the position of the sun can significantly increase the solar energy potential in areas that are farther from the equator. Time variation affects the potential of solar energy because during the nighttime there is little solar radiation on the surface of the Earth for solar panels to absorb (Energy and the challenge of sustainability, 2000).

This limits the amount of energy that solar panels can absorb in one day. Cloud cover can affect the potential of solar panels because clouds block incoming light from the sun and reduce the light available for solar cells.

2.3.3 Types of Tracking: Single Axis and Dual Axis

Solar trackers are grouped under two basic categories: the single axis trackers and the dual axis trackers. The single tracker rotates east to west or north to south following the sun's movement, and the dual trackers include vertical and horizontal movements i.e. they can incline or tilt to account for winter and summer sun angles. Single Axis Trackers are trackers with only one degree through which they rotate or use as axis of rotation. This axis is usually aligned following the North meridian. They rotate azimuthally from east to west following the path of a sun. Double or Dual Axis Tracker have two different degrees through which they use as axis of rotation. The dual axis are usually at a normal of each rotate both east to west (zenithal) and north to south (azimuthally)

2.3.3.1 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) (David, 2011).

2.3.3.2 Dual Axis Trackers

Dual axis trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to one another. The axis that is fixed with respect to the ground can be considered a primary axis. The axis that is referenced to the primary axis can be considered a secondary axis. 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). The orientation of the module with respect to NOTE the tracker axis is important when modeling performance. Dual axis trackers typically have modules oriented parallel to the secondary axis of rotation. Dual axis trackers allow for optimum solar energy levels due to their ability to follow the Sun vertically and horizontally. No matter where the Sun is in the sky, dual axis trackers are able to angle themselves to be in direct contact with the Sun.

2.3.4 Types of Solar Tracker Drives: Active and Passive Solar Tracker Drives

Solar technologies are characterized as either passive or active depending on the way they capture, convert and distribute sunlight and enable solar energy to be harnessed at different levels around the world, mostly depending on distance from the equator.

2.3.4.1 Active tracker

Active trackers use motors and gear trains to direct the tracker as commanded by a controller responding to the solar direction. In order to control and manage the movement of these massive structures special slewing drives are designed and rigorously tested. The technologies used to direct the tracker are constantly evolving and recent developments at Google and Eternegy have included the use of wire-ropes and winches to replace some of the more costly and more fragile components.

Counter rotating slewing drives sandwiching a fixed angle support can be applied to create a "multi-axis" tracking method which eliminates rotation relative to longitudinal alignment. This method if placed on a column or pillar will generate more electricity than fixed PV and its PV array will never rotate into a parking lot drive lane. It will also allow for maximum solar generation in virtually any parking lot lane/row orientation, including circular or curvilinear.

Active solar techniques use photovoltaics, concentrated solar power, solar thermal collectors, pumps, and fans to convert sunlight into useful outputs. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand side technologies (projects, 2014).

Active two-axis trackers are also used to orient heliostats - movable mirrors that reflect sunlight toward the absorber of a central power station. As each mirror in a large field will have an individual orientation these are controlled programmatically through a central computer system, which also allows the system to be shut down when necessary.

Light-sensing trackers typically have two or more photosensors, such as photodiodes, configured differentially so that they output a null when receiving the same light flux. Mechanically, they should be omnidirectional (i.e. flat) and are aimed 90 degrees apart. This will cause the steepest part of their cosine transfer functions to balance at the steepest part, which translates into maximum sensitivity. For more information about controllers see active daylighting.

Since the motors consume energy, one wants to use them only as necessary. So instead of a continuous motion, the heliostat is moved in discrete steps. Also, if the light is below some threshold there would not be enough power generated to warrant reorientation. This is also true when there is not enough difference in light level from one direction to another, such as when clouds are passing overhead. Consideration must be made to keep the tracker from wasting energy during cloudy periods.

2.3.4.2 Passive tracker

Passive tracker head in Spring/Summer tilt position with panels on light blue rack pivoted to morning position against stop. Dark blue objects are hydraulic dampers.

The most common Passive trackers use a low boiling point compressed gas fluid that is driven to one side or the other (by solar heat creating gas pressure) to cause the tracker to move in response to an imbalance. As this is a non-precision orientation it is unsuitable for certain types of concentrating photovoltaic collectors but works fine for common PV panel types. These will have viscous dampers to prevent excessive motion in response to wind gusts. Shader/reflectors are used to reflect early morning sunlight to "wake up" the panel and tilt it toward the Sun, which can take nearly an hour. The time to do this can be greatly reduced by adding a self-releasing tiedown that positions the panel slightly past the zenith (so that the fluid does not have to overcome gravity) and using the tiedown in the evening. (A slack-pulling spring will prevent release in windy overnight conditions.)

A newly emerging type of passive tracker for photovoltaic solar panels uses a hologram behind stripes of photovoltaic cells so that sunlight passes through the transparent part of the module and reflects on the hologram. This allows sunlight to hit the cell from behind, thereby increasing the module's efficiency. Also, the panel does not have to move since the hologram always reflects sunlight from the correct angle towards the cells.

2.4 Zenith Angle, Azimuth Angle and Elevation Angle

The Zenith angle is the angle between the direction of the sun (direction of interest) and the zenith (straight up or directly overhead).

- The Azimuth angle is measured clockwise from true north to the point on the horizon directly below the object.
- The suns elevation or altitude is the angle from the horizontal plane and the Suns central ray or just the compliment of the Zenith angle (90° - Zenith angle).

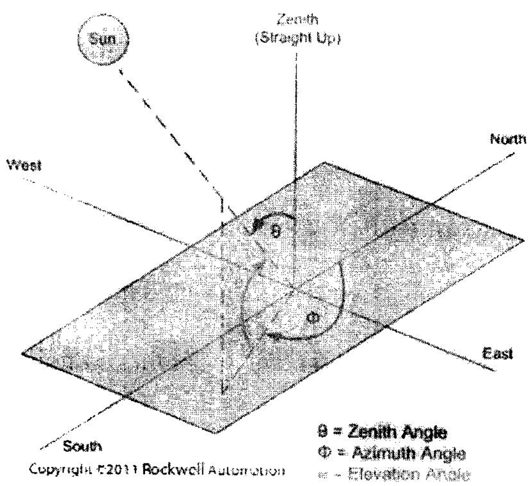


Figure 2.1 Zenith Angle, Azimuth Angle and Elevation Angle

2.5 Sun Path Diagram For Nigeria

Sun path diagram (also known as "solar path diagram", "sun chart" or "solar chart") is a visualization of the sun's path through the sky. This path is formed by plotting azimuth (left-right) and elevation (up-down) angles of the sun in a given day to a diagram.

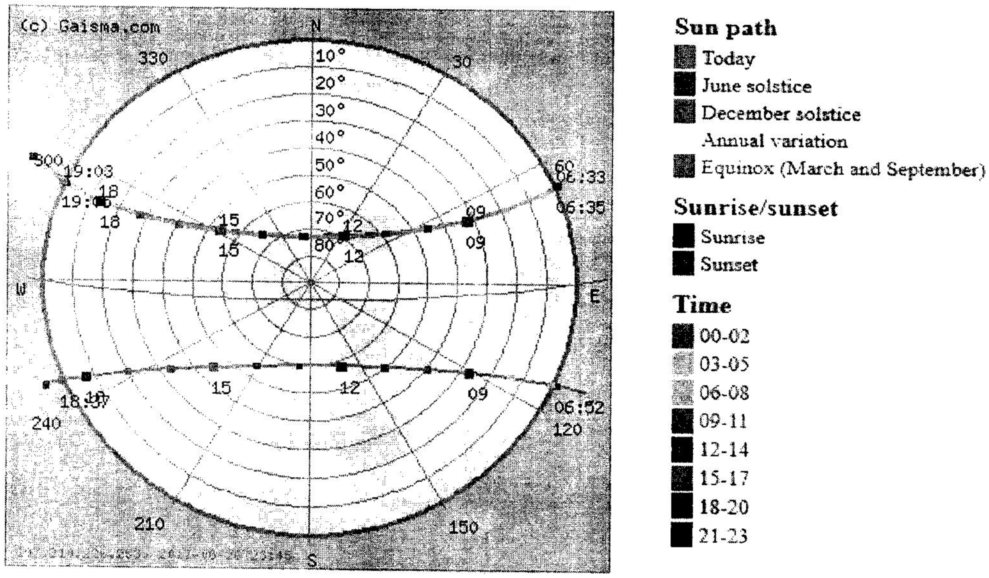


Figure 2.2 Sun path diagram taken for Lagos Nigeria

CHAPTER THREE

3.1 METHODOLOGY

A solar tracker should be designed to meet certain requirements both technical and environmentally to efficiently and cost effectively collect solar energy. These requirements include:

i. Low power consumption
ii. Efficient operation in adapting to changing environmental conditions
iii. Moving digitally with technology, the solar tracker system should programmable and controlled digitally
iv. As mentioned earlier that solar power is projected to become the world's most reliable power source by 2050 in the meantime to compete with available power sources it should be affordable, cost effective and reliable. In other to meet these it is designed with the most basic programmable software, sensors and actuators

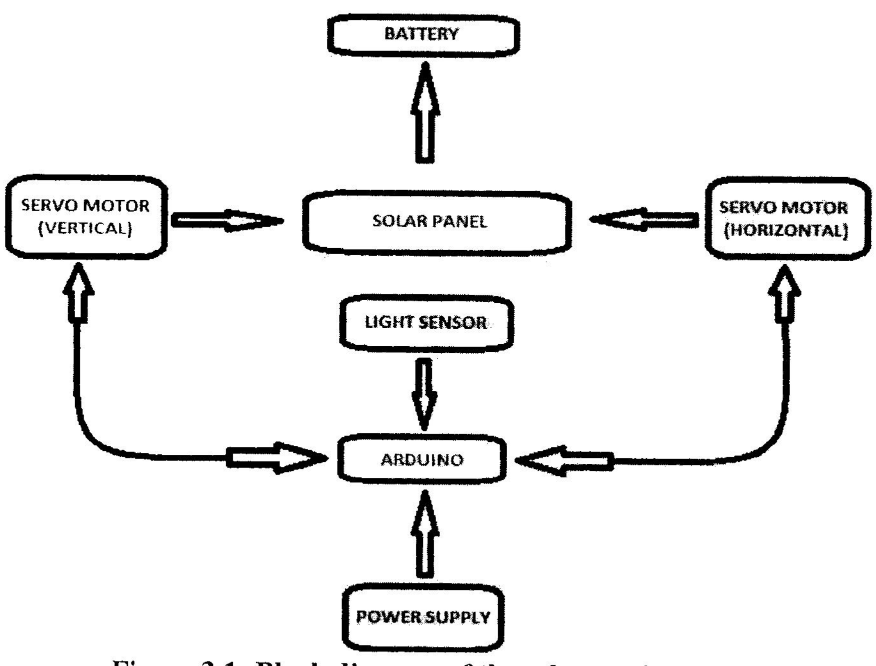


Figure 3.1: Block diagram of the solar tracker system

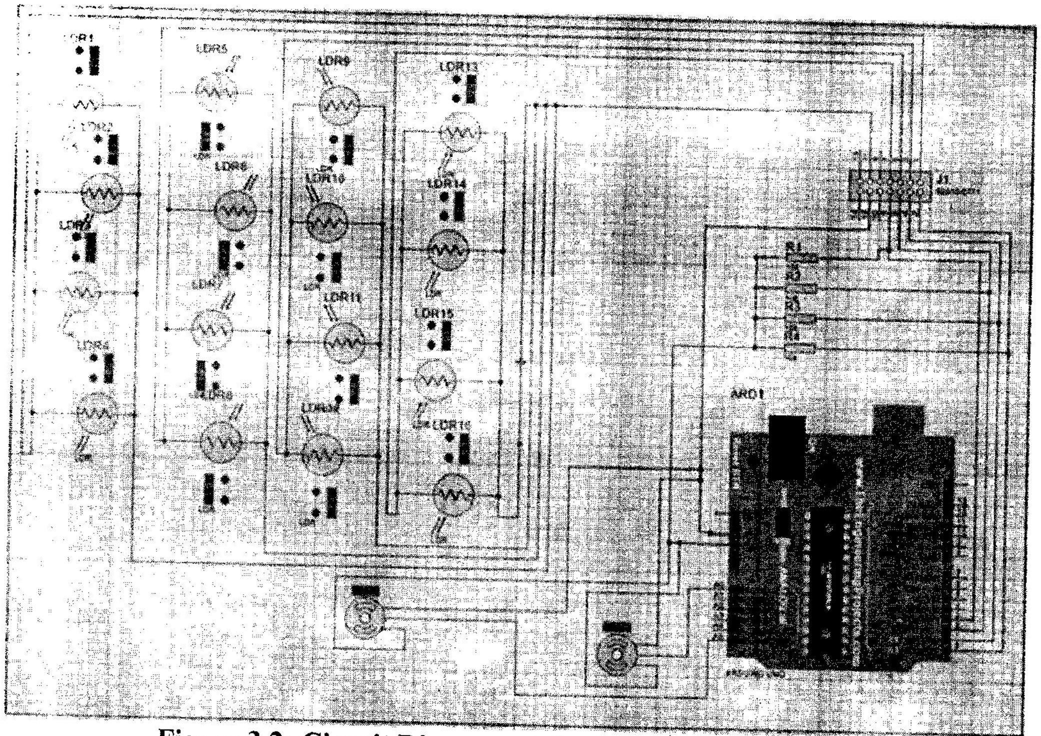
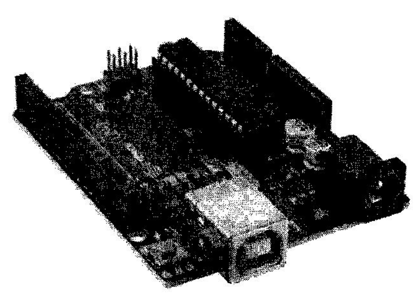
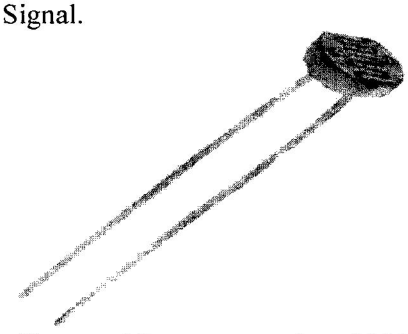
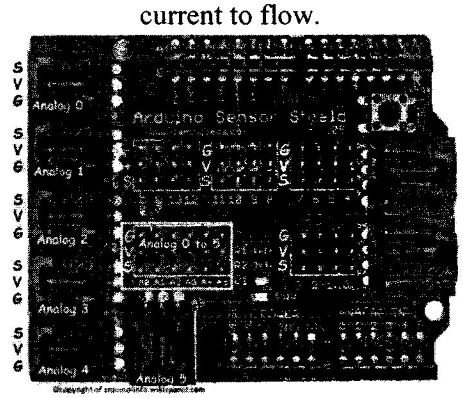


Figure 3.2: Circuit Diagram of the Solar tracking system

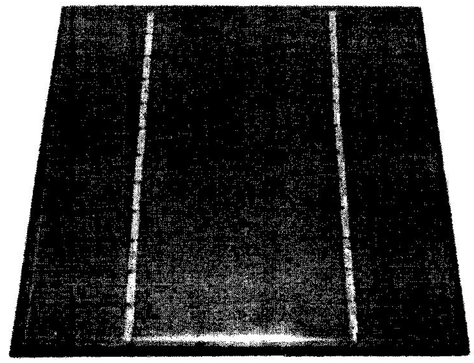
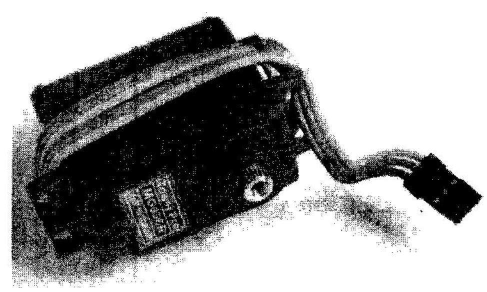
With this requirements and design specification in mind, the following components are employed in the design.

Table 3.1 showing the list and description of components used and function in the system

S/N	COMPONENT USED	QTY	MODEL/ VERSION	DESCRIPTION
1	Arduino	1	V4	ATmega328P-PU 28-lead, 0.300" Wide, 28-pin Plastic Dual Inline Package (PDIP)  (Source: Atmel-42735B, 2016)
2	Sensor Shield	1	v5	The sensor shield is mounted on the Arduino board, the servo motors are connected to ports A0 and A5

<table>
<tr><td></td><td></td><td></td><td></td><td>through its three pins, which are connected to Ground, Vcc + 5 V and Signal.

(Source:Aliexpress, retrieved 2017)</td></tr>
<tr><td>3</td><td>Acrylic Plastic</td><td>100 cm x 100cm x 0.5 cm</td><td></td><td>The structure of the dual axis solar tracker is a model and therefore designed using an acrylic transparent.</td></tr>
<tr><td>4</td><td>Light Sensors</td><td>20 Pcs</td><td>Photoresistor or Light Dependent resistor</td><td>The photoresistor is a device that reacts to changes in light falling on the surface or the resistor. An increase in the light intensity decreases the resistance of the photoresistor thereby allowing current to flow.


(Source:wikispaces, retrieved 2017)</td></tr>
<tr><td>5</td><td>Resistors</td><td>4 pcs</td><td>10kΩ</td><td>The resistor in this circuit acts to increase the sensitivity of the circuit to sunlight. The resistors are arranged as a voltage divider where the voltage across the four phootoresistors.</td></tr>
<tr><td>6</td><td>Terminal Block:</td><td>2 Pcs</td><td>4 Port terminal Block</td><td>Terminal block used in the design of this system is to neatly connect the jumper cables together to avoid short circuit.</td></tr>
<tr><td>7</td><td>Jumper Cables</td><td>40 Pcs</td><td>Male-Male, Female-</td><td>This cables where used to connect system components together</td></tr>
</table>

			Female, Male-Female	
8	Solar Panels	1 Set	12v 160mA 2w. dimension 13.6 cm x 11.0 cm	 (Source: Aliexpress, retrieved 2017)
9	Servo Motors of	4 Pcs	MG996R	Weight: 69 g, Dimension: 40 mm x 19 mm x 43 mm approximately, Stall torque: $13\ kg \cdot cm\ (4.8V), 15kgcm\ (6V)$ The servo motors used in this project are of high torque to be able to move the structure based on the data generated by the microcontroller from the sensory inputs from the light sensor. Two servos were used in this project to keep the solar at all times constantly incident to the incoming solar energy  (Source: Aliexpress, retrieved 2017)
10	Digital voltage Meter	1		The device is used in this project to constantly take reading of the voltage generated by the solar panels
11	Arduino Battery connector	20 Pcs		Battery connector used to power the system
12	Vero Board	1		Used to connect the light sensor components
13	Battery	1	9v	The power for the system
14	Bolts and Nuts cut to	1	M10	

	size of 2 cm			
16	Set of Screw Drivers	2	Sets of flat and star screw drivers	Used to drive the screws into the structure of the solar tracker to hold the structure in position
17	Improvised Cable Warp	1		Used to dress the cables
18	Set of File	1	Flat file, double cut	To create a smooth finish of the surface
19	Hack saw	1		Used to cut the acrylic plastics to size

3.1.1 Light Dependent Resistor Configuration

In this project since the direction of motion of the solar tracker needed to fully maximize the efficiency of the solar panels and also increasingly maximize solar irradiation on the solar panels, four light dependent resistors were used in a quadrant each covering an angle of 90°.

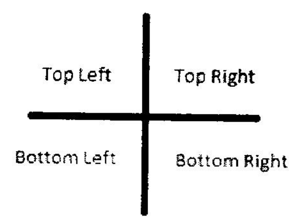


Figure 3.3 Showing LDR configuration

3.2 SOLAR PANELS

Solar panels are devices designed to absorb the sun's rays as a source of energy and converting it for generating electricity or heating. Each module is rated by its DC output power under standard test conditions (STC), and typically ranges from 100 to 365 watts. In this project the solar panels used are four (4) 12v 160mA 2W

3.3 Solar Tracker System Structure

This is the structure which holds the solar panels to move the solar panel in the direction of the sun; the frame consists of movable and fixed parts so designed for the system, to function effectively. To do this certain requirements must be met by the tracking system structure

- The torque of the motors used must be able to carry the movable parts
- It must be able to withstand environmental factors such as heat from the sun, rain and most notable of all wind force and
- The material used must be able to carry the solar panel

3.3.1 Torque

The servo motor used to drive the movable part of this model solar tracker system has the following specification

i. Weight: 69 g
ii. Dimension: 40 mm x 19 mm x 43 mm approximately
iii. Stall torque: 13 $kg \cdot cm$ (4.8V), 15$kg \cdot cm$ (6V)
iv. Operating speed: 0.17 sec/60 degrees (4.7V no load), 0.13sec/degrees (6V no load)
v. Operating voltage: 4.8 V – 7.2V

The choice of servo motor was based on the calculation as follows to determine the required torque necessary to support the load:

$$Torque = F \cdot r$$

$$Torque = (m \cdot g \cdot c \cdot f)r$$

Where

m= Mass

g = Acceleration due to gravity

c = Coefficient of friction between meshing gears (steel - steel) [5]

f = Coefficient of friction between meshing gear and plastic control wheel (steel - polypropylene) (Tables of Coefficient and friction, 2017)

$$m = 1.5\,kg, \quad g = 9.8m/s, \quad c = 0.78, \quad f = 0.35, \quad r = 2cm$$

$$Torque = 1.5\,x\,9.8\,x\,0.78\,x\,0.35\,x\,2 = 8.06kgcm$$

3.3.2 Wind force

Assuming the wind force is acting perpendicular to the maximum area of the solar tracker system structural frame work. Wind Force is defined as a product of the surface area, wind pressure and drag coefficient and is given by the formula below (Andreas, 2002) [3]:

$$F = A * P * C_d$$

Where

A = surface area

P = wind pressure and

C_d = drag coefficient

Area = $0.3m * 0.29m * 0.02m = 0.00174m^2$

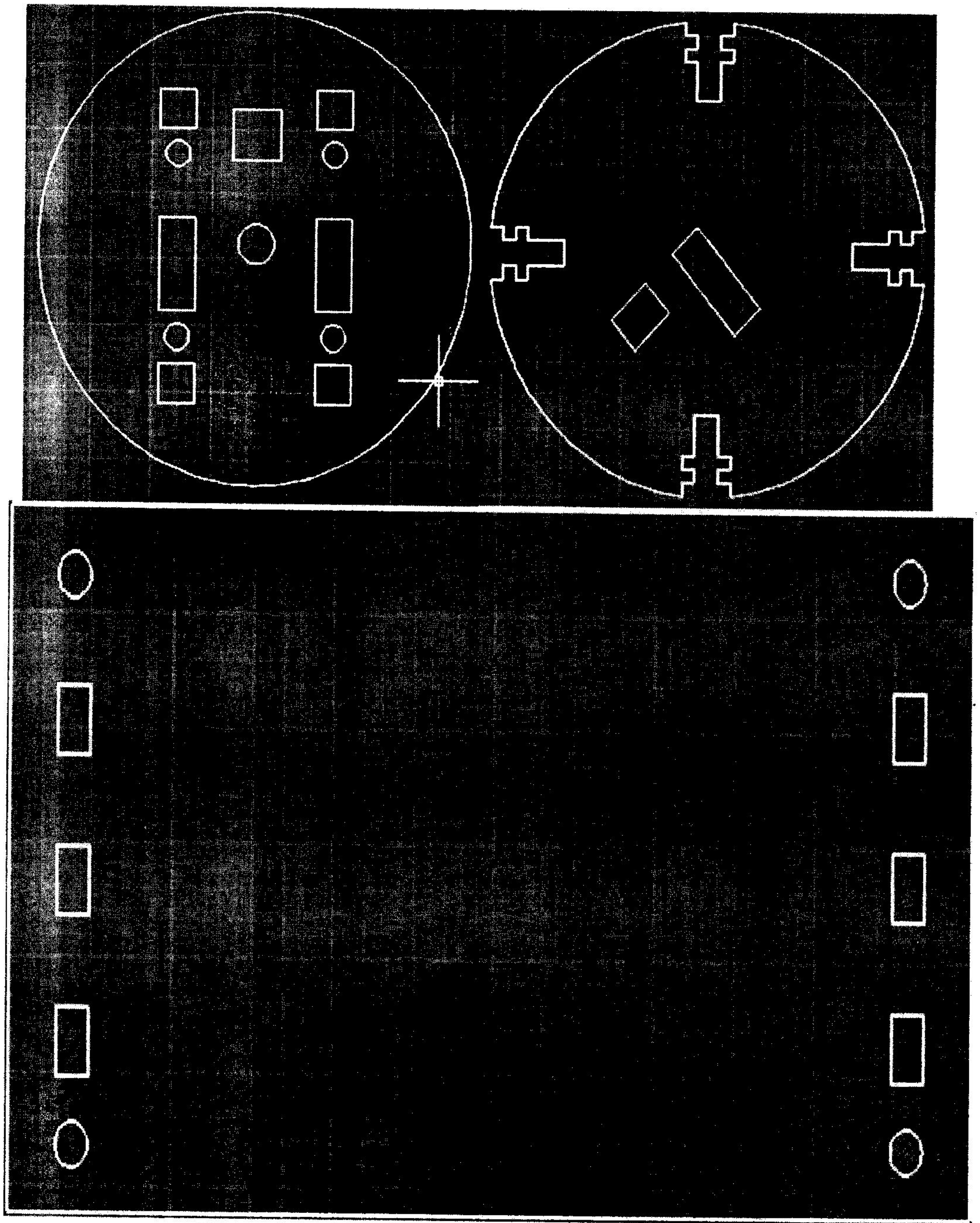
Wind pressure = $0.613V^2\ N/m^2$

Where 0.613 is the result of calculation based on typical values of air density and gravitational acceleration and average wind speed in Nigeria is 2.947 m/s (ogbonnaya et al. 2007).

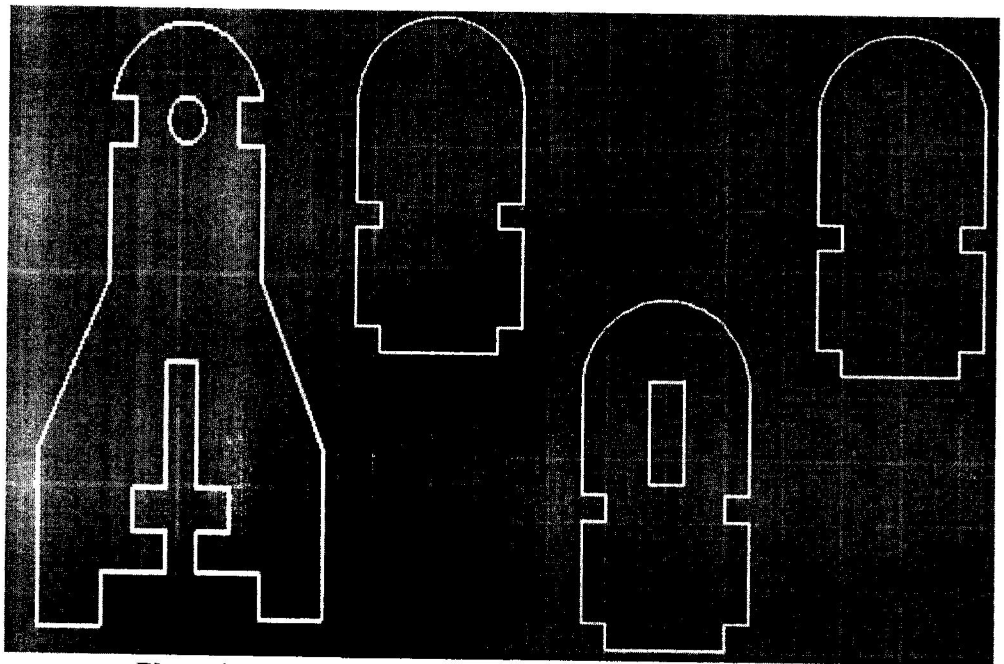
Therefore $0.613\,x\,2.947 = 1.80\ N/m^2$

Drag coefficient for short flat plates = 1.4

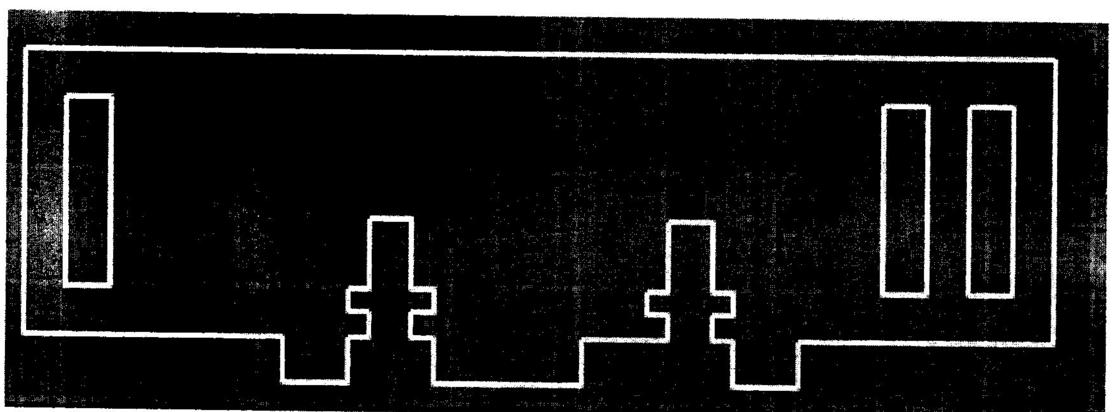
Therefore wind load force = $0.00174\,x\,1.80\,x\,1.4 = 0.0044N$



Plates 3.1: AutoCAD drawing of project design

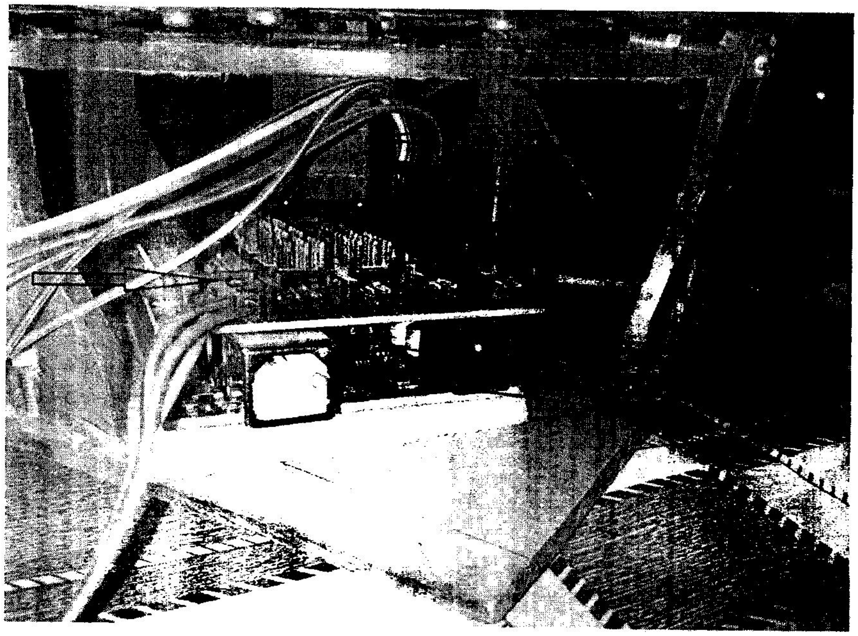


Plates 3.2: Showing AutoCAD Drawing of project design



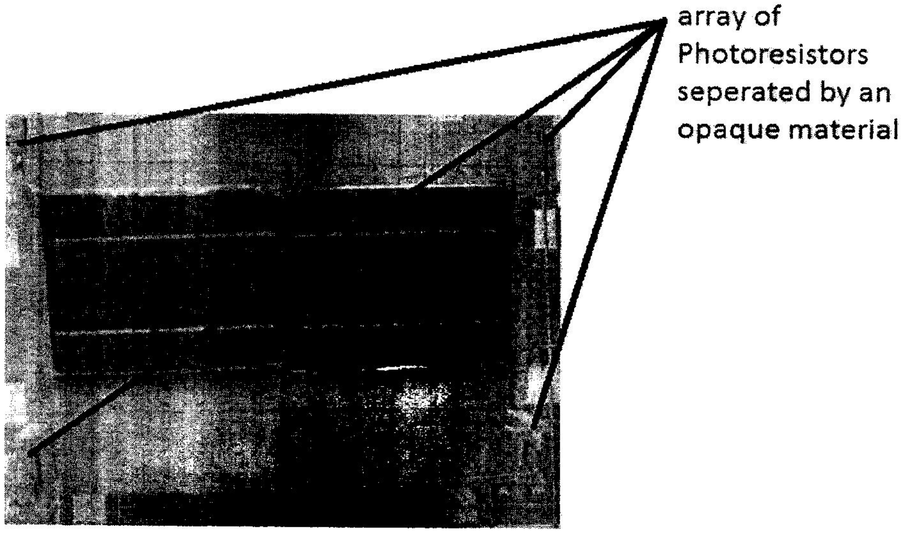
Plates 3.3: Showing AutoCAD Drawing of project design

These designs put together produced the system below:



Plates 3.4: showing the metal gear servo labelled (A), the microcontroller (B), sensor shield (C)

Plates 3.5: showing the digital Voltmeter labelled D and the array of photoresistors used per quadrant



Plates 3.6: showing an array of light sensors connected in parallel to increase the sensing area

The above configuration was then used in experiment, testing the difference between the fixed solar collector and tracking solar collector, from which thee values plotted in chapter four (4) where gotten.

CHAPTER FOUR

4.1 RESULTS AND DISCUSSION

The results obtained in the table below were gotten from monitoring the power generated from the solar tracking system and the fixed tracking system from the 23rd of October 2017 to the 27th of October 2017.

Table 4.1 Results obtained from fixed and tracking system

S/N	Date	Days	FIXED (In Watts)	TRACKING (In Watts)
1	23rd	Monday	1.27	3.24
2	24th	Tuesday	1.34	3.42
3	25th	Wednesday	1.39	3.53
4	26th	Thursday	1.57	3.97
5	27th	Friday	1.76	4.18

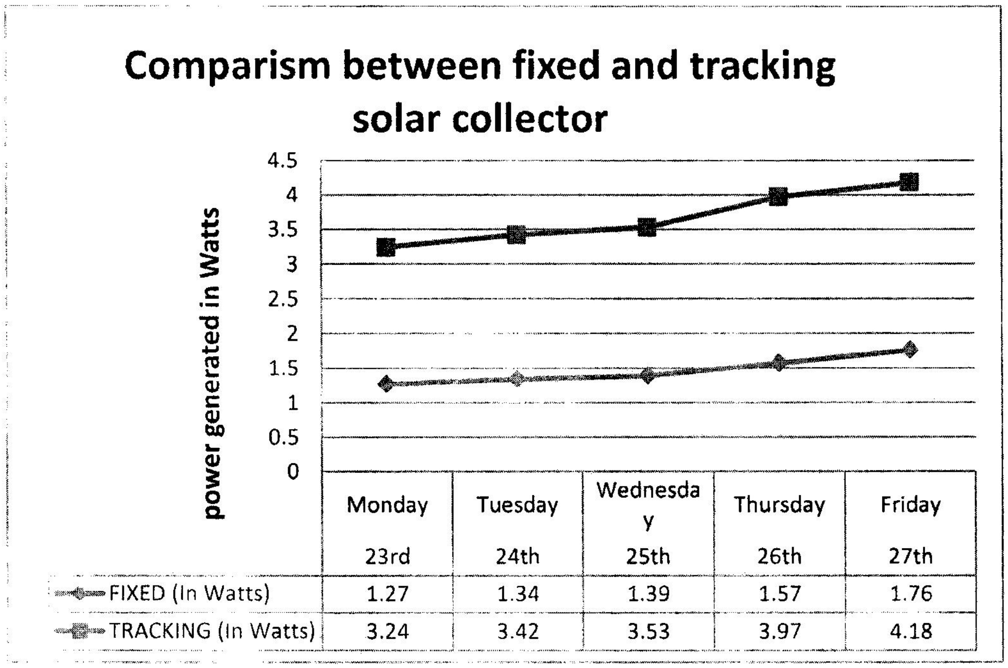


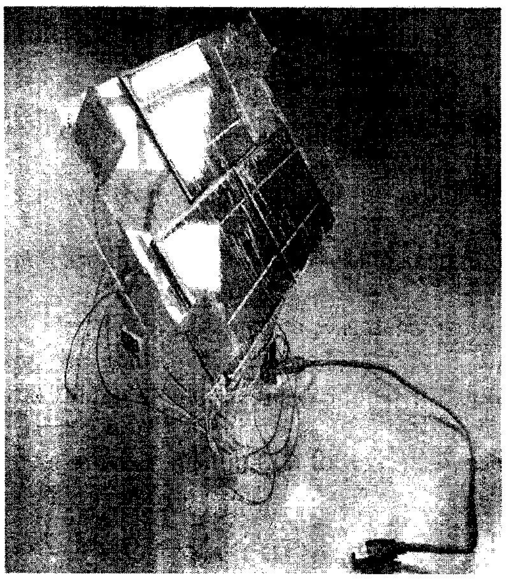
Figure 4.1 showing comparison between power generated by tracking and fixed solar receptors

During the one week of evaluation of the power generated by the two systems being the tracking solar system and the fixed solar system the power produced by the solar tracking system and the fixed solar panel either increased or decreased depending on the solar irradiance. It is observed on each day there was about approximately 25% to 30% more power was generated from the automated solar tracking system than that produced by the fixed solar panel.

Looking at the plotted graph from the tabulated values a positively linear relationship is noted from the plotted graph. Under the same sunlight, the results show a clear increase in power by the tracking system compared to the fixed system.

The model in this project was designed to show that at a low cost an automated solar tracking system can be designed for domestic use and for small scale industries to meet power consumption for everyday use.

4.2 THE FINAL DESIGN



Plates 4.1: After the testing phase (Side view) **Plates 4.2: Dorsal view**

CHAPTER FIVE

5.1 CONCLUSION

In conclusion this project demonstrated a system with the capability to improve the efficiency of a solar panel. The system was designed using a microcontroller of the type Arduino Uno (Atmega 328p), light sensors of the type Light dependent resistor and a 12g servo motor. The light sensor is used in a voltage divider circuit to measure difference in light intensity from four (4) quadrants. The microcontroller uses this data to decide the direction which to rotate the system to keep the solar panel always facing the direction of sunlight. It is of a low maintenance and very cost effective that it could be used in small scale industries and also for home applications. This project is a model that could be readily used to greatly improve the efficiency of a solar panel attached to it.

5.2 RECOMMENDATION

i. To increase the efficiency of the solar tracker a more accurate light sensor can be applied in the design of the solar tracker.

ii. For a higher capacity solar panels a higher torque servo motor should be used

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Appendix I

The Arduino Program for this project

```
#include <Servo.h>

Servo horizontal;

int servoh = 180;

int servohLimitHigh = 180;

int servohLimitLow = 65;

Servo vertical;

int servov = 45:

int servovLimitHigh = 80;

int servovLimitLow = 15;

int ldrlt = 1;

int ldrrt = 0;

int ldrlb = 3;

int ldrrb = 2;

void setup()

{

 Serial.begin(9600);

 horizontal.attach(A5);

 vertical.attach(A0);

 horizontal.write(180);

 vertical.write(65);

 delay(3000);

}

void loop()

{

 int lt = analogRead(ldrlt);
```

```
int rt = analogRead(ldrrt);
int lb = analogRead(ldrlb);
int rb = analogRead(ldrrb);
int dtime = 10;
int tol = 50;
int avt = (lt + rt) / 2;
int avb = (lb + rb) / 2;
int avl = (lt + lb) / 2;
int avr = (rt + rb) / 2;
int dvert = avt - avb;
int dhoriz = avl - avr;
Serial.print(avt);
Serial.print(" ");
Serial.print(avb);
Serial.print(" ");
Serial.print(avl);
Serial.print(" ");
Serial.print(avr);
Serial.print(" ");
Serial.print(dtime);
Serial.print(" ");
Serial.print(tol);
Serial.print(" ");
if (-1*tol > dvert || dvert > tol)
{
 if (avt > avb)
 {
```

```
   servov = ++servov;
   if (servov > servovLimitHigh)
   {
    servov = servovLimitHigh;
   }
  }
  else if (avt < avb)
  {
   servov = --servov;
   if (servov < servovLimitLow)
   {
    servov = servovLimitLow;
   }
  }
  else if (avt = avb)
  {
  }
  vertical.write(servov);
 }
 if (-1*tol > dhoriz || dhoriz > tol)
 {
  if (avl > avr)
  {
   servoh = --servoh;
   if (servoh < servohLimitLow)
  {
   servoh = servohLimitLow;
```

```
  }
  }
  else if (avl < avr)
  {
   servoh = ++servoh;
   if (servoh > servohLimitHigh)
   {
    servoh = servohLimitHigh;
   }
  }
  else if (avl = avr)
  {
  }
  horizontal.write(servoh);
 }
 delay(dtime);

}
```

Appendix II

Table 0.1 BILL OF ENGINEERING MEASUREMENT AND MATERIALS EVALUATION

S/N	DETAILED DESCRIPTION	QUANTITY	UNIT	UNIT RATE IN NAIRA	AMOUNT IN NAIRA
1	Arduino v5 ATmega328P-PU 28-lead, 0.300" Wide, 28-pin Plastic Dual Inline Package (PDIP)	1	1	6,000	6,000
2	Sensor Shield v5	1	1	5,500	5,500
3	Acrylic Plastic	100 cm x 100cm x 0.5 cm			4,000
4	Light Sensors	20 Pcs	1	100	2,000
5	Resistors 10kΩ	4 pcs	1	100	400
6	Terminal Block: 4 Port terminal Block	2 Pcs	1	200	400
7	Jumper Cables: Male-Male, Female-Female, Male-Female	40 Pcs	10	250	1,000
8	Set of Screw Drivers	1 Set	1	1500	1,500
9	Solar Panels of 12v 160mA 2w. dimension 13.6 cm x 11.0 cm	3 Pcs	1	4000	12,000
10	Improvised Cable Warp				
11	Bolts and Nuts cut to size of 2 cm	20 Pcs	1		1,000
12	Vero Board	1	1	200	200
13	Arduino Battery Connector	1	1	100	100
14	Battery 9v	4 Pcs	1	150	900
15	Servo Motors of Weight: 69 g, Dimension: 40 mm x 19 mm x 43 mm approximately, Stall torque: 13 $kg \cdot cm$ (4.8V), 15$kgcm$ (6V)	2	1	5,000	5,000
16	Digital voltage Meter	1	1	500	500
17	Set of File	1	1		1,500

18	Hack saw	1	1	500	500
19	Soldering Iron	1	1	500	500
20	Soldering Lead	1	1	500	500
				Total	43,500