Sun Position Tracking in Solar Panel

by

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18005

Dissertation submitted in partial fulfilment of
the requirements for the

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CERTIFICATION OF APPROVAL

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Approved by,

____

(Dr Lee Kean Chuan)

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
January 2017

CERTIFICATION OF ORIGINALITY

This certifies that I take full responsibility on all of my submitted works for this project and the original work is my own except as specified in the references and acknowledgements. The original work contained herein have not been undertaken or done by any unspecified sources or persons.

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MOHAMED FAZARI RAIDI BIN MOHAMED FIROZ

ABSTRACT

This project will discuss on the design of a prototype which has a two axis of freedom in a solar tracker. An Arduino Uno microcontroller is used for this project as a control circuit based on ATMega328P. The microcontroller is programmed to assist and navigate solar panel to be exposed to maximum light intensity by moving the two micro servo motors with the assistance of four light-dependent resistors (LDR). It is better to use servo motors as it is more efficient with efficiencies in the range of 80-90%. Besides, it can maintain its torque at high speed compared to other motors. They can supply almost twice their rated torque for short period of time and they do not cause much noise or suffer resonance issues. Therefore, the servo motors will navigate the solar panel towards the position where there is high intensity of light while it will remain in a static position if it is in a dark area. In a nutshell, there are many methods that can increase the efficiency of a solar panel and at the same time reducing its cost. This can be done by implementing this solar tracking system as it can increase the power output of a solar panel by increasing the exposure of the panels towards the sun. A dual axes tracking system is implemented in this project as it can track sunlight from both axes, thus increasing the efficiency of solar harnessing. A solar panel with a solar tracking system will have a better power output for energy harvesting.

ACKNOWLEDGEMENTS

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ABBREVIATIONS AND NOMENCLATURES

MPPT	Maximum Power Point Tracking
PV	Photovoltaic
FYP	Final Year Project
LDR	Light Dependent Resistor
TSAT	Tilted Single Axis Trackers
VSAT	Vertical Single Axis Trackers
PSAT	Polar Aligned Single Axis Trackers
HSAT	Horizontal Single Axis Trackers
HTSAT	Horizontal Single Axis Tracker with Tilted Modules
GaAs	Gallium Arsenide
CdS	Cadmium Sulphide
LT LDR	Left Top LDR
RT LDR	Right Top LDR
LD LDR	Left Down LDR
RD LDR	Right Down LDR

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Solar is a renewable and clean energy. All the technologies which include solar will use sun for provision of heat, light and electricity and they are commonly used for domestic and industrial purposes. Besides, renewable energy sources are very important as it can power the future sufficiently. However, it is a challenge to harvest solar energy due to its limited efficiency the array cells even though it is an unlimited resource. Besides, this project will give another way to improve the efficiency of solar panels by implementing the solar tracking system [1]. This tracking mechanism will move and positions the solar panel to be in the position for maximum power output including identifying the sources of losses and finding ways to mitigate them.

There is a process called maximum power point tracking which is commonly named as MPPT. It is used to increase the power output from the solar panel by maintaining its function on the knee point of P-V characteristics. The highest amount of power which can be gained from a fixed position arrays of solar panels at two any given time will only be offered by this technology [2]. However, when the position of the sun is not in a line with the system [3], the power generation cannot be increased. Therefore, this solar tracking system that is designed to increase power output between 30% and 60% by following the sun's position every time rather that it being in a fixed position while most of the photovoltaic (PV) has the efficiency between 10% and 20% [4]. Furthermore, there are different types of solar trackers that usually being used. Dual axis tracker is best used in places where the position of the sun keeps changing during the year at different seasons while 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. Therefore, the efficiency will be different in cases where the weather is sunny and thus favorable for the tracking system [5].

1.2 Problem Statement

In this modernized era, solar trackers are quite popular and are used in many systems for the improvement of harvesting solar energy. However, not everyone truly understands the complete benefits and potential drawbacks of the solar tracking system. The problem that people is facing are solar panels without a solar tracking system are less efficient. Therefore, the control circuit is used by the microcontroller to move the motor to orient the solar panel optimally. Besides that, most of the non-renewable energies will be used up one day which will cause energy crisis, thus this is where solar energy will be needed. However, cost factor is a major concern for things related to solar and people really need to utilize its cost efficiency.

1.3 Objectives of Study

The aim of this study is:

1. To maximize the output of the solar panel during certain period of the day.
2. To develop a new solar panel system with more harvest of light at limited space.
3. To utilize and increase the cost efficiency of a solar tracker to its fullest.

1.4 Scope of Study

The extent of study of this Final Year Project (FYP) is to focus on:

1. Creating a solar panel with maximum power output compared to stationary one at optimum angle.
2. Implementation of two servo motors in controlling pan and tilt movement for dual axis direction.
3. Program the movement of servo motors using Arduino microcontroller.

CHAPTER 2

LITERATURE REVIEW

2.1 Earth: Rotation and Revolution

Earth is the planet which will revolve around the sun and rotates on its own axis from west to east as shown in Fig. 1. Rotation and revolution are the two main motions of the earth. Besides, the axis lies as an imaginary line that passes through both the northern and southern poles. It will take about 24 hours to complete one full rotation and occurrence of day and night phenomena is due to this rotation. The earth takes 24 hours which is the time period for the solar day while 23 hours and 56 minutes will the duration of a sidereal. The position of earth with reference to the sun is not the same every time which is the main reason why there is a difference of 4 minutes within time period.

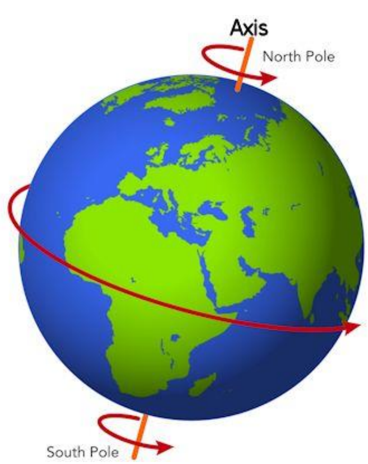


Figure 1: The rotation of earth [13]

In addition to that, another type of motion which is revolution is basically the movement of the earth round the sun. It will move from west to east and it will take about 365 days to make one complete rotation around the sun due to its elliptical orbit of earth. The distance between the earth and the sun will not be the same due to this event. The angle between the axis of earth and the ecliptic plane is 66.5 degrees. Therefore, there will be four critical positions that will be attained by the earth with reference to the sun [6].

2.2 Sun: Solar Irradiation

The energy which is delivered by the sun is caused by a process called electromagnetic radiation. Solar fusion occurs due to a very high temperature and pressure at the sun's core. Besides, helium atoms will be converted from protons about 600 million tons per second. Based on Stefan and Boltzmann's Law, total power of the sun can be estimated using the formula:

$$\mathbf{P=4\pi r^2\ \sigma\epsilon T^4\ W}\ [5]$$

Based on the formula given, the temperature is around **5800K** which is denoted as T, r is **695800 km** which is the radius of the sun. Furthermore, the symbol σ is the Boltzmann constant which is $\mathbf{1.3806488 \times 10^{--23} m^2\ kg\ s^{-2}\ K^{-1}}$ while **ϵ** is the emissivity of the surface. Furthermore, millions of tons of matter are converted to energy each second due to one of Einstein's famous law which uses the formula $E=mc^2$.The solar energy that is irradiated to the earth is nearly about $\mathbf{5.10^{24}}$ Joules per year which is about 10000 times the amount of current global energy consumption annually. There are three main types of solar radiation as shown in Table 1.

Types	Justification
Direct radiation (beam radiation)	It travels to the surface of the earth from the sun on one straight line.
Diffused radiation	Sun rays which has been scattered by particles and molecules in the atmosphere but they are still manage to reach and get to the surface of the earth.
Reflected radiation	Sun rays which has been reflected off from non-atmospheric surfaces such as the ground [7]

Table 1: Types of solar radiation

2.3 Types of trackers

There is a variety type of trackers that have been developed in today's era.

2.3.1 Active trackers

Active trackers are more efficient than passive trackers according to the analysis of efficiency of both trackers [8]. Motors and gear trains are used in an active tracker for directions as instructed by the controller depending on the direction of solar. This will follow and monitor the position of the sun throughout the day. Besides, the tracker will either sleep or stop depending on the framework of the tracker when it is in a dark place. This can be done by using sensors such as LDR which is very sensitive towards light. Lastly, the microcontroller will drive the actuators by moving the solar panel after the voltage output is injected into it [4].

2.3.2 Passive trackers

A lower boiling point compressed gas fluid is used by a passive tracker to drive to one side or another side which will affect the movement of tracker in response to an imbalance. It is unsuitable for concentrating photovoltaic collectors as the orientation is not precise. However, it can work fine without causing any problems with some types of common photovoltaic panels. This is because that they have viscous dampers that can avoid excessive motion which is caused by gusts of wind [4].

2.3.4 Single axis trackers

This tracker has a single degree of freedom which is known as the axis of rotation and it is aligned along the meridian of the true North. Besides, it is necessary to align them in any cardinal direction with the presence of advanced tracking algorithms. A polar mount is commonly been used by a single axis tracker for maximum solar efficiency. The types of solar trackers such as tilted single axis trackers (TSAT), vertical single axis trackers (VSAT), polar aligned single axis trackers (PSAT), horizontal single axis trackers (HSAT) and horizontal single axis tracker with tilted modules (HTSAT) use a single axis tracker concept [3].

2.3.5 Dual axis trackers

A dual axis tracker has two degrees of freedom which is the axis of rotation and they are usually normal to one another. There is a primary axis which is known as the axis that is fixed with respect to the ground while the secondary axis is the axis that is referenced to the primary axis. Dual axis trackers can follow the sun vertically and horizontally and this will allow optimum solar energy levels. Therefore, a dual axis solar tracker can be in position where they can angle themselves to be in direct contact with the sun no matter where the position of the sun is [1].

2.4 Azimuth Angle

The angle between the directions of compass from the directions of sunlight is called the Azimuth Angle. Besides, the sun is in the position hemisphere where in the southern hemisphere, it is directly north while in the northern hemisphere, it is directly south at noon and the angle of azimuth will be different throughout the day. Furthermore, the sun will rise directly to the east and sets directly to the west at the equinoxes regardless of the latitude. Therefore, the azimuth angles will be 90 degrees during sunrise and 270 degrees during sunset [7] as shown in Fig. 2.

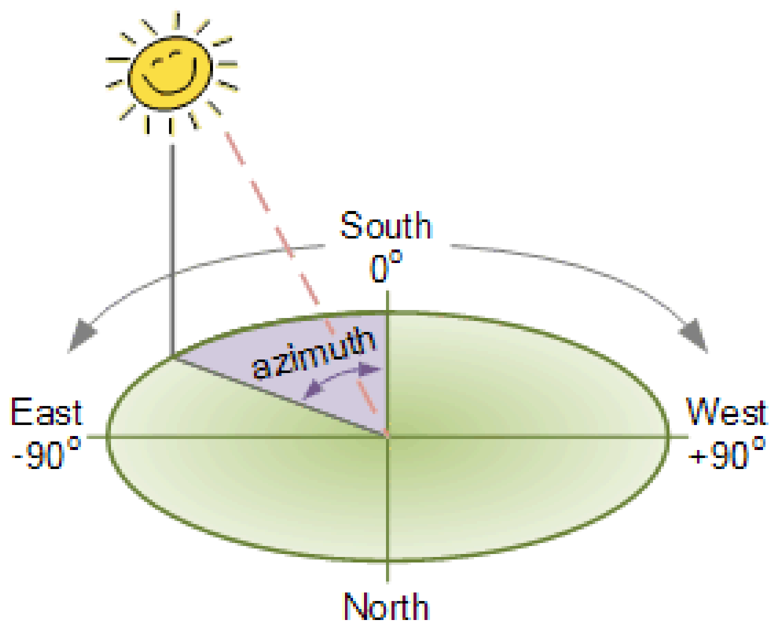


Figure 2: The azimuth angle [14]

2.5 Theory of Light Dependant Resistor

A photocell which can also be called as photon resistor is very sensitive towards light and they are created from Gallium Arsenide (GaAs) and Cadmium Sulphide (CdS) as shown in Fig. 3. Besides, most of the solar tracker system designed using two CdS photocells to sense light. An LDR does not need energy source to do specific functions as the lesser the amount of light intensity it receives, the higher its resistance and it can be connected with capacitor in series. The light saturation and dark resistance are the main concerns in the usage of the photocell in solar tracker. Furthermore, the unit Lux is used to measure the intensity of light and the value for sunlight illumination is about 30,000 lux [11].

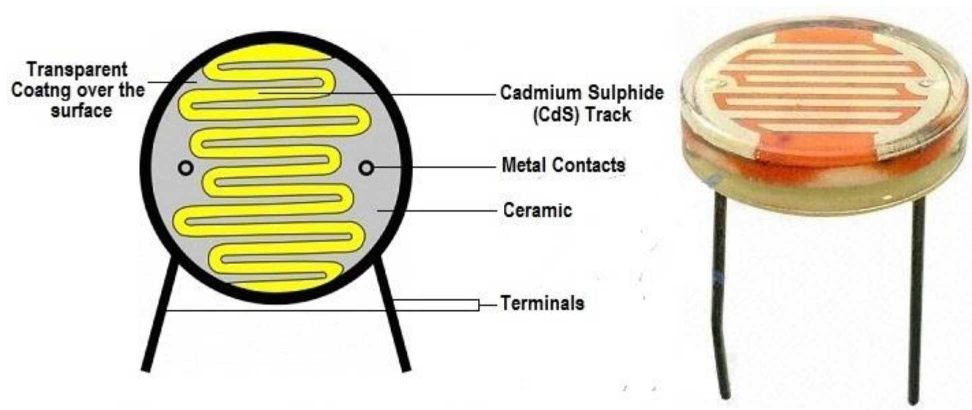


Figure 3: Basic construction of a LDR [15]

In addition to that, the resistance of an LDR is usually very high as it can go up to 1,000,000 ohms, but it can drop drastically when they are illuminated with light resistance. The resistance of the LDR will be high if the level of light intensity is low. Therefore, this case will avoid current from flowing to the base of the transistors. On the other hand, the resistance of the LDR decreases when light is directed onto the LDR.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

There are many research methodologies that can be found which contain many useful information and data while doing this project. All of the details are listed in the Table 2.

3.1.1 Data Gathering

Writing Materials	Writing materials such as project papers and articles related to sun position tracking are used as references to conduct this project.
Discussion	A discussion has been done with the project supervisor during the first meeting to discuss more about the details and understanding of the project.
Internet	There is plenty of information that can be found in the internet for better understanding regarding the project. They can also be used for references and as external sources.

Table 2: Sources of Information

3.2 Applied methods

In addition to that, there are a few additional methods that have been used in conducting this project as shown in the Fig. 4.

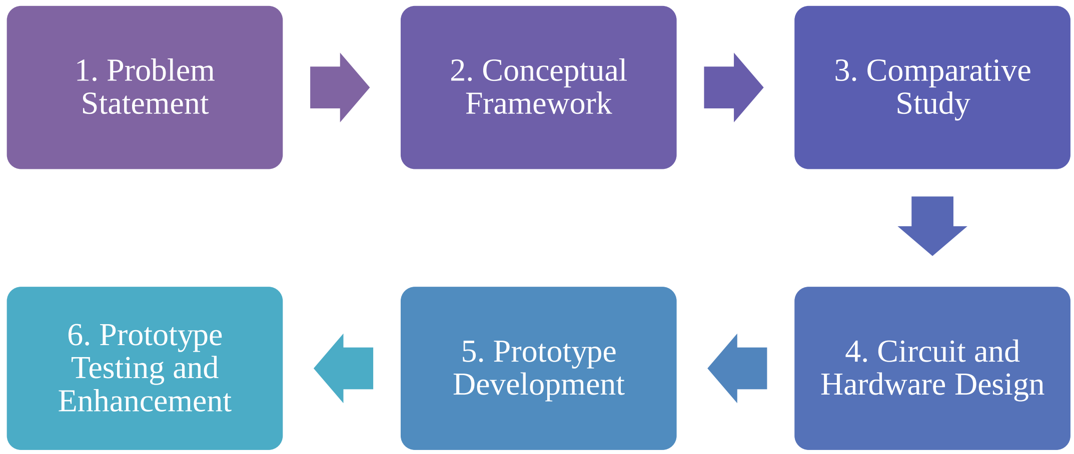


Figure 4: Applied methods throughout the project

3.2.1 Problem Statement

We all know that most of the non-renewable energies will be used up one day which causes energy crisis. Cost factor is a major concern for things related to solar and we need to utilize its cost efficiency. Therefore, the way of tracking light using LDR is an important step to track sunlight where it can be in different positions and might not track sunlight accurately. An LDR holder is constructed using Perspex to ensure that the LDRs stays fit on the right position when tracking sunlight when the servo motors are rotating. This project's objective has been narrowed down by focussing on improving the efficiency of the solar tracker by modelling a pan and tilt dual axes solar tracker can move along the x-y axis by referencing to the LDR and sunlight.

3.2.2 Conceptual Framework

The conceptual framework for this project is shown in Figure 5.

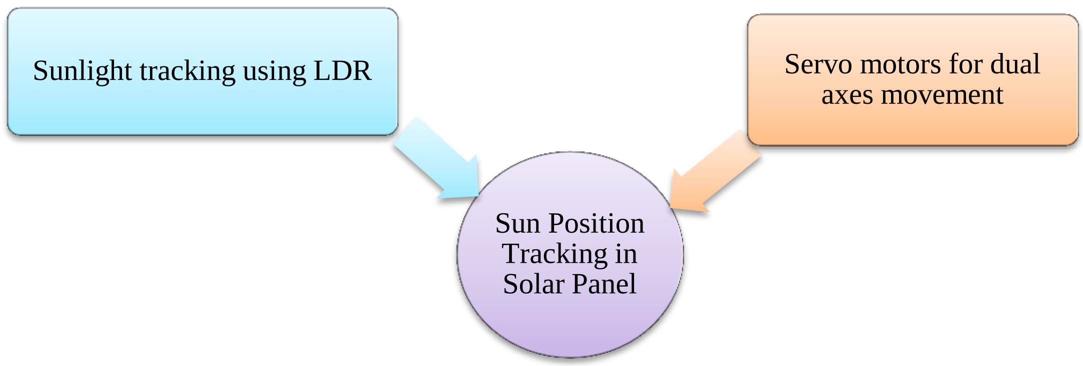


Figure 5: Conceptual framework of the project

3.2.3 Comparative Study

Plenty of research and analysis has been done before deciding to implement an appropriate design for this project. The main things that have been taken consideration are the type of motors, micro controller used and the appropriate prototype design for the project.

3.2.4 Circuit and Hardware Design

The circuit and hardware design is done after completing the conceptual framework and comparative studies to demonstrate on how this Sun Position Tracking in Solar Panel works. The basic circuit wiring and installation is show in Fig. 6 and Fig. 7. The hardware and software tools used are explained in details in Section 3.6.

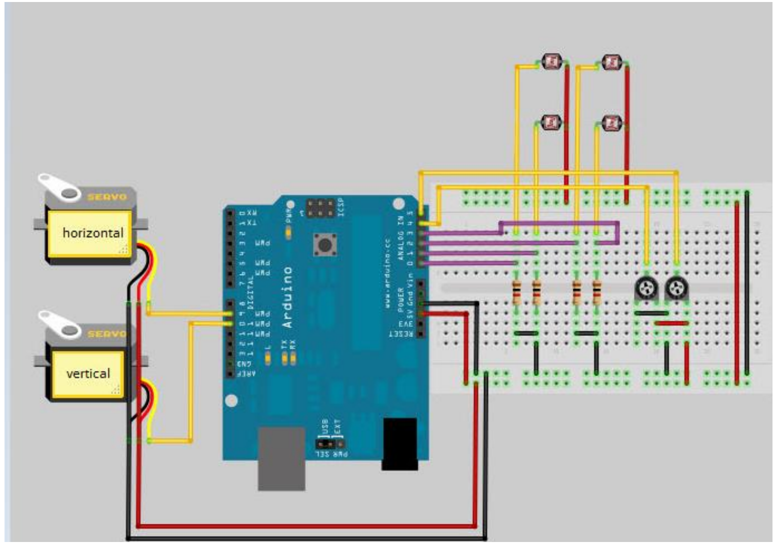


Figure 6: Basic circuit wiring

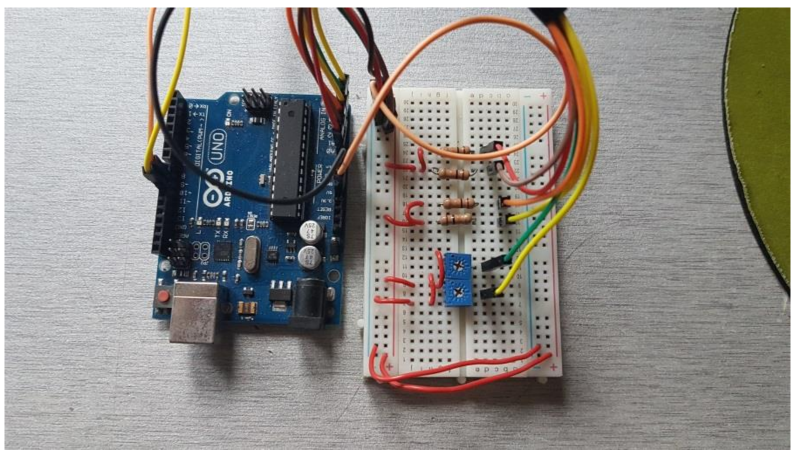


Figure 7: Circuit installation

Based on the figures above, the Arduino Digital Pin 9 is connected to the horizontal servo while Pin 10 is connected to the vertical servo. The Analog input pins A0 until A5 are connected to the LDR and potentiometers. The potentiometers are used to control the reaction speed of the servos and tolerance towards light.

3.2.5 Prototype Development

The main parts used are the brackets for the servo motors to be mounted on and the LDR holder is built using Perspex as shown in Figure. The dimension used for the holder is 40x40x75mm. The LDR holder is cut using a Perspex cutter.

Lastly, the prototype is completed by adding all the necessary components by adding two micro servo motors, servo motor brackets, LDR holder and other small parts. These are needed for the dual axes movement of servo motors as shown in Fig. 8.

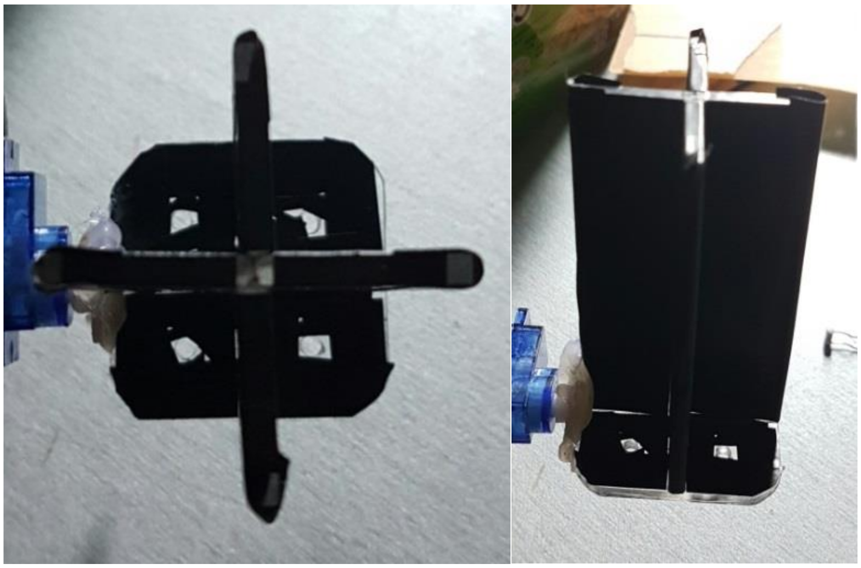


Figure 8: Top and side view for LDR holder

3.2.6 Prototype Testing and Enhancement

The final stage involved for this project is to implement and all the hardware needed for further testing. It is very crucial to do several tests on the accuracy of the LDR especially with different light intensity and different positions. Figure 9 shows how the LDR holder looks like.

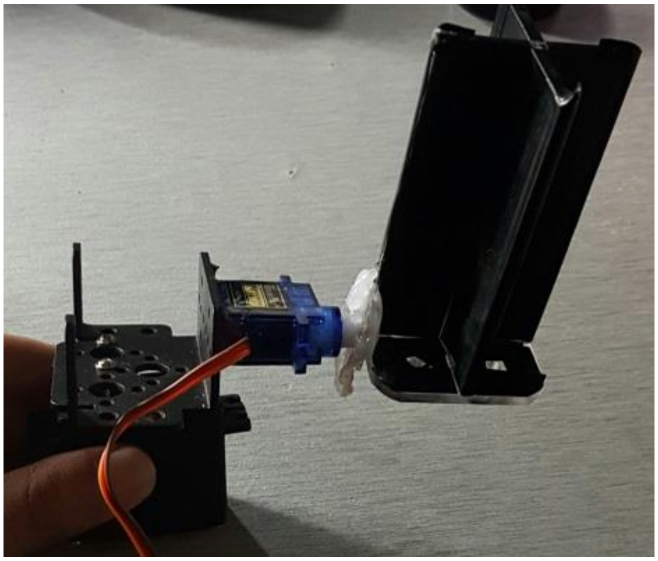
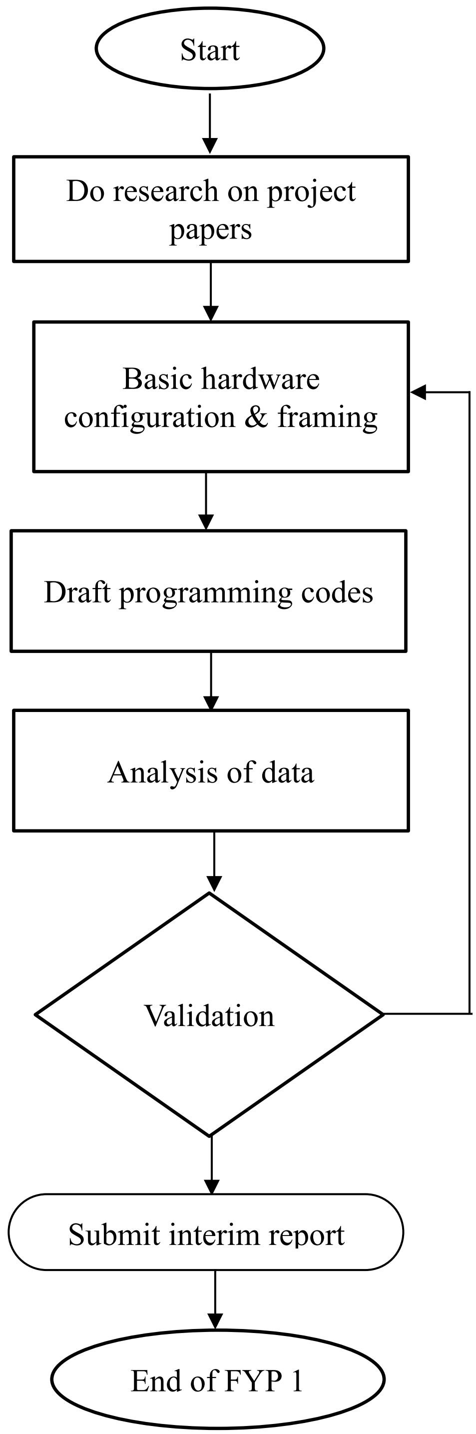


Figure 9: Full view of LDR holder

3.3 Project Activities

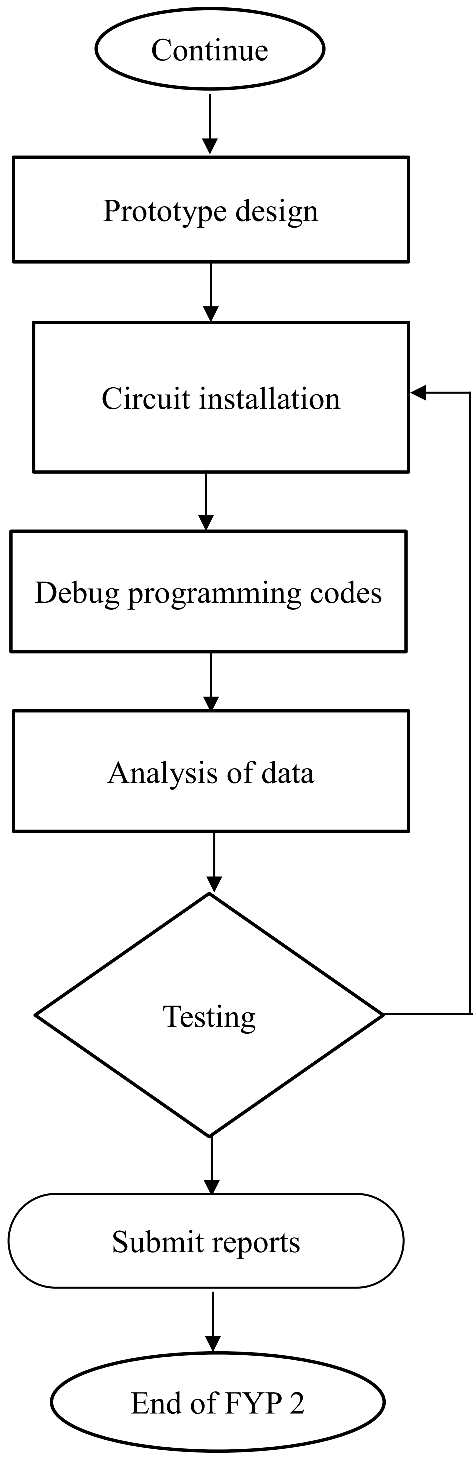


- Identify problem statements
- Do some research Find the information and thesis from the related project

- Verify all information found
- Prepare tools needed
- Analyze data
- Repeat process for improvement by performing debugging process

- Prepare report based on the methodology or procedures of the project based on the progress that has been made

Figure 10: FYP 1 Project Process Flow Chart



- Do some research and planning for the design of the prototype
- Create LDR holder and brackets installation

- Verify all information found
- Construct prototype and circuit
- Analyze data
- Repeat process for improvement by performing debugging process
- Prototype testing

- Prepare all the reports needed by referring to the methodology or procedures of the project based on the progress that has been made
- Submission including progress report, final report and dissertation

Figure 11: FYP 2 Project Process Flow Chart

3.4 Key Milestones

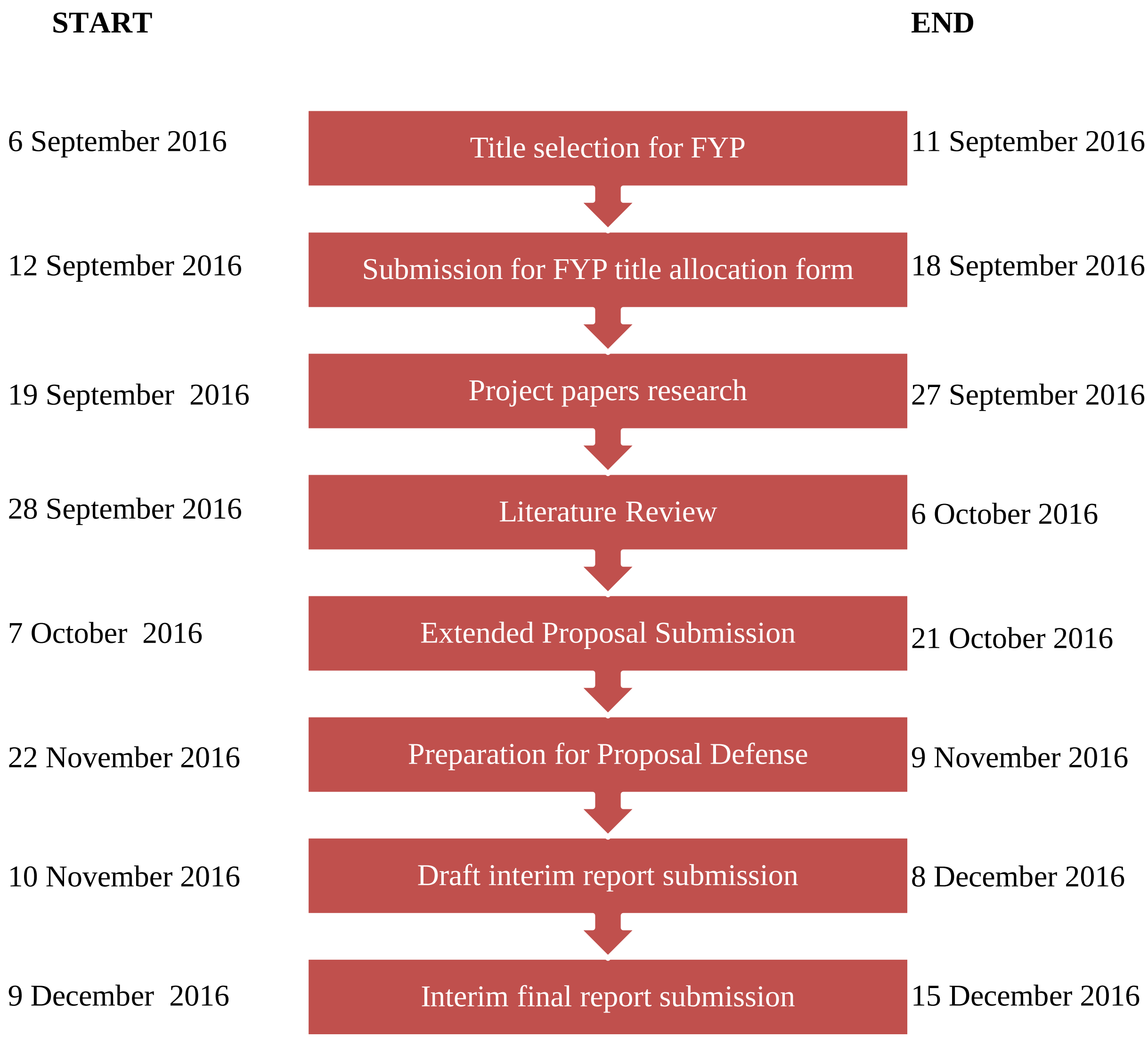


Figure 12: FYP 1 Key Milestone

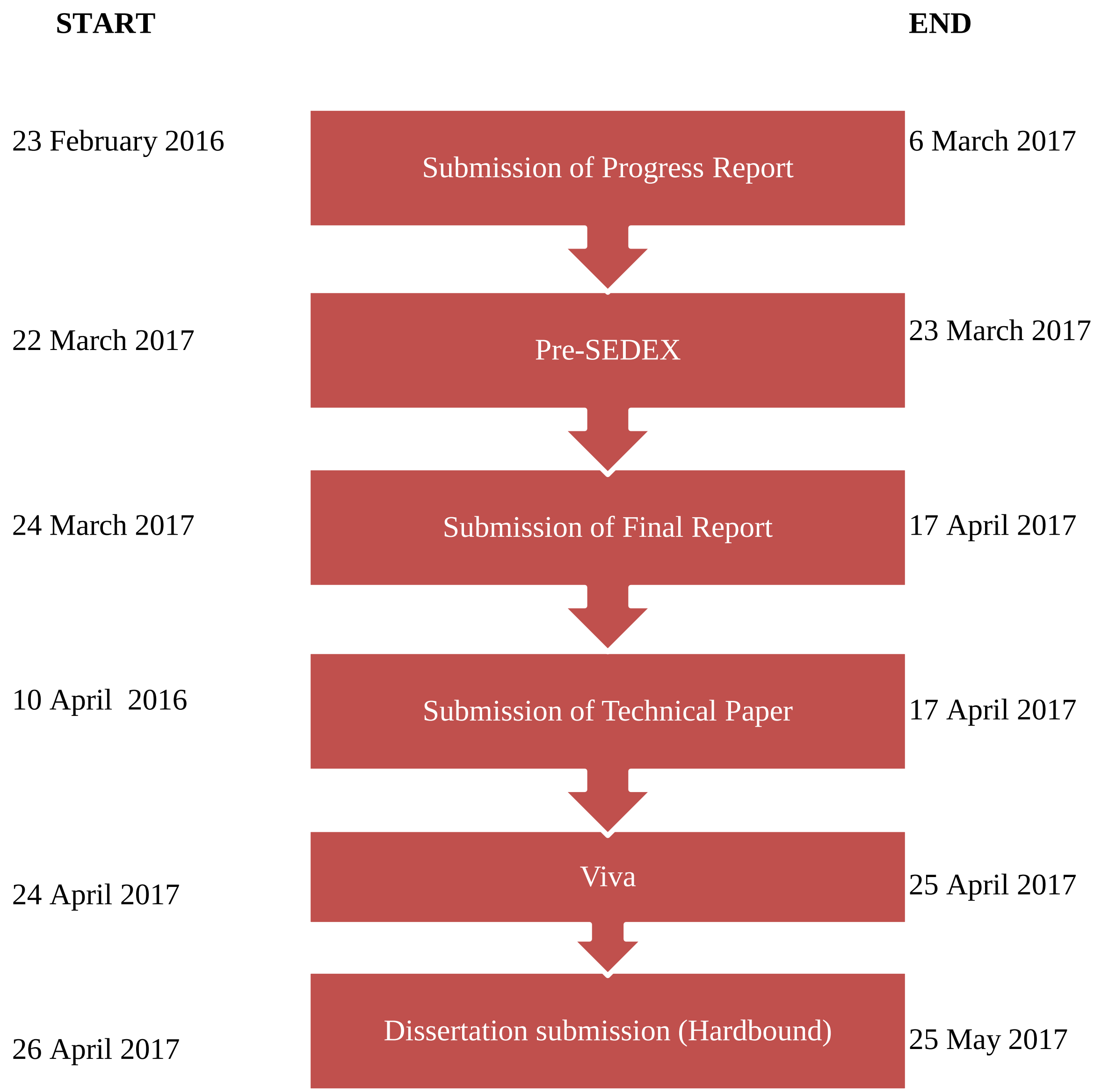


Figure 13: FYP 2 Key Milestone

3.5 Gantt charts

PLANNING ACTIVITIES	WEEK NO													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project title selection & form submission														
Literature review														
Extended Proposal Submission														
Components Listing /Gathering														
Arduino IDE installation														
Proposal Defence														
Basic framing (servo brackets)														
Initial draft for coding														
Interim report drafting														
Final interim report submission														
Algorithms debugging														
End of FYP 1														

Table 3: FYP 1Gantt Chart

PLANNING ACTIVITIES	WEEK NO													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Prototype design														
Circuit installation														
LDR holder construction														
Pan and tilt servo motors movement configuration														
Prototype development														
Coding and functionality testing														
Progress report submission														
Pre-SEDEX														
Draft of final report submission														
Final report and technical paper submission														
Viva and dissertation submission														
End of FYP 2														

Table 4: FYP 2 Gantt Chart

3.6 Tools & Software Required

HARDWARE	DESCRIPTION
Arduino Uno R3 	This model of Arduino board is used as a microcontroller due to its low-cost and small in size. It is programmed to move the micro servo motors based on the algorithms created.
Solar Panel 	This solar panel is used to make it expose towards sunlight and to show that harvesting of energy occurs.
Pan and tilt bracket 	The pan and tilt bracket use brackets and some necessary parts needed in constructing the mechanism of pan and tilt. Both micro servos will be attached to these brackets to make a dual axes movement.

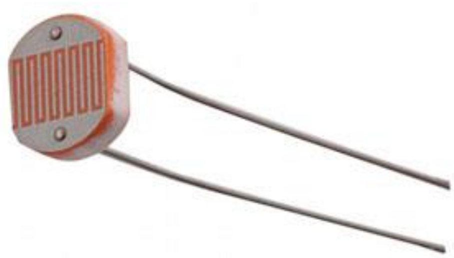
Micro Servo Motors 	Two micro servo motors are used to move the solar panel in dual axes directions and this type of motors are high in performance. They are used to move in horizontal and vertical axis.
LDR 	Four LDRs are used for this project. It is placed on each corner of the LDR holder as a sensor to track sunlight
LDR Holder 	A casing is constructed using Perspex to hold each of the LDR in position. This is to increase the sensitivity of LDR towards light. Those four LDR are differentially shaded by the 'X' shape at the top and their values are used to point the array directly towards the highest intensity of light.

Table 5: Hardware required

SOFTWARE	DESCRIPTION
Open-Source Arduino Software (IDE)	Writing codes will be easier with the Arduino Software (IDE). This open-source software can be used with any compatible Arduino boards and it is used to program the microcontroller to move the servo motors. The program is written using C Language.

Table 6: Software required

3.7 Project Flow

Based on Fig. 14, the basic algorithm of this solar tracking system consists of three stages which are input, processor and output. The system is initialized and power up in the input stage. It will later detect area with high intensity of light with the assistance of LDR. The system will process it by moving the servo motors to the area with higher light intensity which acts as an output as shown in Fig. 15.

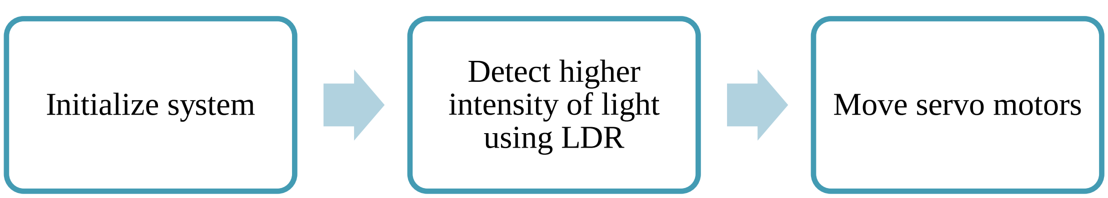


Figure 14: General block diagram of a solar tracker

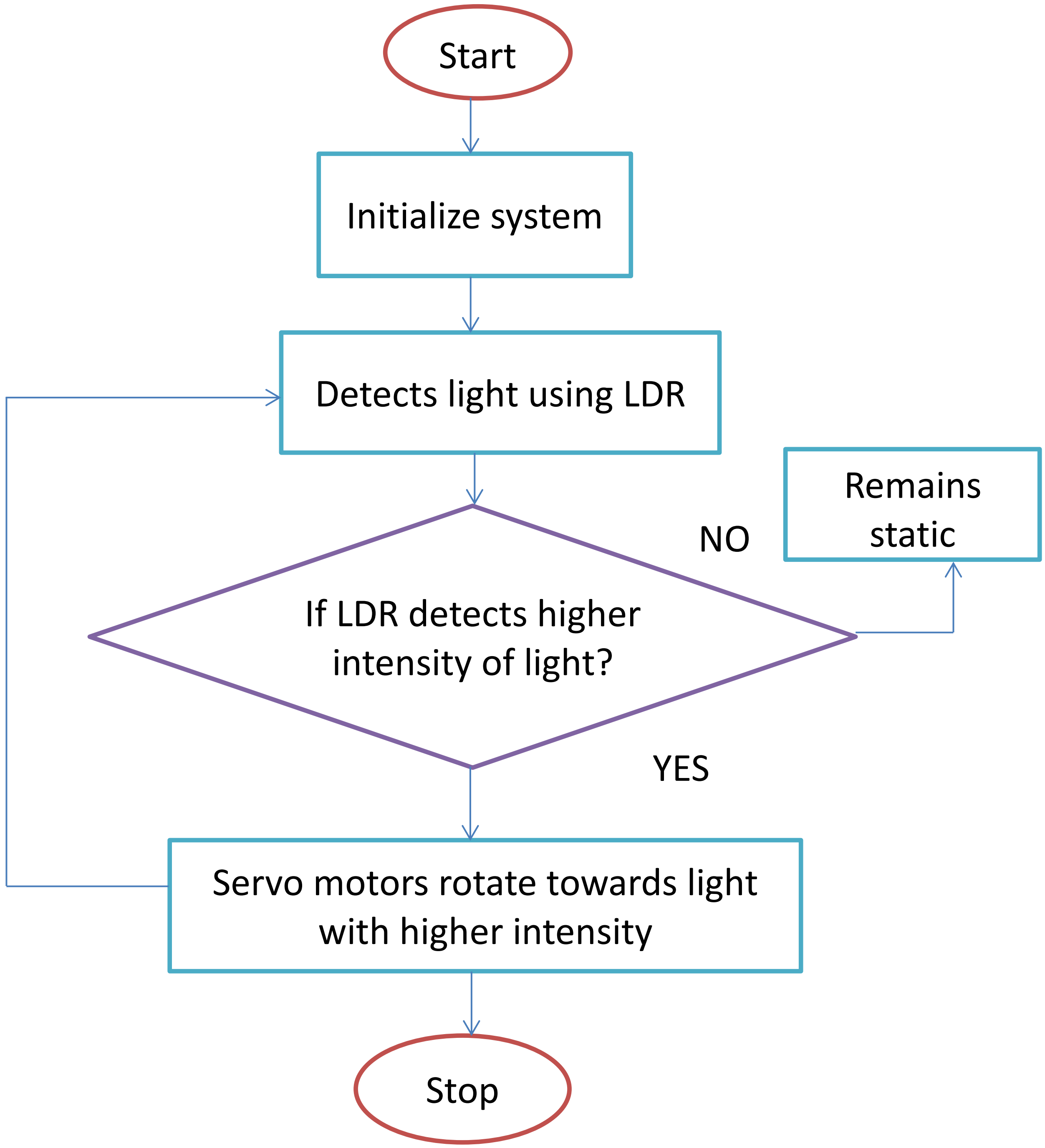


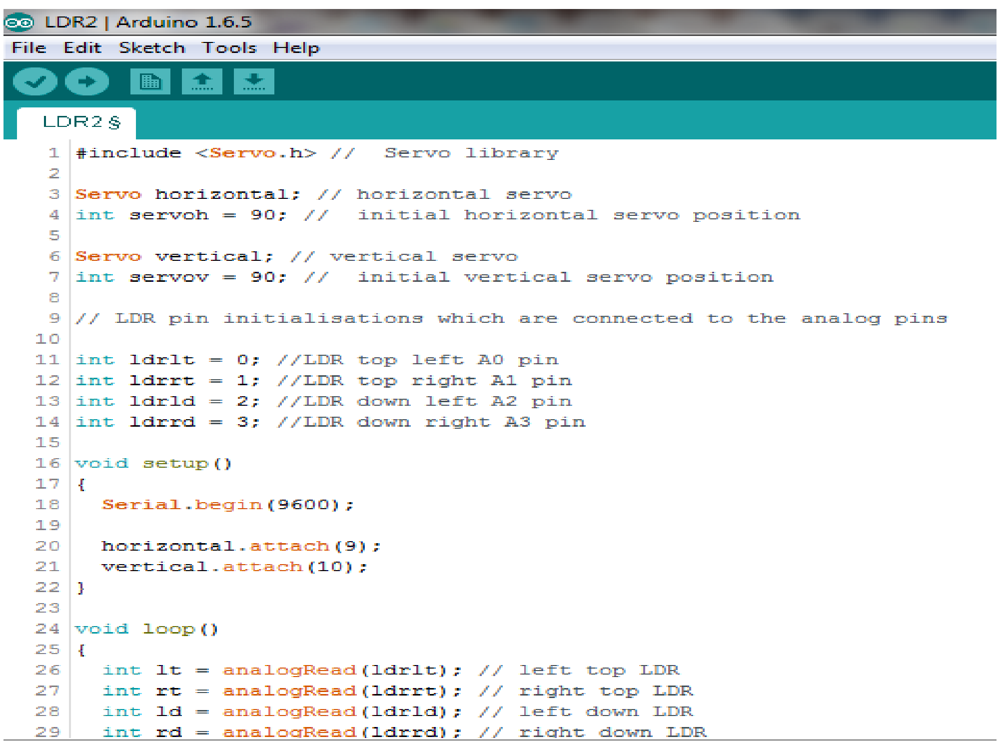
Figure 15: Flowchart/algorithm of a solar tracking system

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Program Implementation

The first draft for the C based code program was written using Arduino IDE for testing and debugging purpose. The most important part is the movement of both servo motors for dual axes directions which are the pan and tilt movement. Below are the screenshots of the main program codes been use.




```
#include <Servo.h> //  Servo library

Servo horizontal; // horizontal servo
int servoh = 90; //  initial horizontal servo position

Servo vertical; // vertical servo
int servov = 90; //  initial vertical servo position

// LDR pin initialisations which are connected to the analog pins

int ldrlt = 0; //LDR top left A0 pin
int ldrrt = 1; //LDR top right A1 pin
int ldrld = 2; //LDR down left A2 pin
int ldrrd = 3; //LDR down right A3 pin

void setup()
{
  Serial.begin(9600);

  horizontal.attach(9);
  vertical.attach(10);
}

void loop()
{
  int lt = analogRead(ldrlt); // left top LDR
  int rt = analogRead(ldrrt); // right top LDR
  int ld = analogRead(ldrld); // left down LDR
  int rd = analogRead(ldrrd); // right down LDR
```

Figure 16: Basic variables initializations

Based on the Fig 16, all the variables are initialized using the analog pins connected. There is also a function to move both servos through a full range of motion for both servos. After the process is complete, they will move to the ideal location for sensing light with the highest intensity.

```
if (-1 * tol > dvert || dvert > tol) // check if the diffirence is in the tolerance else change vertical angle
{
  if (avt > avd)
  {
    servov = ++servov;
    if (servov > 180)
    {
      servov = 180;
    }
  }
  else if (avt < avd)
  {
    servov = --servov;
    if (servov < 0)
    {
      servov = 0;
    }
  }
  vertical.write(servov);
}


if (-1 * tol > dhoriz || dhoriz > tol) // check if the diffirence is in the tolerance else change horizontal angle
{
  if (avl > avr)
  {
    servoh = --servoh;
    if (servoh < 0)
    {
```

Figure 17: Movement of servo motors

The following lines of codes explain about how much the servo is set to turn in degrees. The movement process that it takes for the vertical servo is almost the same as the movement of process of the horizontal servo as shown in Fig 17. Next, it will calculate the average value for the top, down, left and right part of the LDR position and check their difference in value. If the total difference is not within the range of the tolerance else it will change the vertical and horizontal angle.

A few functions are created which can move the servos safely. These functions have two purposes. Firstly, it allows us to control the speed of movement of servos. Basically, servos can move quickly. Therefore, we want to ensure they don't move too quickly. Furthermore, we also need to ensure that the servo motors do not move out of range. In a nutshell, we can use these functions to adjust the movement range and tolerance to whatever we want.

4.2 Motor movement at different position of light

The movement of the servo motors is captured based on the previous program codes. Figure 18 shows the movement of motor in different positions of light source.

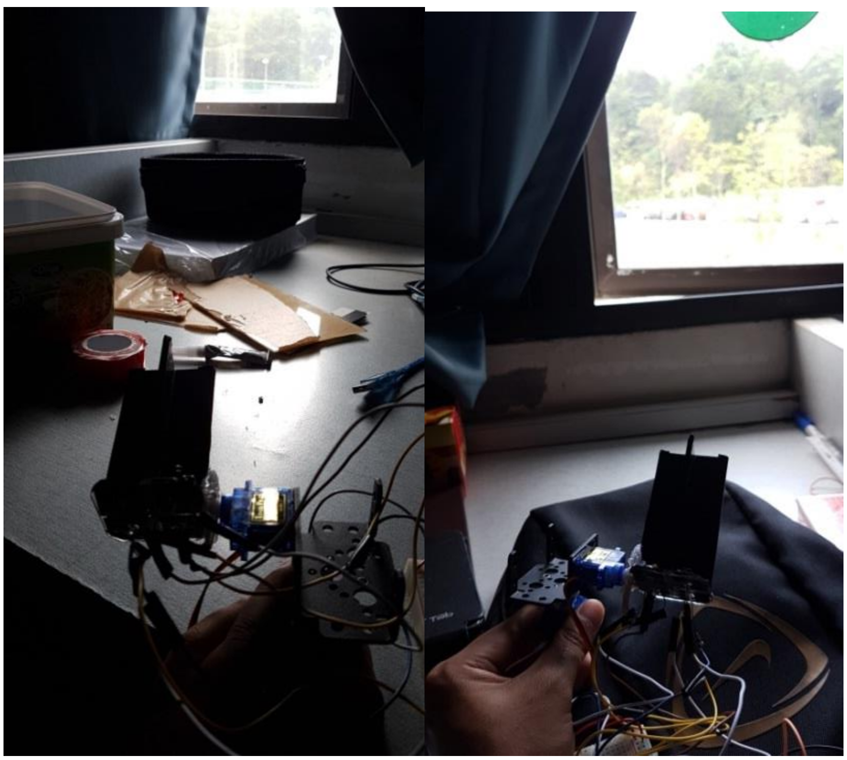
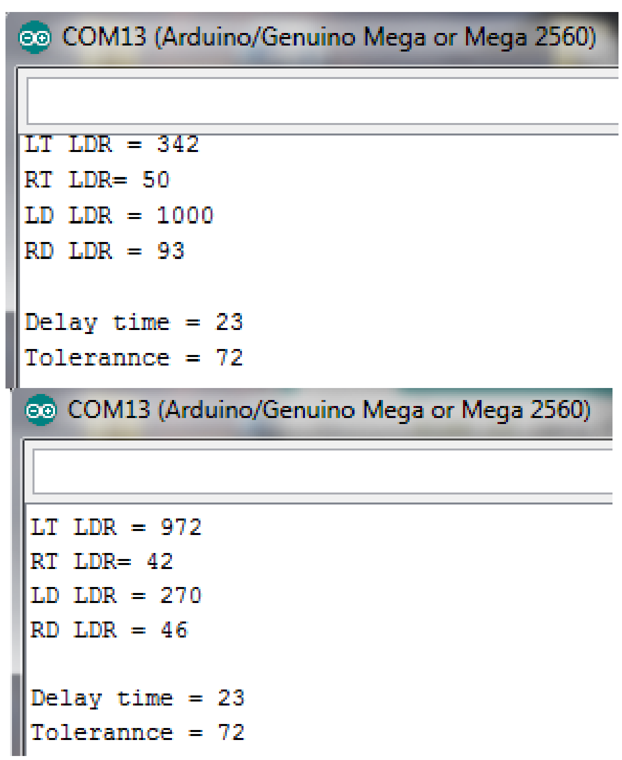


Figure 18: Movement of servo motors in different positions of light source

The four LDRs will get the same amount of light on them when the tracker is pointing towards the sun or the brightest point The LDR which has the highest light intensity pointed to it will cause the servo motors to move to the particular position where the light source is. For example, if there is high intensity of light pointing to the left/right/front/bottom side of the LDRs, the microcontroller will send signal to the servos to rotate towards the light.

4.3 Output of LDR reading using Arduino IDE serial monitor

The LDR will take a number from the analog output within the range 0-1023 and converts it into a reading as the LDR output including the delay time and tolerance as shown in Fig. 19. Therefore, the LDR which has the highest light intensity will have the highest reading, while the LDR with the lowest light intensity will have the lowest reading. Besides, the longer the delay time and the tolerance, the slower it takes for the servos to move and sense light towards the highest light intensity.



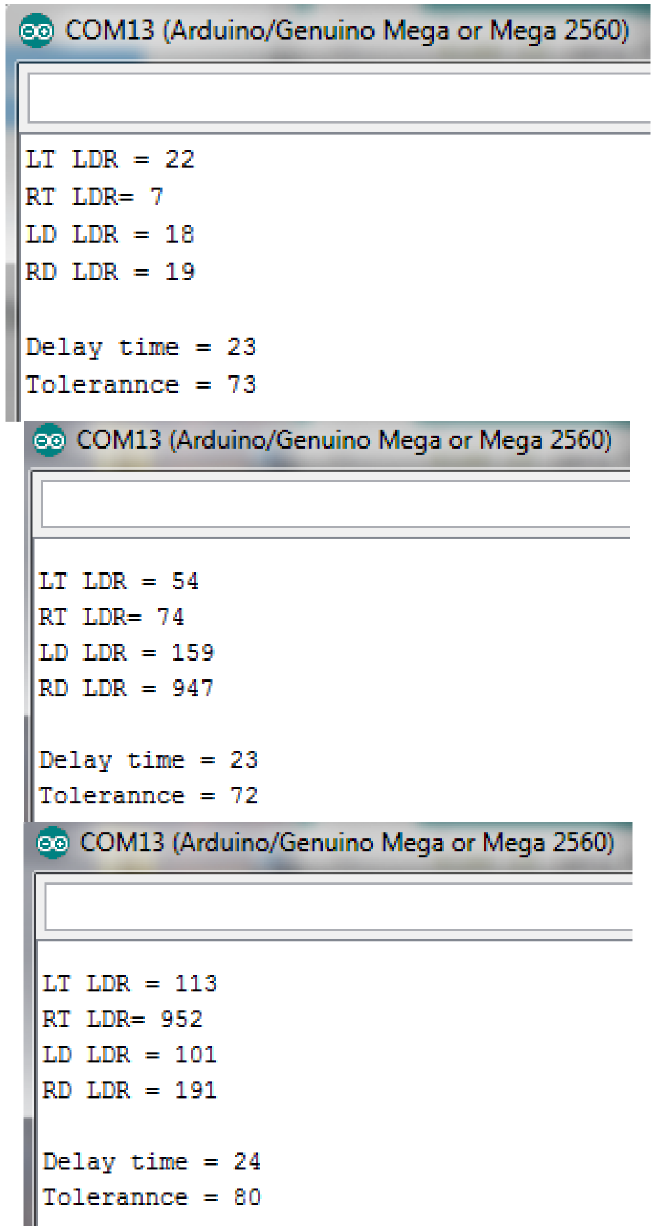


Figure 19: LDR readings including tolerance and delay time

LDR Analog Output Readings	LDR with Highest Light Intensity
LT LDR = 342 RT LDR = 50 **LD LDR = 1000** RD LDR = 93	**Bottom Left LDR (1000)**
LT LDR = 972 RT LDR = 42 LD LDR = 270 RD LDR = 46	**Top Left LDR (972)**
LT LDR = 22 RT LDR = 7 LD LDR = 18 RD LDR = 19	**None. It is not within the range as it is in a dark place**
LT LDR = 54 RT LDR = 74 LD LDR = 159 **RD LDR = 947**	**Bottom Right LDR (947)**
LT LDR = 113 **RT LDR = 952** LD LDR = 101 RD LDR = 191	**Top Right LDR (952)**

Table 7: LDR readings with highest light intensity

Based on Table 7, the highest reading of LDR will be the one which is pointing towards the highest light intensity. There is a range of reading where it is considered as being at the position which has a higher light intensity (850-1000). If the values of LDR reading are too low, it shows that there is no sunlight in that area. (LT=top left; RT=top right; LD=bottom left; RD=bottom right).

4.4 Solar Panel Experimental Results

Data analysis and experimental results are taken to show the efficiency energy harvesting of a static solar panel and also a solar panel with the implementation of a solar tracking system. Table 8 and Table 9 shows the measurements of current, voltage and power output of both the static and tracking solar panel in different period of times in a day.

Time	Voltage (V)	Current (mA)	Power (mW)
9.00 AM	8.13	27.1	220.3
10.00 AM	8.14	27.2	221.4
11.00 AM	7.91	26.4	208.8
12.00 PM	7.96	26.5	210.9
1.00 PM	8.04	26.8	215.4
2.00 PM	8.59	28.7	246.5
3.00 PM	8.19	27.3	223.5
4.00 PM	8.28	27.6	228.5
Average power (mW)			221.9

Table 8: Power output of static solar panel

Time	Voltage (V)	Current (mA)	Power (mW)
9.00 AM	8.69	28.9	251.1
10.00 AM	8.28	27.5	227.7
11.00 AM	8.01	26.6	213.1
12.00 PM	7.98	26.5	211.4
1.00 PM	8.06	26.8	216.0
2.00 PM	8.83	29.4	260.0
3.00 PM	8.33	27.7	230.7
4.00 PM	8.64	28.7	248.0
Average power (mW)			232.1

Table 9: Power output of solar panel with solar tracker

There is some improvement in current by the tracking solar panel compared to the static solar panel. However, there is a slight difference between these two solar panels. This difference will start to increase when the sun continue to move to the west. The highest reading of power outputs for both ways are is 246.5 mW and 260.0 mW respectively at 2:00 pm. Figure 20 shows the comparison of power output curves for both the static and tracking solar panel.

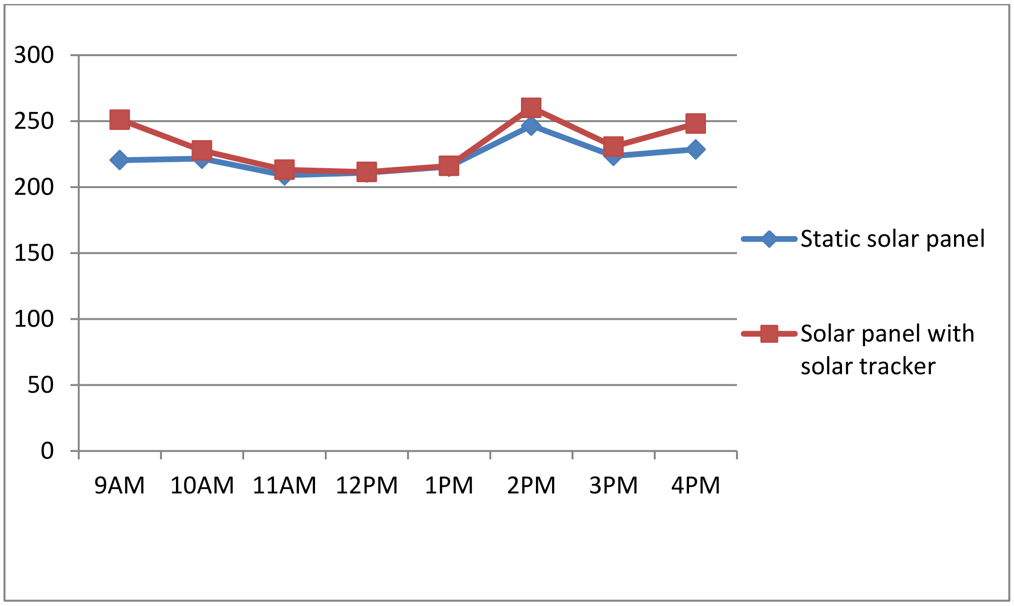


Figure 20: Power output vs time curve for both static and tracking solar panel

The average power output of a static solar panel is 221.9 mW while for tracking solar panel is 232.1 mW. This shows that the solar panel with a solar tracker has the biggest power. Therefore, a solar panel with a solar tracking system is better and efficient.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In a nutshell, it is very important for students or engineers from some engineering fields to deeply understand the technologies used in solar trackers which is related in harvesting solar energy. This project will help in designing and constructing **a** solar tracking system using a microcontroller. Besides, this technology will allow higher amount of energy to be harvested due to the solar arrays being in aligned position with sun. Results show that a solar panel with a tracking system has a better power output than a static solar panel.

In addition to that, there are many ways and things that can be improved for this project. Solar energy has always been a good option in producing power in terms of efficiency. Therefore, the efficiency for the sun tracker can be increased by using an LDR sensor module or wrapping the outer part of the LDR with a black tape, thus will allow light to be pointing directly towards it to increase the accuracy. Besides, we can place an LCD which will display the reading of LDRs at different light intensity. They are also economical and easy to be implemented.

REFERENCES

[1] G. M. Dousoky, A. H. M. El-sayed, and M. Shoyama, "Maximizing Energy-Efficiency in Single-Axis Solar Trackers for Photovoltaic Panels," in *8th International Conference on Power Electronics - ECCE Asia*, 2011, pp. 1458-1463.

[2] W. J. C. Melis, S. K. Mallick, and P. Relf, "Increasing Solar Panel Efficiency in A Sustainable manner," in *2014 IEEE International Energy Conference (ENERGYCON)*, 2014, pp. 912-915.

[3] J. Choi, J. Ko, and D. Chung, “Development of a Novel Tracking System for Photovoltaic Efficiency in Low Level Radiation,” Journal of Power Electronics, Vol. 10, No. 4, pp.405–411, 2010.

[4] S. J. Hamilton, “Sun-Tracking Solar Cell Array System,” University of Queensland, Department of Computer Science and Electrical Engineering, Bachelors Thesis, 1999.

[5] A.K. Saxena and V. Dutta, “A Versatile Microprocessor Based Controller for Solar Tracking,” in Proc. IEEE, 1990, pp. 1105 – 1109.

[6] A. L. Luque and A. Viacheslav, *Concentrator photovoltaics*: Springer, 2007.

[7] David Cooke, "Single vs. Dual Axis Solar Tracking", Alternate Energy eMagazine, April 2011.

[8] A. Kulkarni, T. Kshirsagar, A. Laturia, and P. H. Ghare, "An Intelligent Solar Tracker for Photovoltaic Panels," in *India Educators' Conference (TIIEC), 2013 Texas Instruments*, 2013, *pp*. 390-393.

[9] Poulek, V. and M. Libra, *New solar tracker.* Solar Energy Materials and Solar Cells, 1998**.** 51(2): p. 113-120.

[10] D. Mereddy, V. Vijaya Rama Raju, and T. Sadula, "Smart Dual Axes Solar tracking," in *2015 International Conference on Energy Systems and Applications*, 2015, pp. 370-374.

[11] T.A. Papalias and M. Wong, "Making sense of light sensors," http://www.embedded.com, 2006.

[12] "Fabrication of Dual-Axis Solar Tracking Controller Project", Nader Barsoum, Curtin University, Sarawak, Malaysia, Intelligent Control and Automation, 2011, 2, 57-68.

[13] Tagawa, M. (n.d.) , *A Learning Family*. Retrieved January 8, 2017 from Rotation Slyavula Education: http://www.alearningfamily.com/main/earths-rotation-day-and-night/rotationslyavulaeducation/.

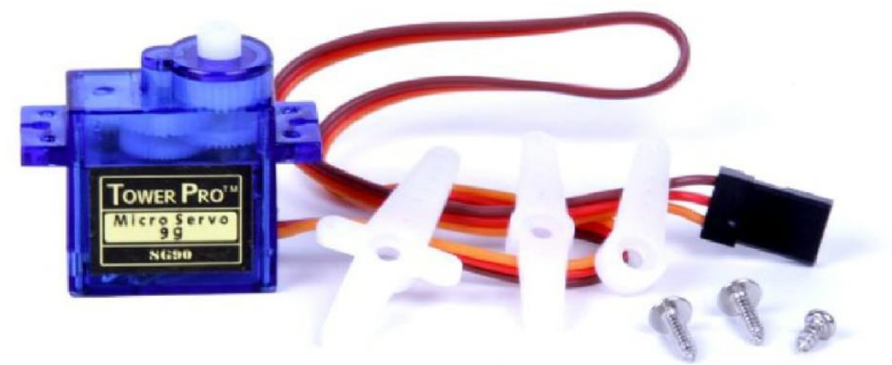
[14] Vemana, P. (Ed.). (2016). *Novel Mech*. Retrieved February 6, 2017 from http://novelmech.com/2016/08/what-is-azimuth-angle-zenith-angle-angle-of-incidence.html

[15] Electrical Technology (2015). Retrieved March 12, 2017 from http://www.electricaltechnology.org/2015/01/resistor-types-resistors-fixed-variable-linear-non-linear.html

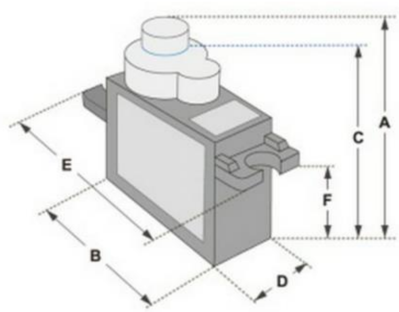
APPENDICES

Appendix 1: Servo Motor Datasheet

SERVO MOTOR SG90 **DATA SHEET**

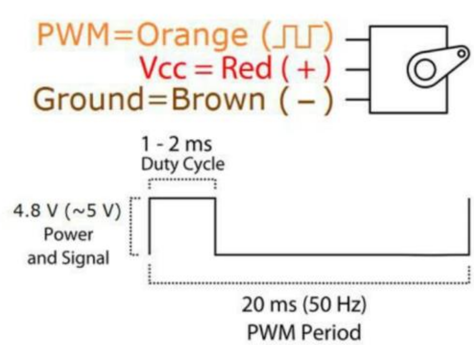


Tiny and lightweight with high output power. Servo can rotate approximately 180 degrees (90 in each direction), and works just like the standard kinds but smaller. You can use any servo code, hardware or library to control these servos. Good for beginners who want to make stuff move without building a motor controller with feedback & gear box, especially since it will fit in small places. It comes with a 3 horns (arms) and hardware.

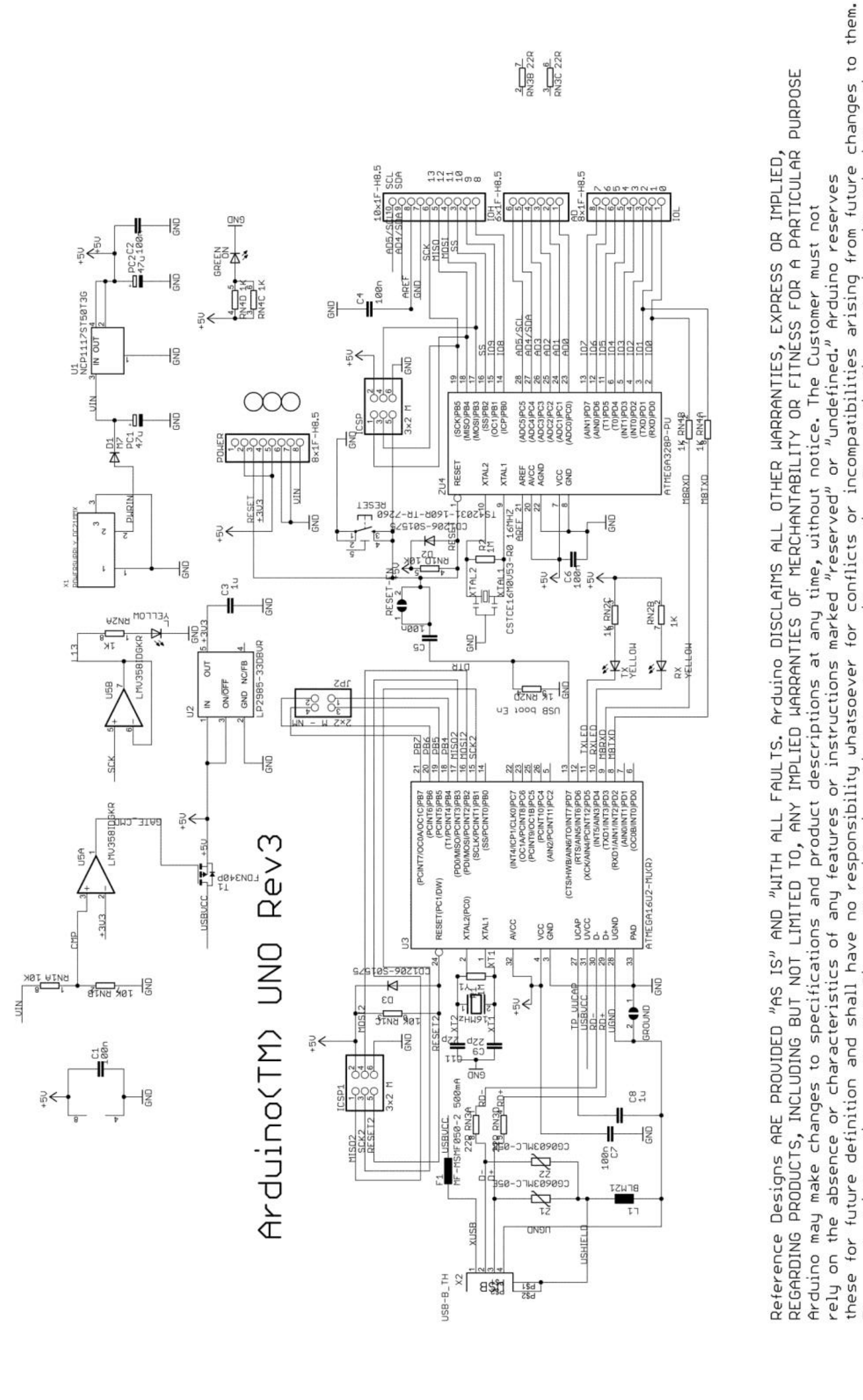


Dimensions & Specifications
A (mm) : 32
B (mm) : 23
C (mm) : 28.5
D (mm) : 12
E (mm) : 32
F (mm) : 19.5
Speed (sec) : 0.1
Torque (kg-cm) : 2.5
Weight (g) : 14.7
Voltage : 4.8 - 6

Position "0" (1.5 ms pulse) is middle, "90" (~2ms pulse) is middle, is all the way to the right, "-90" (~1ms pulse) is all the way to the left.



Appendix 2: Arduino UNO Datasheet



Appendix 3: Complete Arduino Coding

```
#include <Servo.h> // include the servo library provided by Arduino

Servo horizontal; //declaration of horizontal servo

int servohorizontal = 90; // initial position of horizontal servo


Servo vertical; // declaration of vertical servo

int servovertical = 90; // initial position of vertical servo


// Connections of LDR pins

int LDRLT = 0; //Top left LDR

int LDRRT = 1; //Top Right LDR

int LDRLD = 2; //Down Left LDR

int LDRRD = 3; //Down Right LDR


void setup()

{

  Serial.begin(9600);

  horizontal.attach(9);

  vertical.attach(10);

}


void loop()

{

  int LT = analogRead(LDRLT); //Read value from left top LDR

  int RT = analogRead(LDRRT); // Read value from right top LDR

  int LD = analogRead(LDRLD); // Read value from left down LDR

  int RD = analogRead(LDRRD); // Read value from  right down LDR


  Serial.print("Left Top LDR = "); // Display value from left top LDR

  Serial.println(LT);

  Serial.print("Right Top LDR= "); //Display value from right top LDR

  Serial.println(RT );
```

```
Serial.print("Left Down LDR = "); // Display value from left down LDR
Serial.println(LD);
Serial.print("Right Down LDR = "); // Display value from  right down LDR
Serial.println(RD);

int delaytime = analogRead(4)/20; // read potentiometer of delay time
int tolerance = analogRead(5)/4;// read potentiometer of tolerance
Serial.print("Delay time = "); // display potentiometer of delay time
Serial.println(delaytime);
Serial.print("Tolerance = "); // display potentiometer of tolerance
Serial.println(tolerance );
delay(3000);

int avt = (lt + rt) / 2; // average value top
int avd = (ld + rd) / 2; // average value down
int avl = (lt + ld) / 2; // average value left
int avr = (rt + rd) / 2; // average value right

int dvert = avt - avd; // calculate the difference of up and down
int dhoriz = avl - avr;// calculate the difference of left and right

if (-1 * tolerance > dvert || dvert > tolerance) // check if the difference is within the tolerance else change vertical angle
{
 if (avt > avd)
 {
   servovertical = ++servovertical;
   if (servovertical > 180)
{
     servovertical = 180;
   }
 }
 else if (avt < avd)
 {
   servovertical = --servovertical;
```

```
      if (servovertical < 0)
      {
        servovertical = 0;
      }
    }
    vertical.write(servovertical);
  }

  if (-1 * tolerance > dhoriz || dhoriz > tolerance) // check if the difference is within the tolerance else change horizontal angle
  {
    if (avl > avr)
    {
      servohorizontal = --servohorizontal;
      if (servohorizontal < 0)
      {
        servohorizontal = 0;
      }
    }
    else if (avl < avr)
    {
      servohorizontal = ++servohorizontal;
      if (servohorizontal > 180)
      {
        servohorizontal = 180;
      }
    }
    else if (avl == avr)
    {
    }
    horizontal.write(servohorizontal);
  }
  delay(delaytime);
}
```