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FACULTY OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

SOLAR TRACKER FOR SOLAR PANEL

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BY

OLOKA REAGAN OTIENO

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SUPERVISOR: MR. S.A. Ahmed

EXAMINER: Professor Elijah Mwangi

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DECLARATION OF ORIGINALITY

FACULTY/ SCHOOL/ INSTITUTE: Engineering

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NAME OF STUDENT: Oloka Reagan Otieno

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COLLEGE: Architecture & Engineering

WORK: SOLAR TRACKER FOR SOLAR PANEL

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DEDICATION

To my family for their support during my university education, particularly my Dad and sister Linda Oloka for always being available for me and their unwavering support.

ACKNOWLEDGEMENT

I would like to express my gratitude to Mr. S.A. Ahmed, who was my supervisor, for his constant guidance in the implementation of this project. I must particularly thank him for his commitment and unrelenting effort to see me do all the assignments appertaining to this project and finally I can say I am done. He was always available for consultation and ensured there was no laxity in the implementation of the project. I particularly thank him for his insight, his advice and help towards the overall success of this project. Without his encouragement, I am not sure if the project would have been implemented as successfully as is the case.

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ABBREVIATIONS AND ACRONYMS

ADC	Analog to Digital Converter
EEPROM	Electrical Erasable programmable Read Only Memory
D	Diode
DC	Direct current
GND	Ground
I	Current
I/O	Input/ Output
IDE	Integrated Development Environment
LDR	Light Dependent Resistor
LED	Light Emitting Diode
LUX	Luminous Flux
LED	Light Emitting Diode
MAX	Maximum
MCU	Microcontroller
MIN	Minimum
VCC	Supply voltage
UV	Ultra Violet Light
PCB	Printed Circuit Board
PV	Photovoltaic panels
R	Resistor
GaAs	Gallium Arsenide
MPPT	Maximum Power Point Tracking
CMOS	Complementary Metal–Oxide–Semiconductor
RISC	Reduced Instruction Set Computing
IDE	Integrated Development Environment
PWM	Pulse Width Modulation

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 single axis of freedom. Light Dependent Resistors (LDRs) are used for sunlight detection.

The control circuit is based on an ATMega328P microcontroller. It was programmed to detect sunlight via the LDRs 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.

CHAPTER ONE: INTRODUCTION

1.1 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 [1].

1.2 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.

1.3 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.

1.4 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.

1.5 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 Atmega 328P is programmed using the C language before the chip removed from the Arduino board. The Arduino IDE was used for the coding. It is then used as a standalone unit on a PCB during fabrication and display. The design is limited to Single Axis tracking because the use of a dual axis tracking system would not add much value. Nairobi has coordinates of 1.2833^{0}S, 36.8167^{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. There is the design of an input stage that facilitates conversion of light into a voltage by the light dependent resistors, LDRs. There is comparison of the two voltages, then the microcontroller uses the difference as the error. The servo motor uses this error to rotate through a corresponding angle for the adjustment of the position of the solar panel until such a time that the voltage outputs in the LDRs are equal.

The difference between the voltages of the LDRs is gotten as analog readings. The difference is transmitted to the servo motor and it thus moves to ensure the two LDRs are an equal inclination. This means they will be receiving the same amount of light. The procedure is repeated throughout the day.

1.6 Methodology

The circuit of the solar tracker system is divided into three sections. There is the input stage that is composed of sensors and potentiometers, a program in embedded software in the microcontroller and lastly the driving circuit that has the servo motor. The input stage has two LDRs that are so arranged to form a voltage divider circuit. A C program loaded into the Atmega 328P forms the embedded software. There is a metallic frame that houses the components. The three stages are designed independently before being joined into one system. This approach, similar to stepwise refinement in modular programming, has been employed as it ensures an accurate and logical approach which is straight forward and easy to understand. This also ensures that if there are any errors, they are independently considered and corrected.

Project report organization

The project is divided into 5 chapters;

Chapter 1: This is the introduction to the project report that describes the justification for doing the project. The objectives, methodology and scope of the work are also described.

Chapter 2: This has the literature review that is based on the background of the problem. The chapter also includes material studied and which is pertinent to the study. There is a brief review of methods used for tracking and how tracking the apparent movement of the sun increases efficiency of solar panels.

Chapter 3: The chapter involves the design and implementation of the project.

Chapter 4: It involves design of the system, simulations and implementation.

Chapter 5: This chapter has the discussion, conclusion and recommendations for further work with regard to this project.

CHAPTER 2: LITERATURE REVIEW

2.1 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 2.1: 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 [4].

2.2 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.

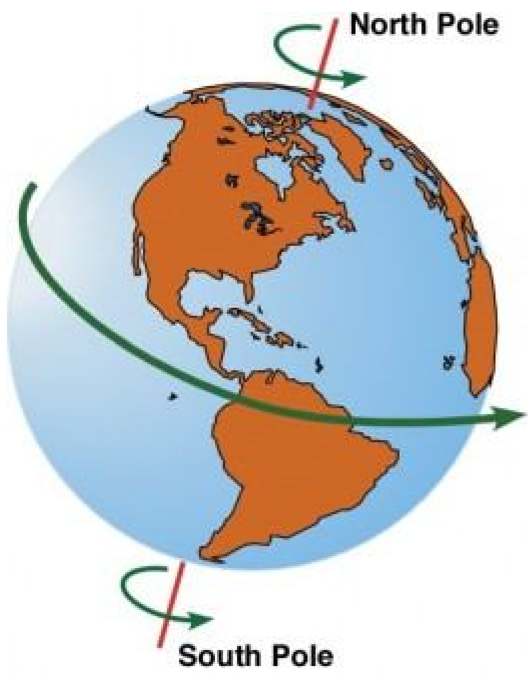

Figure 2.2: Earth's rotation

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 [7].

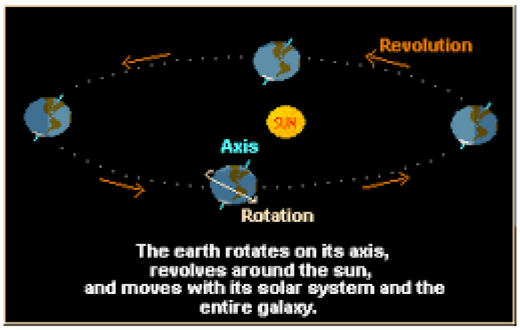

Figure 2.3: Revolution and rotation

2.3 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.

$$P=4\pi r^2 \sigma \epsilon T^4 \text{ W} \quad [1]$$

T is the temperature that is about 5800K, r is the radius of the sun which is 695800 km and **σ** 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 [8].

2.4 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;

$$1 \text{ lx} = 1 \text{lm} \cdot \text{m}^{-2} = 1 \text{ cd} \cdot \text{sr} \cdot \text{m}^{-2} \quad \textbf{(1)}$$

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

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

Table 2.1: Range of the brightness of sunlight (lux)

Time of day	Luminous flux (lux)
Sunrise or sunset on a clear day	400
Overcast day	1000
Full day (not direct sun)	10000 – 25000
Direct sunlight	32000 – 130000

2.4.1 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.

2.4.2 Zenith angle

This is the angle between the sun and the vertical. It is similar to the angle of elevation but is measured from the vertical rather than from the horizontal. Therefore, the zenith angle = 90 degrees – elevation angle [8].

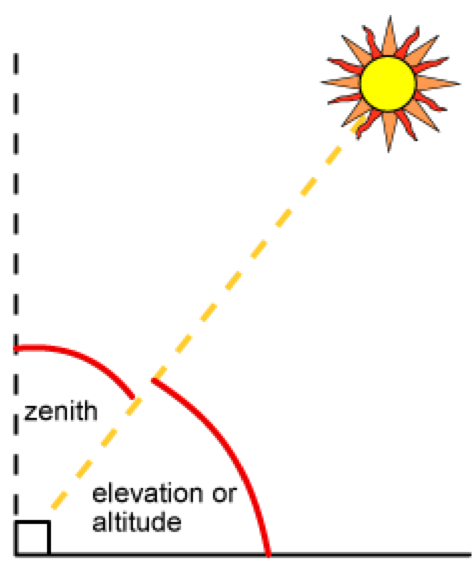

Figure 2.4: angle of elevation and zenith angle

2.4.3 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 [8].

2.5 Types of solar trackers and tracking technologies

There are various categories of modern solar tracking technologies;

2.5.1 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 [7].

2.5.2 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 [7].

2.5.3 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.

2.5.4 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].

2.5.5 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.

2.6 Fixed and tracking collectors

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

2.6.1 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. 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 Nairobi is shown below.

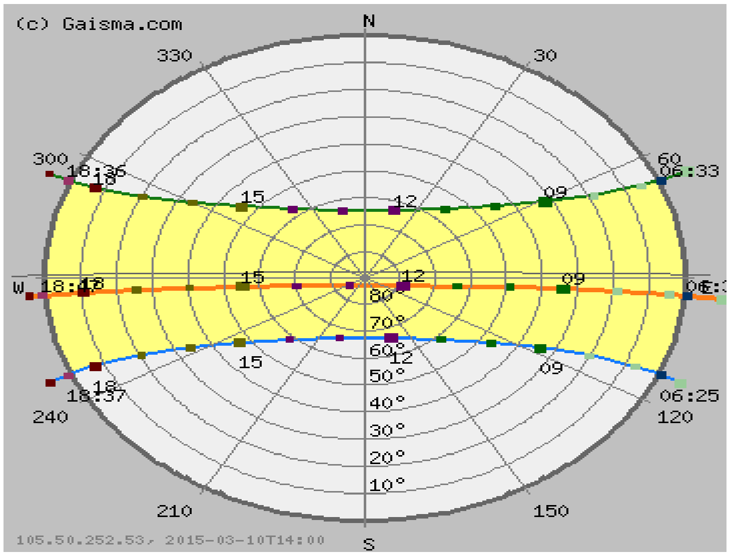

Figure 2.5: Sun path diagram for Nairobi

Key:

Sun path
- Today
- June 21
- December 21
- Annual variation
- Equinox (March and September)

Sunrise/sunset
- Sunrise
- Sunset

Time
- 00-02
- 03-05
- 06-08
- 09-11
- 12-14
- 15-17
- 18-20
- 21-23

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.

2.6.2 CASE I: The Fixed Collector

For collectors that are fixed, the projection area on the area that is perpendicularly oriented to the direction of radiation is given by $S = S_o \cos\theta$, where θ changes in the interval $(-\pi/2, +\pi/2)$ during the day. The angular velocity of the sun as it moves across the sky is given by $\omega = 2\pi/T = 7.27\times10^{-5}$ rad/s with the differential of the falling energy given by $dW = ISdt$. The energy per unit that is calculated for the whole day neglecting atmospheric influence is given by:

$$W = \int_{-21600}^{+21600} IS_o \cos\omega t \, dt = I S_o \left[\frac{\sin\omega t}{\omega}\right]_{-21600}^{+21600} = \frac{2IS}{\omega}, \textbf{(2)}$$

$= 3.03 \times 10^7 \text{W/m}^2$ day

$= 8.41$ kWh/m^2 day, **(3)**

2.6.3 Tracking collectors: Improvement of efficiency

For tracking collectors, theoretical extracted energy is calculated assuming that maximum radiation intensity $I=1100\text{W/m}^2$ is falling on the area that is perpendicularly oriented to the direction of radiation. There is comparison of intensity on the tracking collector and the fixed one. More energy is gotten from the tracking collector than the fixed one.

2.6.4 CASE II: The Tracking Collector

For tracking collectors, if atmospheric influence is neglected, the energy per unit of area for an entire day is given by

$W = IS_o t = 4.75 \times 10^7$ Ws, **(4)**

= 13.2kWh/m^2 day.**(5)**

Comparing the theoretical results for the two cases, more energy is obtained from the second case, for the tracking collector. However, as the rays of the sun travel towards the earth, they go through the thick layers of the atmosphere in both of the cases. That notwithstanding, the tracking collector has more exposure to the sun's energy at any given time.

2.7 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.

2.8 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:

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

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}}$$ **[6]**

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

I_{sc} is the short-circuit current

FF is the fill factor

η 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 100×100 mm^2 cell is 10 W.

2.9 Benefits and demerits of solar energy

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

2.9.1 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.

2.9.2 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.

CHAPTER 3: DESIGN AND IMPLEMENTATION

3.1 Light Sensor Theory and Circuit of Sensor Used

Light detecting sensor that maybe used to build solar tracker include; phototransistors, photodiodes, LDR and LLS05. A suitable, inexpensive, simple and easy to interface photo sensor is analog LDR which is the most common in electronics. It is usually in form of a photo resistor made of cadmium sulfide (CdS) or gallium arsenide (GaAs). Next in complexity is the photodiode followed by the phototransistor [2].

3.2 Light Dependent Resistor Theory

The simplest optical sensor is a photon resistor or photocell which is a light sensitive resistor these are made of two types, cadmium sulfide (CdS) and gallium arsenide (GaAs).

The sun tracker system designed here uses two cadmium sulfide (CdS) photocells for sensing the light. The photocell is a passive component whose resistance is inversely proportional to the amount of light intensity directed towards it. It is connected in series with capacitor.

The photocell to be used for the tracker is based on its dark resistance and light saturation resistance. The term light saturation means that further increasing the light intensity to the CdS cells will not decrease its resistance any further. Light intensity is measured in Lux, the illumination of sunlight is approximately 30,000 lux [2].

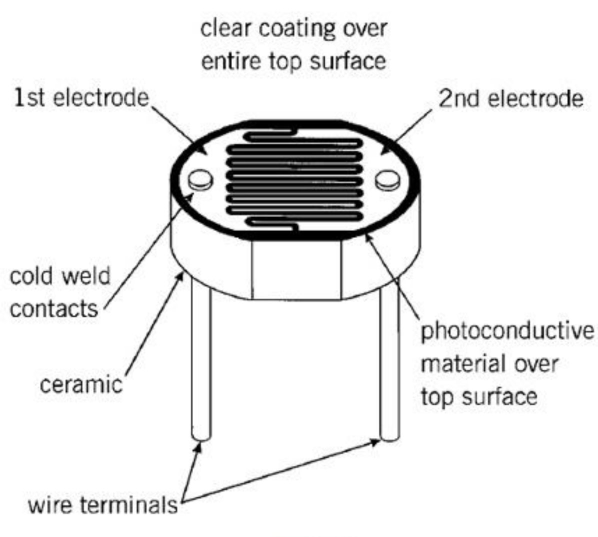

Figure 3.1: LDR construction

Normally the resistance of an LDR is very high, sometimes as high as 1000 000 ohms, but when they are illuminated with light resistance drops dramatically. When the light level is low the resistance of the LDR is high. This prevents current from flowing to the base of the transistors. Consequently the LED does not light. However, when light shines onto the LDR its resistance falls.

3.2.1 The concept of using two LDRs

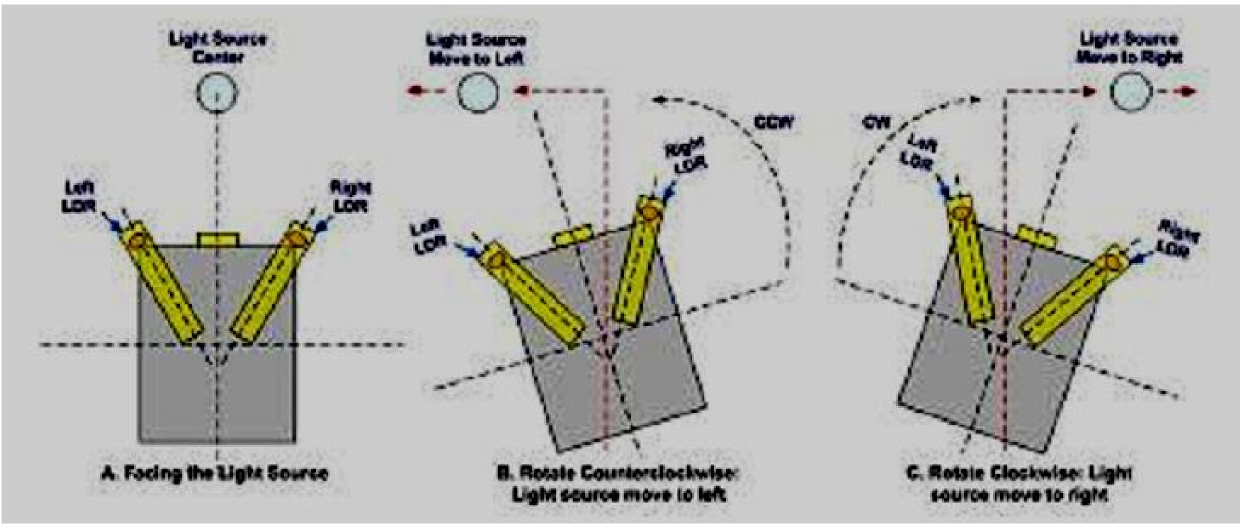

Figure 3.2: use of two LDRs

Concept of using two LDRs for sensing is explained in the figure above. The stable position is when the two LDRs having the same light intensity.When the light source moves, i.e. the sun moves from west to east, the level of intensity falling on both the LDRs changes and this change is calibrated into voltage using voltage dividers. The changes in voltage are compared using built-in comparator of microcontroller and motor is used to rotate the solar panel in a way so as to track the light source.

3.3 Light sensor design

The solar tracker makes use of a Cds photocell for detecting light. There was use of a complementary resistor with a value of 10k. With the resulting configuration, the output voltage will increase with increase in light intensity. The value of the complementary resistor is chosen such that the widest output range is achieved. The photocell resistance is measured under bright light, average light and dark light conditions. The results are listed in the table below.

Table 3.1 Photocell Resistance Testing Data

Measured Resistance	Comment
50 KΩ	Dark light conditions (black vinyl tape placed over cell)
4.35 KΩ	Average light conditions (normal room lighting level)
200 Ω	Bright light conditions (flashlight directly in front of cell)

The voltage divider circuit formed is shown below.

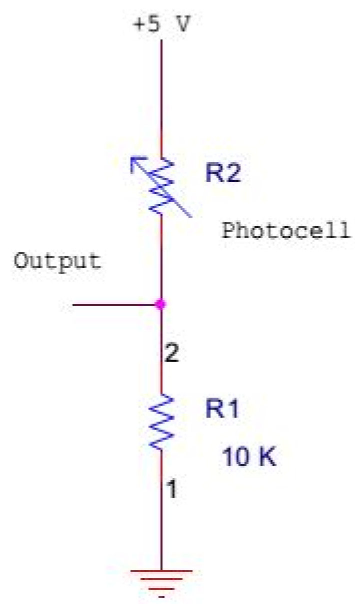

Figure 3.3: The input circuit that employs a voltage divider.

From the given relationship, the input-output relationship for the voltage divider circuit is given by:

$$V_i = V_{cc}\left\{\frac{\text{Rpot}}{\text{LDR} + \text{Rpot}}\right\}$$

In this case,

$V_{i\,=-}$ input voltage into the microcontroller

R=Resistance of the [potentiometer which is10K

Vcc= Supply voltage to Microcontroller and LDRs

Vi=Input voltage to the Microcontroller

3.4 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.

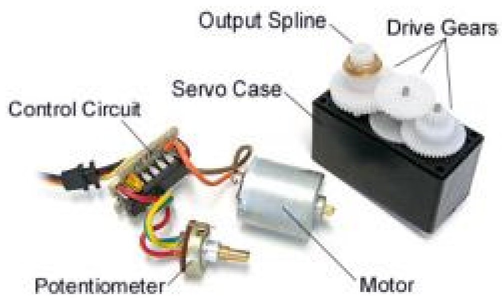

Figure 3.4: servo motor inside features

3.4.1 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 [7].

3.4.2 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 [7].

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.

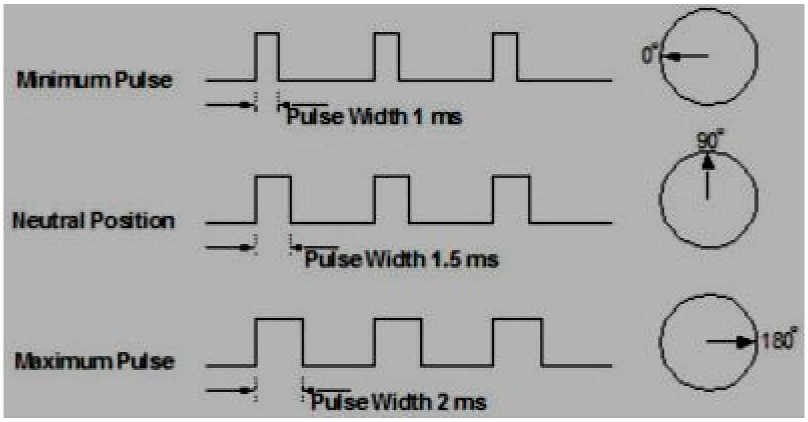

Figure 3.5: variable pulse width control servo position

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.

3.4.3 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.

3.5 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.

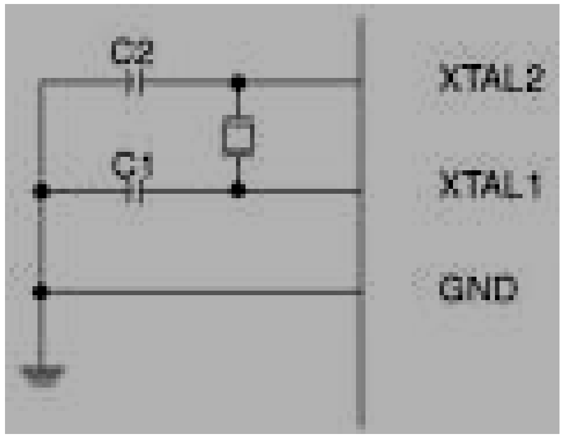

Figure 3.6 circuit diagram of a crystal

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.

3.6 Voltage regulation

Voltage regulators are designed to automatically maintain voltages at a constant level. The LM7805 voltage regulator is used. It is a member of the 78xx series of fixed linear voltage regulator ICs. Voltage sources in circuits could be having fluctuations and thus not be able to give fixed voltage output. The voltage regulator IC maintains the output voltage at a value that is constant. The LM7805 provides +5V regulated power supply. Capacitors are connected at the input and output depending on respective levels of voltage [6].

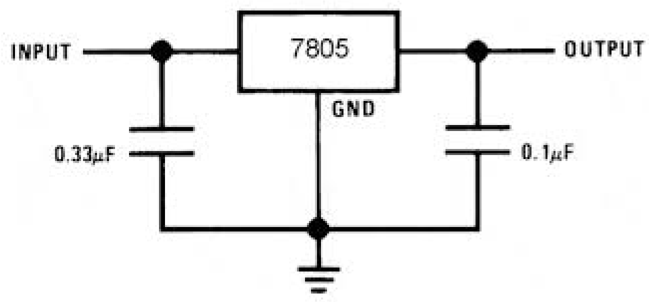

Figure 3.7: Voltage Regulator Circuit LM7805
The pin diagram of the 7805 is shown below.

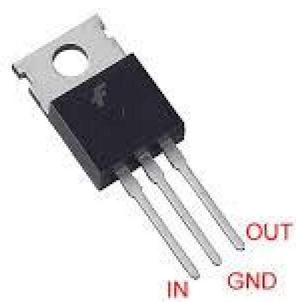

Figure 3.8: the LM7805 pin diagram

Table 3.2: Pin Description

Pin No	**Function**	**Name**
1	Input voltage (5V-18V)	Input
2	Ground (0V)	Ground
3	Regulated output; 5V (4.8V-5.2V)	Output

The maximum value for input to the voltage regulator is 35V. it also comes with a provision for a heat sink. In cases where the voltage is near 7.5V there is no heat production and therefore there is o need for a heat sink. If the voltage output is more, the excess electricity will be liberated as heat.

3.7 Microcontroller

Microcontroller is a single chip micro computer made through VLSI fabrication. A microcontroller also called an embedded controller because the microcontroller and its support circuits are often built into, or embedded in, the devices they control. A microcontroller is available in different word lengths like microprocessors (4bit,8bit,16bit,32bit,64bit and 128 bit microcontrollers are available today).

A microcontroller contains one or more of the following components:

- Central processing unit (CPU)
- Random Access Memory (RAM)
- Read Only Memory (ROM)
- Input/Output ports
- Timers and Counters
- Interrupt controls
- Analog to digital converters
- Digital analog converters
- Serial interfacing ports
- Oscillatory circuits

Microcontrollers need to be programmed to be capable of performing anything useful. It then executes the program loaded in its flash memory – the code comprised of a sequence of zeros and ones. It is organized in 12-, 14- or 16-bit wide words, depending on the microcontroller's architecture. Every word is considered by the CPU as a command being executed during the operation of the microcontroller [1].

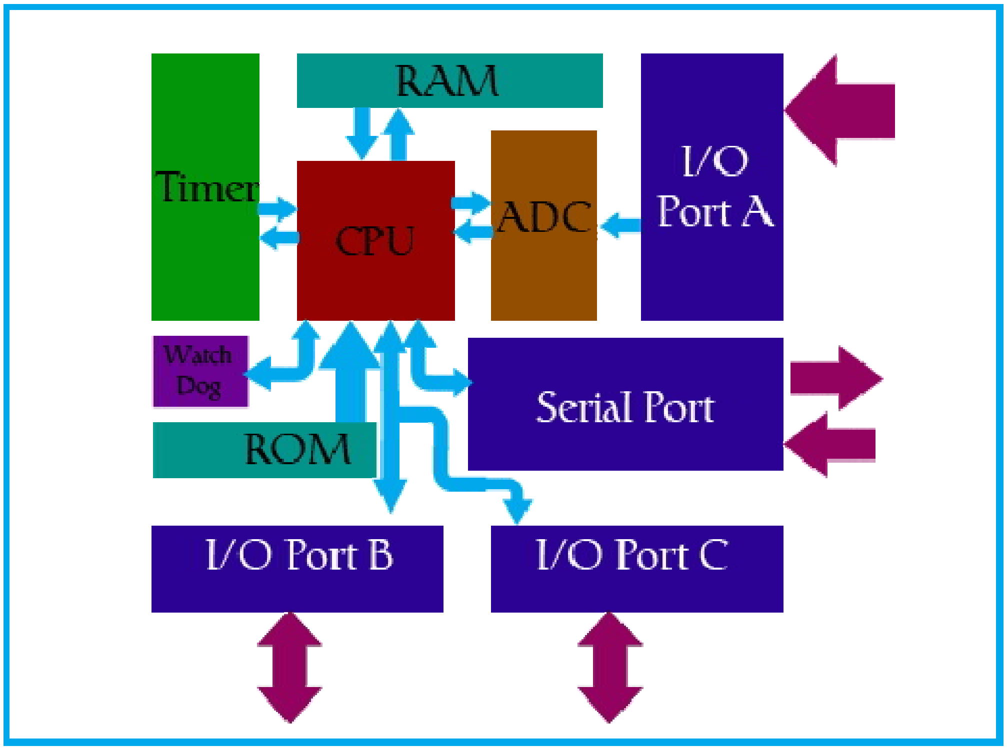

Figure 3.9: Microcontroller Architecture

3.7.1 ATmega328P

The ATmega328P is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega328P achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed.

It has 28 pins. There are 14 digital I/O pins from which 6 can be used as PWM outputs and 6 analog input pins. The I/O pins account for 20 of the pins. The 20 pins can act as input to the circuit or as output. Whether they are input or output is set in the software.

Two of the pins are for the crystal oscillator and are supposed to provide a clock pulse for the Atmega chip. The clock pulse is needed for synchronization so that communication occurs in synchrony between the Atmega chip and a device connected to it. Two of the pins, Vcc and GND are for powering the chip. The microcontroller requires between 1.8-5.5V of power to operate.

The pin-out for the microcontroller is shown below:

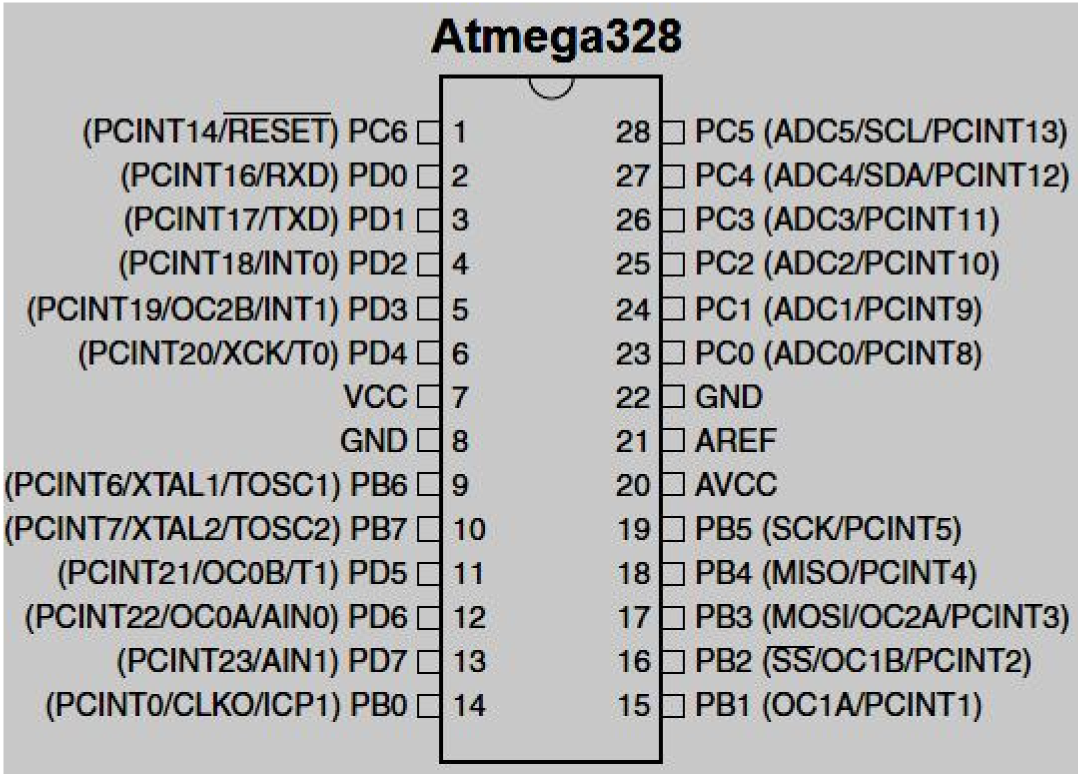

Figure 3.10: Atmega 328P

The Atmega328 chip has an analog-to-digital converter (ADC) inside of it. This must be or else the Atmega328 wouldn't be capable of interpreting analog signals. Because there is an ADC, the chip can interpret analog input, which is why the chip has 6 pins for analog input. The ADC has 3 pins set aside for it to function- AVCC, AREF, and GND. AVCC is the power supply, positive voltage, that for the ADC. The ADC needs its own power supply in order to work. GND is the power supply ground. AREF is the reference voltage that the ADC uses to convert an analog signal to its corresponding digital value. Analog voltages higher than the reference voltage will be assigned to a digital value of 1, while analog voltages below the reference voltage will be assigned the digital value of 0. Since the ADC for the Atmega328 is a 10-bit ADC, meaning it produces a 10-bit digital value, it converts an analog signal to its digital value, with the AREF value being a reference for which digital values are high or low. Thus, a portrait of an analog signal is shown by this digital value; thus, it is its digital correspondent value [7].

The last pin is the RESET pin. This allows a program to be rerun and start over.

The table below gives a description for each of the pins and their functions.

Table 3.3 Pins and their functions

Pin Number	**Description**	**Function**
1	PC6	Reset
2	PD0	Digital Pin (RX)
3	PD1	Digital Pin (TX)
4	PD2	Digital Pin
5	PD3	Digital Pin (PWM)
6	PD4	Digital Pin
7	Vcc	Positive Voltage (power)
8	GND	Ground
9	XTAL 1	Crystal Oscillator
10	XTAL 2	Crystal Oscillator
11	PD5	Digital Pin (PWM)
12	PD6	Digital pin (PWM)
13	PD7	Digital pin
14	PB0	Digital pin
15	PB1	Digital pin (PWM)
16	PB2	Digital pin (PWM)
17	PB3	Digital pin (PWM)
18	PB4	Digital pin
19	PB5	Digital pin
20	AVcc	Positive voltage for ADC (power)
21	Aref	Reference voltage
22	GND	Ground
23	PC0	Analog input
24	PC1	Analog input
25	PC2	Analog input
26	PC3	Analog input
27	PC4	Analog input
28	PC5	Analog input

There are various features that make the ATmega 328P a good choice for the project:

- Temperature Range:-40°C to 85°C
- Operating Voltage: 1.8 - 5.5V
- Low Power Consumption at 1 MHz, 1.8V, 25°C

  - ✓ Active Mode: 0.2 mA
  - ✓ Power-down Mode: 0.1 µA
  - ✓ Power-save Mode: 0.75

- Special Microcontroller Features:

  - ✓ Power-on Reset and Programmable Brown-out Detection
  - ✓ Internal Calibrated Oscillator
  - ✓ External and Internal Interrupt Sources
  - ✓ Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby

- High Endurance Non-volatile Memory Segments

  - ✓ 32K Bytes of In-System Self-Programmable Flash progam memory
  - ✓ 1K Bytes EEPROM
  - ✓ 2K Bytes Internal SRAM
  - ✓ Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - ✓ Data retention: 20 years at 85°C/100 years at 25°C
  - ✓ Optional Boot Code Section with Independent Lock Bits
  - ✓ Programming Lock for Software Security

3.8 The design tool

Arduino IDE

The software design was done using Arduino IDE which was used for the programming. The pargram was written using the C language. The Proteus circuit editing software was used for drawing the PCB circuit. The design of the circuit was done using Eagle software.

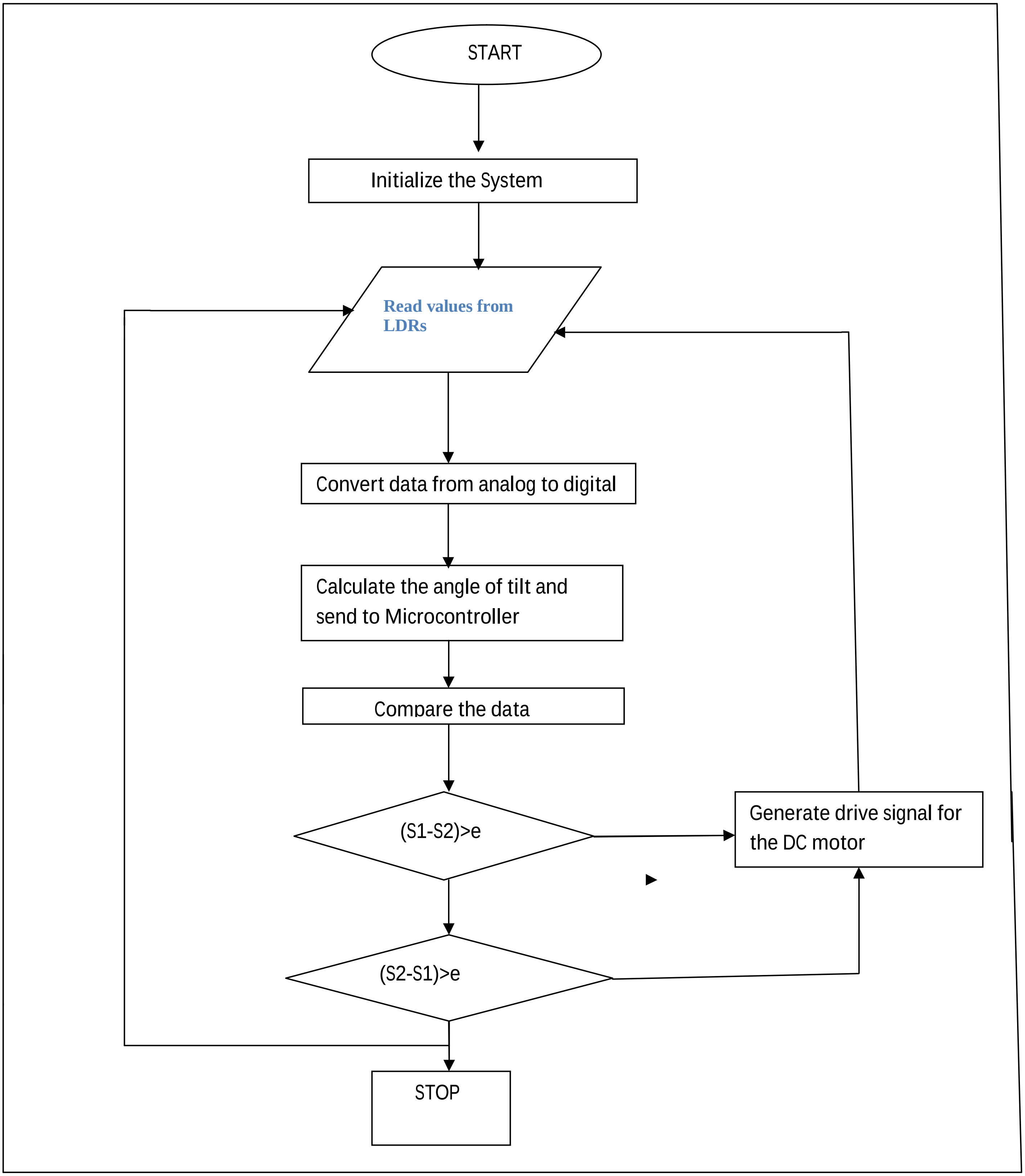

Figure 3.11: A Simplified Flow Chart of the Assembly

3.9 Algorithm for Motor Control

The algorithm gives the description of the general steps undertaken for the project:

1. There is input of the voltages from the two LDRs.
2. The inputs are analog. They are converted to digital values that range between 0-1023.
3. The two digital values are compared and the difference between them obtained.
4. The difference between the values obtained is the error proportional angle for the rotation of the servo motor.
5. If the LDR voltages are the same, the servo stops. Otherwise, the servo rotates until the difference is the same.

The flow chart of figure is an illustration of how the algorithm is implemented. The inputs into the system are the two LDR voltages into pins 23 and 24 of the Atmega 328. There is then the conversion of the analog voltages into their digital values. The larger of the two signals is sent to the circuit which drives the DC motor to the direction with more light intensity. The block diagram of the solar tracking system is shown below.

After that, all the components are assembled as is illustrated in the diagram below. The input stage comprises the LDRs which feed the voltage outputs to the microcontroller. From the LDRs are potentiometers that are used for varying the resistance. When there is plenty of sunshine, the potentiometers are adjusted to their maximum value that is 10K. For days when the weather is not very sunny, the resistance is reduced by varying the potentiometer to ensure readings are more easily taken. The LDRs are connected to pins 4 and 5.

The embedded software design has the C code loaded into the Atmega 328P. The code that was used is shown at the appendix of the report. The resistor R1 is a pull up resistor for preventing the microcontroller from continually resetting.

Pins 8 and 22 are grounded as specified by the specifications of the microcontroller. Digital pin 9 is connected to the signal pin of the servo motor and serves to control the movement of the servo. There is also the power pin of the servo that is connected to power. The last servo pin is grounded. Pins 9 and 10 are for the quartz crystal. There are various switches that control the powering of different components. The LED indicates when the circuit is powered and the entire system is functional.

There is a reset button for positioning the panel to an initial position which is at an inclination of 40 degrees. This is done preferably in the evening after the sun has set. It makes the LDR go back to an initial position, ready for tracking sunlight on the next day. There is also a push button for initializing the servo motor. It switches it on, leaving it on standby mode.

Pins 7, 20 and 21 are for powering the microcontroller. It requires 5V. The inputs to the LDR are simulated. The hardware schematic diagram is shown in figure

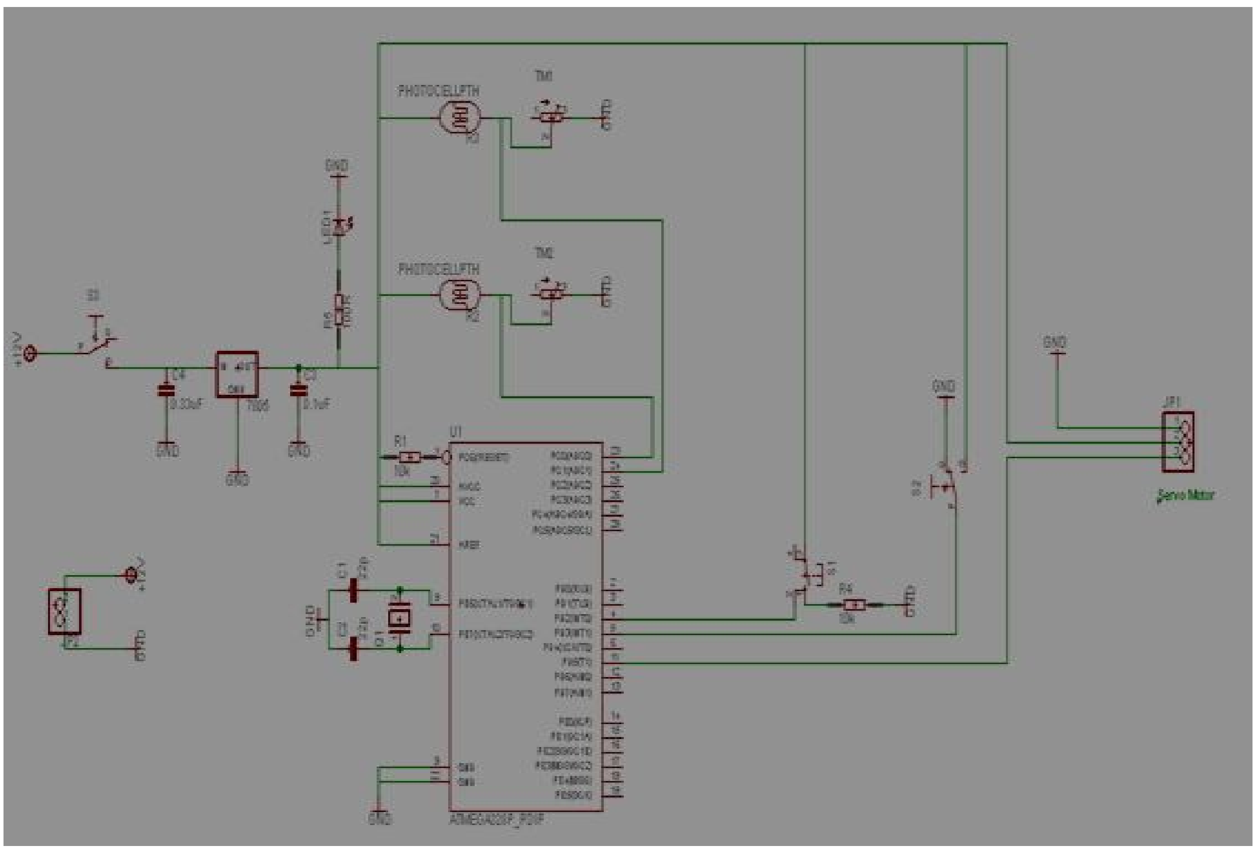

Figure3.12: Hardware schematic diagram

CHAPTER 4: RESULTS, SIMULATIONS AND ANALYSIS

4.1 Results

The results for the project were gotten from LDRs for the solar tracking system and the panel that has a fixed position. The results were recorded for four days, recorded and tabulated. The outputs of the LDRs were dependent on the light intensity falling on their surfaces. Arduino has a serial that communicates on digital pins 0 (RX) and 1 (TX) as well as with the computer through a USB. If these functions are thus used, pins 0 and 1 can be used for digital input or output.

Arduino environment's built in serial monitor can be used to communicate with the arduino board. To collect the results, a code was written that made it possible to collect data from the LDRs after every one hour. The values from the two LDRs are to be read and recorded at the given intervals.

The LDRs measure the intensity of light and therefore they are a valid indication of the power that gets to the surface of the solar panel. As a result, by measuring the light intensity at a given time, it will be possible to get the difference in efficiency between the tracking panel and the fixed one. The light intensity is directly proportional to the power output of the solar panel.

A code was written that made it possible to obtain readings from the two LDRs at intervals of one hour. The EEPROM came in handy in this. It is the memory whose values are kept when the board is turned off. The ATmega 328P has 1024 bytes of EEPROM.

To get the values at the end of the day, the Arduino board was used to connect the microcontroller to the computer. The RX and TX pins are used for the connection. The code for reading the values that were recorded is loaded into the microcontroller. The various values are obtained and converted into volts. The Vcc to the microcontroller and the LDRs is 5volts. The Atmega 328P has 1024 voltage steps and 5volts. When they are converted into digital values, the values will be in the range of 0-1023. The conversion is done using the relation below.

$$\text{LDR Output} = \frac{\text{Equivalent Digital Output} * 5}{1023}\ \text{Volts}$$

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 cloudy Morning and Sunny Afternoon for 6th and 7th April 2015

	LDR readings for Fixed Panel		**LDR readings for a Tracking Panel**	
Time	LDR1	LDR2	LDR12	LDR22
0630Hrs	0.196	0.176	1.477	1.487
0730Hrs	0.249	0.210	1.804	1.839
0830Hrs	0.225	0.196	2.757	2.933
0930Hrs	0.723	0.567	3.631	3.783
1030Hrs	0.733	0.816	3.900	3.798
1130Hrs	3.211	2.297	3.910	3.969
1230Hrs	4.888	4.941	4.990	4.990
1330Hrs	3.803	3.910	4.985	4.990
1430Hrs	3.456	4.057	4.976	4.985
1530Hrs	3.930	3.846	4.941	4.892
1630Hrs	1.999	1.544	4.824	4.594
1730Hrs	1.090	1.144	3.128	2.981
1830Hrs	0.718	0.787	0.982	0.968

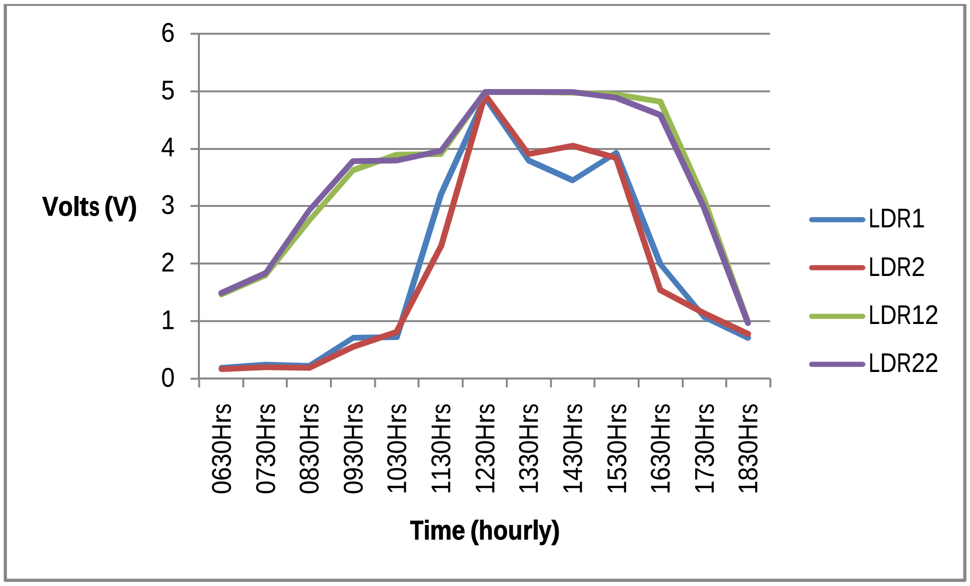

Figure4.1: Graph of results obtained on 6th and 7th April

Table 4.2: LDR outputs for bright sunny day on 2nd April 2015

	LDR readings for Fixed Panel		**LDR readings for a Tracking Panel**	
Time	LDR1	LDR2	LDR12	LDR22
0630Hrs	0.679	0.489	1.477	1.487
0730Hrs	0.792	1.061	2.804	2.839
0830Hrs	1.779	1.672	3.203	3.990
0930Hrs	3.167	1.199	3.990	3.990
1030Hrs	3.421	3.226	4.130	4.149
1130Hrs	4.604	3.208	4.500	4.590
1230Hrs	4.990	4.980	4.990	4.990
1330Hrs	4.980	4.990	4.888	4.990
1430Hrs	4.888	4.941	4.976	4.985
1530Hrs	4.413	3.878	4.941	4.892
1630Hrs	3.935	3.824	4.873	4.790
1730Hrs	2.639	2.639	3.964	3.940
1830Hrs	1.569	1.031	2.708	2.815

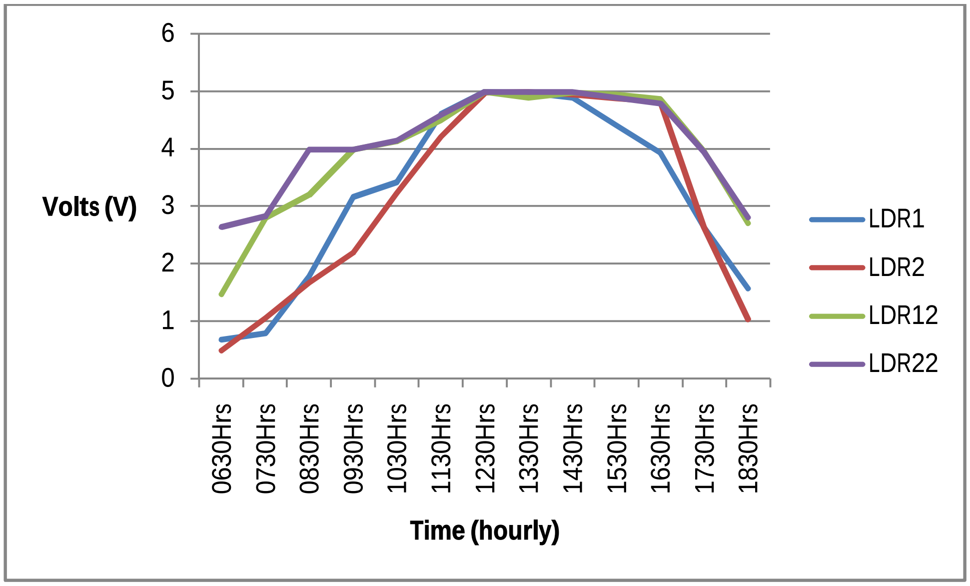

Figure 4.2: Graph for bright sunny day of 2nd April 2015

Table 4.3: Results for LDR outputs for a cloudy day on 12th April 2015

	LDR Readings for Fixed Panel		**LDR Readings for a Tracking Panel**	
Time	LDR1	LDR2	LDR12	LDR22
0630Hrs	0.147	0.117	0.274	0.244
0730Hrs	0.161	0.156	0.547	0.601
0830Hrs	0.274	0.205	1.090	1.075
0930Hrs	0.435	0.279	1.227	1.276
1030Hrs	0.572	0.547	1.271	1.305
1130Hrs	1.041	0.816	1.618	1.569
1230Hrs	2.175	1.965	2.165	2.151
1330Hrs	1.975	1.794	1.848	1.794
1430Hrs	1.119	1.623	1.090	1.075
1530Hrs	1.022	1.510	0.982	0.943
1630Hrs	0.543	1.017	0.762	0.728
1730Hrs	0.264	0.367	0.547	0.538
1830Hrs	0.064	0.103	0.327	0.220

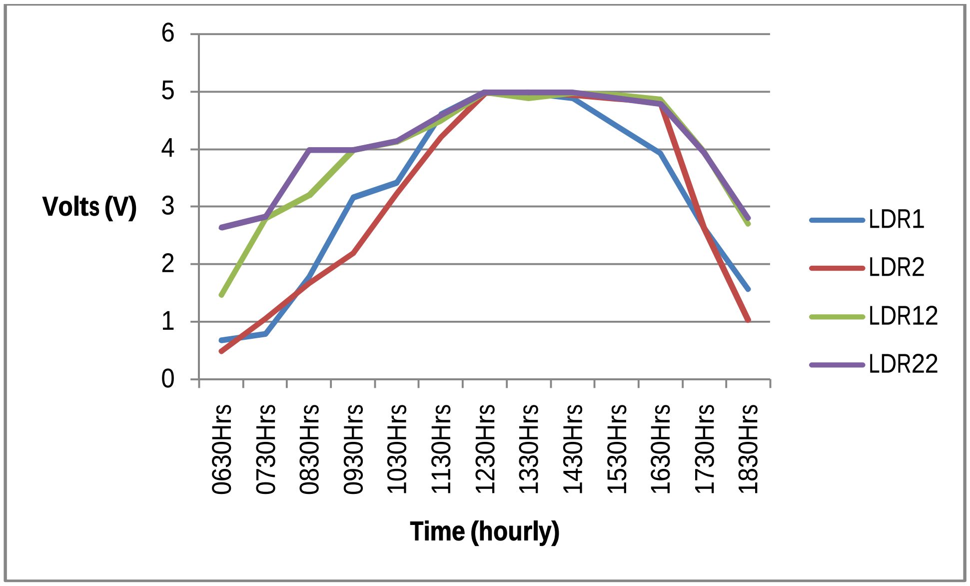

Figure 4.3: Graph of LDR outputs for a cloudy day on 12th April 2015

Key points to note:

LDR1 is the photo resistor 1 reading for a solar panel that is fixed.

LDR2 indicates the 2nd photo resistor for a fixed solar panel.

LDR 12 indicates the 1st photo resistor reading in the tracking solar panel.

LDR 22 indicates the 2nd photo resistor for a tracking solar panel.

4.2 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.

For the panel fitted with the tracking system, the values of the LDRs are expected to be close. This is because whenever they are in different positions there is an error generated that enables its movement. The motion of the panel is stopped when the values are the same, meaning the LDRs receive the same intensity of sunlight. For the fixed panel, the values vary because the panel is at a fixed position. Therefore, at most times the LDRs are not facing the sun at the same inclination. This is apart from midday when they are both almost perpendicular to the sun.

Days with the least cloud cover are the ones that have the most light intensity and therefore the outputs of the LDRs 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.

A few values can be used to illustrate the difference in efficiency between the two systems:

For a bright sunny day, we can take the averages for LDR22 and LDRS 2 for the entire day. We then use 5 as the base because it is the maximum value of the LDR output. It is calculated as a percentage and the two values compared. While this may not give the clearest indication of the exact increase in efficiency, it shows that the tracking system has better efficiency.

$$\frac{\text{average value of LDR 22 or LDR2}}{\text{5 volts}} * 100$$

For LDR 22:

$$\frac{4.027}{5} * 100 = 80.54\%$$

For LDR 2:

$$\frac{2.856}{5} * 100 = 57.14\%$$

The difference between the two values is 23.4%. this means the LDR for the tracking system has an increased efficiency of 23.4%.

CHAPTER FIVE: DISCUSSION, CONCLUSION AND RECOMMENDATIONS FOR FURTHER WORK

5.1 Discussion

The objective of the project was to design a system that tracks the sun for a solar panel. This was achieved through using light sensors that are able to detect the amount of sunlight that reaches the solar panel. The values obtained by the LDRs are compared and if there is a significant difference, there is actuation of the panel using a servo motor to the point where it is almost perpendicular to the rays of the sun.

This was achieved using a system with three stages or subsystems. Each stage has its own role. The stages were;

- An input stage that was responsible for converting sunlight to a voltage.
- A control stage that was responsible for controlling actuation and decision making.
- A driver stage with the servo motor. It was responsible for actual movement of the panel.

The input stage is designed with a voltage divider circuit so that it gives desired range of illumination for bright illumination conditions or when there is dim lighting. This made it possible to get readings when there was cloudy weather. The potentiometer was adjusted to cater for such changes. The LDRs were found to be most suitable for this project because their resistance varies with light. They are readily available and are cost effective. Temperature sensors for instance would be costly.

The control stage has a microcontroller that receives voltages from the LDRs and determines the action to be performed. The microcontroller is programmed to ensure it sends a signal to the servo motor that moves in accordance with the generated error.

The final stage was the driving circuitry that consisted mainly of the servo motor. The servo motor had enough torque to drive the panel. Servo motors are noise free and are affordable, making them the best choice for the project.

5.2 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 single 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 Kenya 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.

5.3 Recommendations for further work

With the available time and resources, the objective of the project was met. The project is able to be implemented on a much larger scale. For future projects, one may consider the use of more efficient sensors, but which are cost effective and consume little power. This would further enhance efficiency while reducing costs. If there is the possibility of further reducing the cost of this project, it would help a great deal. This is because whether or not such projects are embraced is dependent on how cheap they can be.

Shading has adverse effects on the operation of solar panels. Shading of a single cell will have an effect on the entire panel because the cells are usually connected in series. With shading therefore, the tracking system will not be able to improve efficiency as is required.

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APPENDIXES

Appendix One: Code used in the microcontroller

```
#include <Servo.h>

Servo tiltServo;

#define LDR1 A0 // LDR 1 pin
#define LDR2 A1 // LDR 2 pin
#define servoPin 9 // servo pin

long sumErrors = 0; // sum of errors for PID
long wait = 0; // time between steps
uint8_t lastPosition = 0; // last servo position
int difference = 0; // difference between the two readings
boolean switchSides = false; // boolean variable to manage direction of rotation
volatile boolean commence = false; // starts the servo process

void setup() {
  Serial.begin(9600);
  tiltServo.attach(servoPin);
  attachInterrupt(0, initialize, RISING);
  attachInterrupt(1, activateServo, RISING);
}

void loop() {

  int ldrValue1 = analogRead(LDR1); // get analog reading of LDR1
  int ldrValue2 = analogRead(LDR2); // get analog reading of LDR2
  difference = ldrValue1 - ldrValue2; // calculate difference between the two values

  if (commence){
    if ( difference >= -20 && difference <= 20 ){
      Serial.println("e");
      lastPosition = tiltServo.read();
    }
    else if (difference < -20){
      if (switchSides){
        sumErrors = 0;
        wait = 0;
        switchSides = false;
      }
      tilt(1);
    }
    else if (difference > 20){
```

```
      if (!switchSides){
        sumErrors = 0;
        wait = 0;
        switchSides = true;
      }
      tilt(0);
    }
  }


  //Serial.print("LDR1: "); Serial.println(ldrValue1);
  //Serial.print("LDR2: "); Serial.println(ldrValue2);
  Serial.print("Difference: "); Serial.println(difference);
  //Serial.print("Sum: "); Serial.println("sumErrors");
  //Serial.println("");
}

void tilt(boolean flag){
  int returnInt = 0; // holds PID value
  if (flag && tiltServo.read() > 0){ // while servo is more than 0 degrees
    tiltServo.write(lastPosition--);
    returnInt = PID();
    delay(returnInt);
  }
  else if (!flag && tiltServo.read() < 180){ // while servo less than 180 degrees
    tiltServo.write(lastPosition++);
    returnInt = PID();
    delay(returnInt);
  }
}

int PID(){
  wait = abs(difference) + abs(sumErrors); // PI controller. Assuming Kp and Ki are equal to 1
  sumErrors += difference; // get the integral of errors

  return(wait / 300); // return delay value
}

void initialize(){ // go back to initial position
  uint8_t pos = tiltServo.read(); // get current servo position
  for(uint8_t i = pos; pos > 30; pos--){
    tiltServo.write(pos); // set servo positition
    delay(20);
  }
}
```

```
void activateServo(){ // activate servo movement
  if (commence) commence = false;
  else
  commence = true;
}
```

Appendix Two: Code for obtaining the results from the LDRs

```
#include <EEPROM.h>
#include <Servo.h>

Servo tiltServo;

#define LDR1 A0 // LDR 1 pin
#define LDR2 A1 // LDR 2 pin
#define servoPin 9 // servo pin

long sumErrors = 0; // sum of errors for PID
long wait = 0; // time between steps
uint8_t lastPosition = 0; // last servo position
int difference = 0; // difference between the two readings
boolean switchSides = false; // boolean variable to manage direction of rotation
int addr = 0;
long time = 0;
int ldrValue1 = 0;
int ldrValue2 = 0;

void setup() {
  Serial.begin(9600);
  tiltServo.attach(servoPin);
  attachInterrupt(0, initialize, RISING);
}

void loop() {
  ldrValue1 = analogRead(LDR1); // get analog reading of LDR1
  ldrValue2 = analogRead(LDR2); // get analog reading of LDR2
  if (addr < 24)logData();
  difference = ldrValue1 - ldrValue2; // calculate difference between the two values

  if (digitalRead(3) == HIGH){
    if ( difference >= -20 && difference <= 20 ){
      Serial.println("equilibrium");
      lastPosition = tiltServo.read();
    }
    else if (difference < -20){
      Serial.println("turn left");
      if (switchSides){
        sumErrors = 0;
        wait = 0;
        switchSides = false;
      }
      tilt(1);
    }
```

```
    else if (difference > 20){
      Serial.println("turn right");
      if (!switchSides){
        sumErrors = 0;
        wait = 0;
        switchSides = true;
      }
      tilt(0);
    }
  }
  //Serial.print("LDR1: "); Serial.println(ldrValue1);
  //Serial.print("LDR2: "); Serial.println(ldrValue2);
  Serial.print("Difference: "); Serial.println(difference);
  //Serial.print("Sum: "); Serial.println("sumErrors");
  //Serial.println("");
}

void tilt(boolean flag){
  int returnInt = 0; // holds PID value
  if (flag && tiltServo.read() > 40){ // while servo is more than 0 degrees
    tiltServo.write(lastPosition--);
    returnInt = PID();
    delay(returnInt);
  }
  else if (!flag && tiltServo.read() < 140){ // while servo less than 180 degrees
    tiltServo.write(lastPosition++);
    returnInt = PID();
    delay(returnInt);
  }
}

int PID(){
  wait = abs(difference) + abs(sumErrors); // PI controller. Assuming Kp and Ki are equal to 1
  sumErrors += difference; // get the integral of errors

  return(wait / 300); // return delay value
}

void initialize(){ // go back to initial position
  uint8_t pos = tiltServo.read(); // get current servo position
  for(uint8_t i = pos; pos > 40; pos--){
    tiltServo.write(pos); // set servo positition
    delay(10);
  }
}
//log data
```

```
void logData(){
  time = millis()/1000;
  if (time >= 3600){
    EEPROM.write(addr, (float(ldrValue1)/4));
    addr++;
    EEPROM.write(addr, (float(ldrValue2)/4));
    addr++;
    time = 0;
  }
  delay(10);
}
```

Appendix Three: Code for obtaining the stored values of readings from the LDRs in Volts

```
#include <EEPROM.h>

// start reading from the first byte (address 0) of the EEPROM
int address = 0;
byte value;

void setup()
{
  // initialize serial and wait for port to open:
  Serial.begin(9600);
}

void loop()
{
  while(address < 26){
    // read a byte from the current address of the EEPROM
    float value = float(EEPROM.read(address)) * 4;
    value = (value * 5)/1023;
    Serial.print(address);
    Serial.print("\t");
    Serial.print(value);
    Serial.print("V");
    Serial.println();

    // advance to the next address of the EEPROM
    address = address + 1;

    delay(500);
  }
}
```

Appendix Four: Screenshot of some of the readings obtained