

# **MICRO-CONTROLLER BASED REAL TIME AUTOMATIC SOLAR TRACKING SYSTEM WITH HOMING MECHANISM**

A Dissertation submitted in fulfillment of the requirements for the Degree  
of

**MASTER OF ENGINEERING**  
*in*  
**Electronic Instrumentation & Control Engineering**

*Submitted by*

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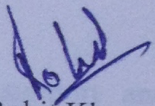
**July 2015**

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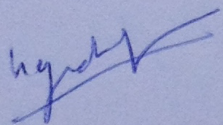
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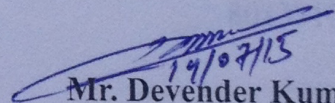
I hereby certify that the work which is presented in dissertation entitled, "Micro-Controller Based Real Time Automatic Solar Tracking System With Homing Mechanism" in partial fulfillment of the requirements for the award of the degree of **Master of Engineering in Electronic Instrumentation and Control** submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala is as authentic record of my own work carried under the supervision of **Dr. Gagandeep Kaur**, Assistant Professor, EIED and **Mr. Devender Kumar**, Assistant Professor, MED. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

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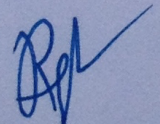
  
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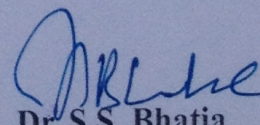
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## ABBREVIATIONS

PV	Photovoltaic
LDR	Light dependent resistor
DC	Direct current
AC	Alternating current
RPM	Revolutions per minute
IC	Integrated circuit
PCB	Printed circuit board
ADC	Analog to digital convertor
GPS	Global positioning system

## **ABSTRACT**

A stable and energy efficient design of a solar tracker is the basic need of the present world. Objective of a solar tracker is to align solar panel perpendicular to the sun rays. A prototype of dual axis automatic solar tracker is developed which is based on solar radiation at that location, in real time. A dual axis solar tracker provides two degree of freedom to a solar panel viz. horizontal motion and vertical motion. DC geared motors have been used to provide motion to solar panel. LDRs are used as a light sensor to detect sunlight. A Freescale micro-controller MCU9S12XDT512 has been used to control the motion of DC motors according to the feedback signal given to it by sensors. Concept of homing mechanism is introduced in this work which works on real time and align the solar panel towards the rising sun in the morning. The prototype developed in this work is independent of seasonal variations and temporary climate changes, by following the solar radiations available at any time during the day.

# CHAPTER 1

## INTRODUCTION

### **1.1 Renewable Energy**

Renewable energy sources are types of natural energy flux useful for human beings that are always present on or near Earth's surface. All known renewable energy sources originate in, or are close derivatives of electromagnetic radiation of Sun, the Earth's and Moon's gravitational fields and heat radiating from earth's interior. Renewable energy sources are practically inexhaustible though some sources such as geothermal and ocean thermal energy conversion may become locally depleted by human use at a rate that exceeds replenishment by natural flux. Solar energy is radiant light and heat from the sun harnessed using a range of ever-evolving technologies such as solar photovoltaics, solar heating, solar architecture, solar thermal energy and artificial photosynthesis. Sun radiates an enormous amount of energy. The radiated energy from sun per second is much more than it reaches earth and utilised by human beings. This energy comes from within the sun. Like other stars sun is also a big ball of gases. Helium and hydrogen atoms present in sun. Hydrogen atoms combine to form a helium atom inside the sun with the emission of a large amount of energy as shown in figure 1.1. During nuclear fusion high temperature and pressure cause hydrogen atoms to come apart and their nuclei to fuse or combine. Four hydrogen atoms fuse to combine one helium atom. Mass of helium atom is lighter than four hydrogen atoms so there is a loss of matter in this reaction causing the emission of a large amount of energy. It takes millions of years for this energy to make its way from sun's core to the sun's surface and 8 minutes to travel 93 million miles to earth. This energy travels to earth with a speed of 186000 miles per second. In spite of such a large amount of energy emitted from sun only one part in two billion strikes the earth. 15% of the total energy coming on earth is reflected back, 30% is used in evaporating water that causes rainfall and rest can be used for our energy requirements. [1]

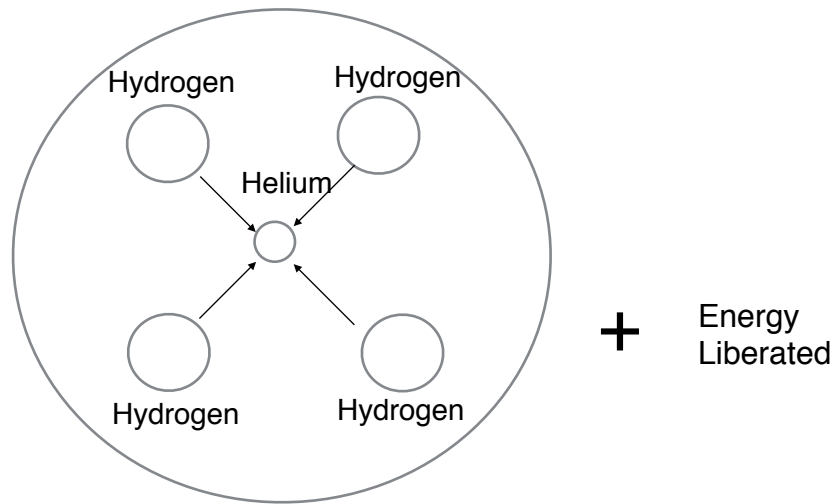


Figure 1.1: Fusion Reaction inside sun[1]

## 1.2 Solar Power in India

India is a tropical country therefore receives adequate solar radiation for 300 days in a year, equivalent to 3,000 hours of sunshine which provides 5,000 trillion kWh. Almost every region in India receive 4-7 kWh of solar radiation per square meters with about 2,300–3,200 sunshine hours/year. [2] The current projects which have been installed and under installation are shown in table 1.1.

Table 1.1 Projects in India [2]

States	Photovoltaic Capacity(Mw)	Solar Thermal Capacity(Mw)
Rajasthan	43	400
Gujrat	722	45
Maharashtra	133	—
Karnataka	10	—
Andhra Pradesh	20.5	—
Uttrakhand	4	—
Punjab	5	—
Haryana	7.8	—
Uttar Pradesh	11	—

States	Photovoltaic Capacity(Mw)	Solar Thermal Capacity(Mw)
Jharkhand	16	—
Chattisgarh	4	—
Madhya Pradesh	7.25	—
Orrisa	11	—
Tamil Nadu	12	—

At present capacity of electricity installed in India is 135,401.63 MW. So it has been observed that there is a peak power lack of about 10% and overall power lack of 7.5%. The 11th plan and MNRE has sets up to add 100,000 MW and 14,500 MW by 2012 from renewable energy resources out of which 50 MW comes out from solar power. [3]

### 1.3 Solar Radiation On Earth Surface

There are two types of radiations which fall on earth surface.

- Beam radiation- The radiation which falls directly on the earth surface is called beam radiations.
- Diffuse radiation- The radiation which comes on surface after being scattered from atmosphere is called diffuse radiation.

The sum of above two mentioned radiations is the total radiation which is received by earth surface.[3]

### 1.4 Angles Related to Sun's Movement

1. **Declination angle-** It is the between the equatorial line and the line drawn from earth's centre to sun's centre point.The declination angle is maximum  $23.45^{\circ}$  in summers or winters, in India which is on 21 June and 22 December. The declination angle varies seasonally due to the tilt of the Earth on its axis of rotation and the rotation of the Earth around the sun.

2. **Hour angle**- It is defined as the angular distance travelled by the earth in an hour. It can be easily obtained from the fact that there are total 24 hours and earth rotates  $360^\circ$  during the whole day. So hour angle comes out to be  $15^\circ$ .
3. **Solar altitude angle**- It is defined as the angle between the horizontal line and the line joining the sun from the centre point. It is denoted by  $\mathcal{M}$  in figure 1.2.
4. **Solar Azimuth Angle**- This angle is denoted by  $z$  in figure 1.2. It is measured in horizontal plane and also in clockwise direction. [4]

Figure 1.2 explains the way to find azimuth and altitude angle. It has east west north and south co-ordinates which forms the basis for the latter angles.

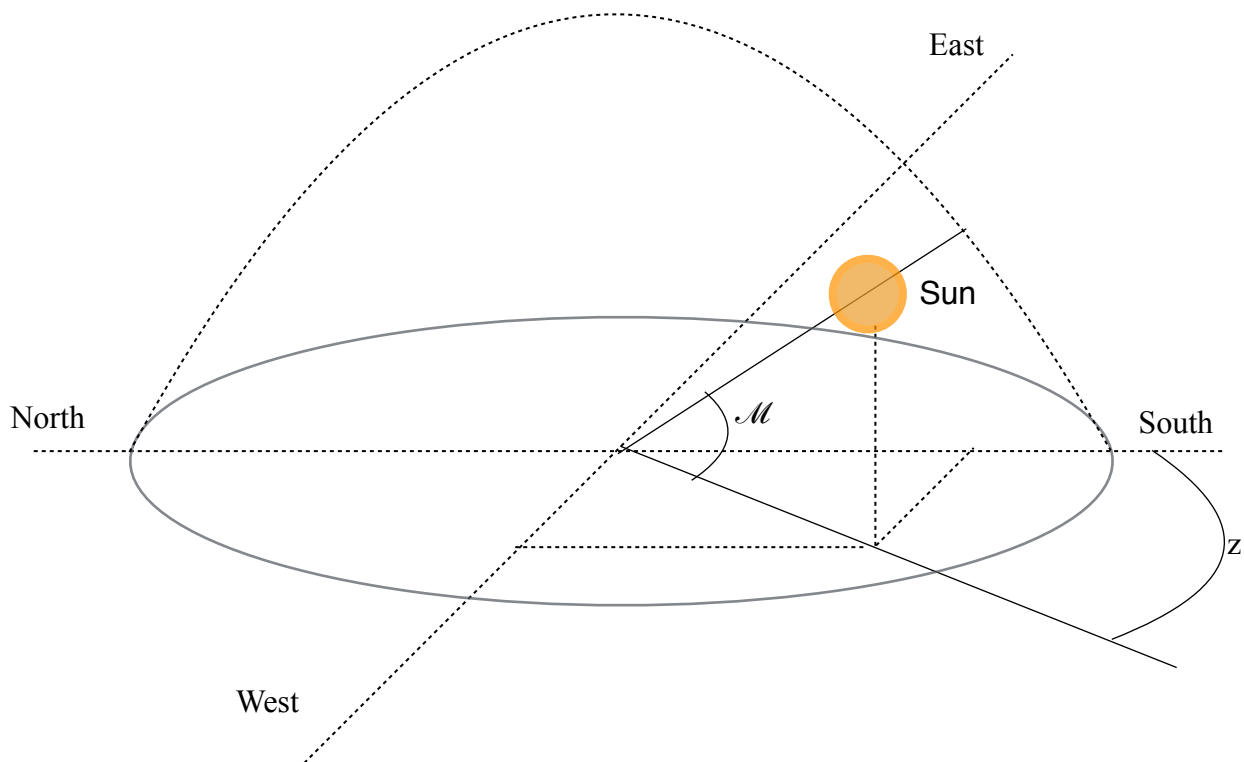


Figure 1.2: Altitude angle and azimuth angle [4,13]

## 1.5 Solar Tracker

Solar tracker is a device that follows the sun's motion during the day. The objective of this device is to provide one or two degree of freedom in movement. Main aim of such devices is to keep the solar panels always at right angle to the sun's light and by doing so increasing the energy output of the solar panel either it be the electric energy or heat energy. [4]

## 1.6 Need For Solar Tracker

The energy share of beams coming from sun drops off by the cosine of angle between the incident light and the solar panel. Table 1.2 shows the direct loss due to the mis alignment angle. [4]

Table 1.2 Direct power loss due to mis alignment angle [4]

Misalignment angle(i) (degree)	Direct power loss= 1- cos(i) (percentage)
0	0
1	0.015
3	0.14
8	1
23.4	8.3
30	13.4
45	30
60	>50
75	>75

Sun moves 360° east-west during a day but taking any fixed point as a reference its motion is visible only for 180°. Location limitations reduces the visible motion to about 150°. A fixed solar panel misses the 75° motion therefore its been shown in the table a loss greater than 75% in morning and evening. Sun also moves 46° in north direction with changing seasons. The same set of panels set at mid point now misses 23° motion on either sides so there is a loss of about 8.3% because of seasonal variations. [4]

## 1.7 Types Of Solar Tracker

Solar trackers can be classified in various ways i.e. classification is based on hanger types, classification on the basis of tracking principle and classification on the basis of sun position sensors. [5]

### 1.7.1 Tracker Classification By Hanger Type

Solar trackers can be classified in two groups single axis and dual axis trackers. Classification is shown in figure 1.3.

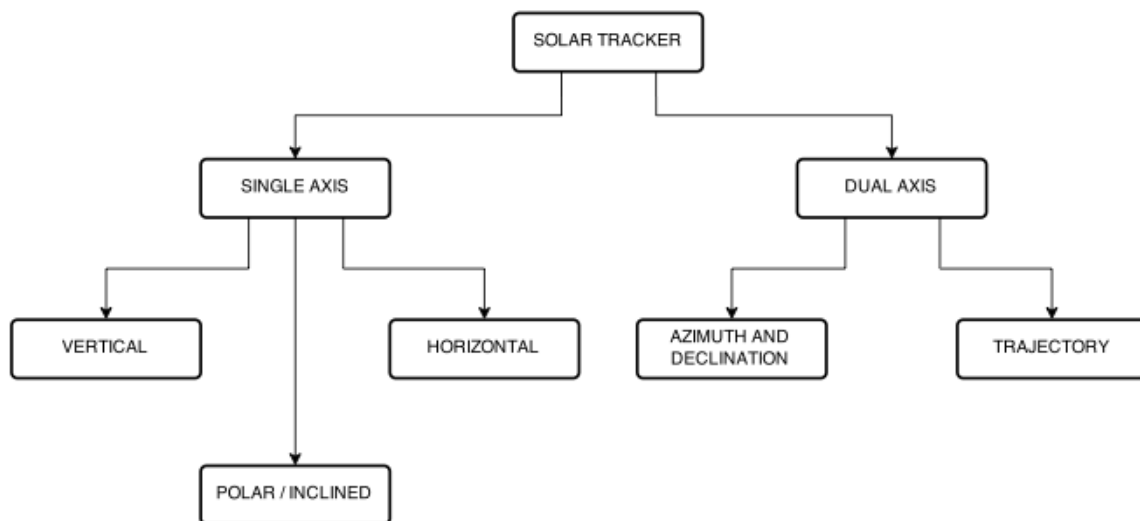


Figure 1.3: Classification Of Solar Tracker[5]

#### 1.7.1.1 Single Axis Solar Tracker

Single axis trackers have one degree of freedom as shown in figure 1.4. These are used to track the solar panels in one direction only. Single-axial trackers are of three types azimuth tracking i.e. vertical, altitude angle tracking i.e. horizontal and fixed altitude angle, which chosen according to the location latitude which are polar or tilted trackers. The azimuth trackers are beneficial to use at high latitude areas where the Sun in summer days doesn't rise high above the horizon, while the length of the day is very long. The horizontal trackers have the highest efficiency if these are installed in regions located near the equator. There is 20% increase in the efficiency of single axis trackers as compared to fixed panels.[5]



Figure 1.4: Single axis tracker [5]

Advantage of this type of tracker is that it is cheaper than dual axis solar tracker. It gives less losses if implemented in wide empty areas where seasonal variation in the motion of sun has negligible effect on tracking. The circuitry and the hardware used to implement single axis tracker is simple and less as compared to dual axis tracker.

#### 1.7.1.2 Dual Axis Solar Tracker

This type of solar tracker tracks the sun in both directions at a time which are east-west and north-south directions. It has two degrees of freedom as shown in figure 1.5. It considers both altitude angle and azimuth angle of sun. This type of tracker has generally two motors to provide motion in two planes i.e. vertical plane and horizontal plane. [5] The dual axis trackers are of two types one with independent azimuth and altitude tracking and second with tracking in a coordinate system directed perpendicularly to the plane of Sun movement. The first type of trackers has the highest efficiency as compared to all other trackers but they are also the more complex in design and control.[5]



Figure 1.5: Dual axis tracker [5]

Advantage of dual axis solar tracker is that it considers variation on motion of sun due to seasonal variation. Efficiency improvement of solar panel is greater than that of single axis solar tracker. Dual axis solar trackers are independent of location.

### **1.7.2 Classification on The Basis of Tracking Principles**

On the basis of tracking principles solar trackers can be classified in three categories.

#### **1.7.2.1 Open Loop Trackers**

This type of tracker determines the position of the Sun for a particular location and time by using mathematical formulas. Such trackers are insensitive to cloudy atmosphere and illuminations. These trackers must be calibrated periodically. In addition, it is necessary to use expensive actuators with position feedback.

#### **1.7.2.2 Closed Loop Trackers**

This tracker orients the panel by using a feedback signal from the sensor. The advantage of this system is its ability to use any actuators. This tracker is insensitive to placement errors and ability to function even in transportable units i.e. no need for the precise placement by the cardinal directions after transportation.

#### **1.7.2.3 Hybrid Trackers**

This tracker has the Sun position sensor, which is used to precisely orient the panel in some region near the calculated position. During sunny weather tracker can be controlled by the signals from the sensors, while in cloudy sky the orientation is calculated by program. Hybrid systems can provide the highest precision in orientation. They are widely used in concentrator PV which requires lowest orientation tolerance.[5]

### **1.7.3 Classification By The Type of Sun Position Sensors**

If the highest precision in orientation is required, a camera with PC image processing can be used as a sensor. Such systems are used only in powerful solar installations. The most common sensor in active solar tracker is an optic-electric converter i.e. photocell for example photo-resistor. Its resistance varies with the variation in incident light i.e. the more light, the

better conductivity of the photo-resistor and therefore less resistance. These photocells are used in pairs in solar trackers, difference in the output values of the two used as a signal to the control system. They are placed in parallel to the surface of the PV panels. Different sensor designs are shown in Figure 1.6. In the simplest, "shaded" sensors, an obstacle is used to the Sun's rays which are perpendicular to the surface of the photosensors to determine the position. "Shaded" sensors are sensitive to parasitic side illumination which are caused by rays reflected from clouds and buildings but they have low sensitivity. Sensitivity factor is improved in pyramidal sensors in which photocells are placed at a certain angle to the surface of the panel. The tunnel sensors are insensitive to parasitic illuminations. Photocells are placed at the bottom of the tube with a hole on the opposite side known as aperture. The value of the aperture decides the sensitivity and accuracy. The tunnel sensor has a limited operation angle where the Sun can be found. To maintain the low cost and complexity of the system a modified pyramidal sensor was proposed which is shown in figure 1.7. This system provides high sensitivity and protected from the parasitic illuminations. A compromise between the range of operating angles and protection can be achieved by adjusting the angle and height of the protective cone.[5]

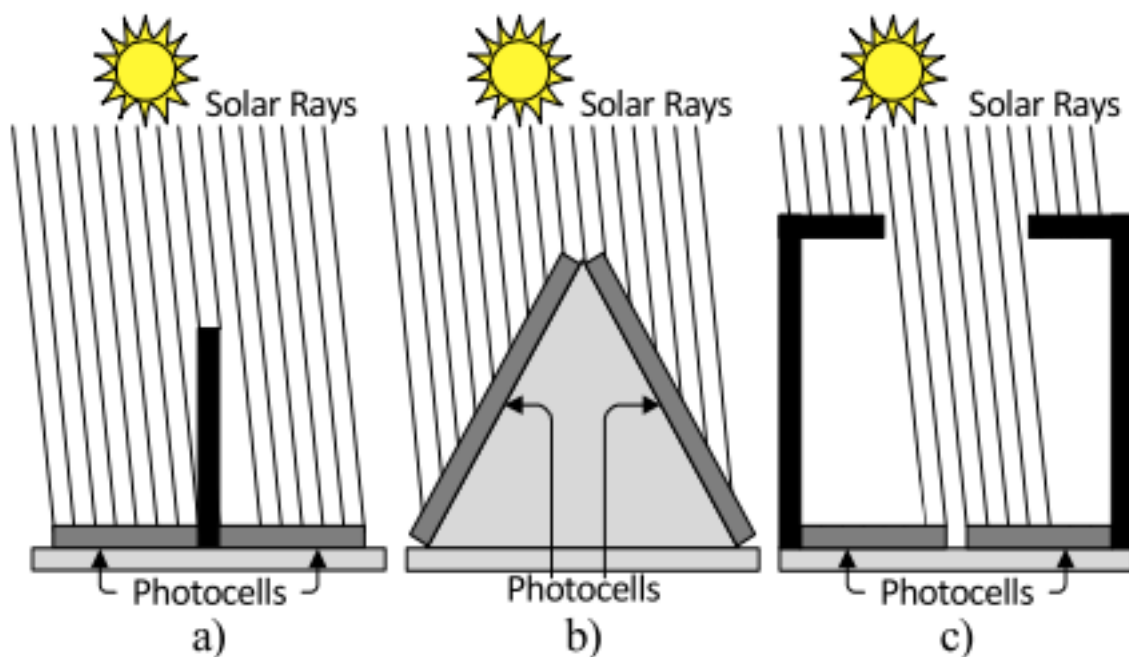


Figure 1.6: a) Shaded, b) pyramidal, c) Tunnel [5]

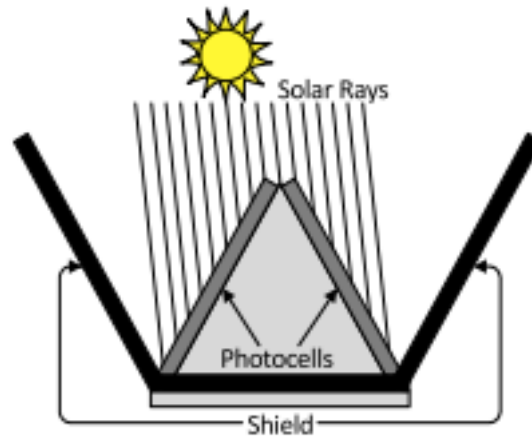


Figure 1.7: Modified pyramidal sensor [5]

## 1.8 Basic Components In A Solar Tracker

Components required to develop a solar tracker are sensors, motor, motor driver, controller and potentiometer. All of these are explained here in brief.

### 1.8.1 Sensors

Various sensors that can be used to sense sun light in a solar tracker are light dependent resistors (LDR), photodiode, phototransistors etc. But LDR is considered as best sensor to be used in solar tracker. Though Photo-diodes have quicker response time than an LDR but this property does not plays an important role in tracking sunlight. In contrast to this connections of LDR is simple as it is a bidirectional device whereas photodiodes are unidirectional. Besides this photodiodes are digital in nature and thus makes the circuit more complex and sophisticated. Adding to disadvantages photodiodes are temperature sensitive and costlier than LDRs. Talking about phototransistor, it is slower in response time. Phototransistors are basically used in those applications where amplification of the light signal is required. In a solar tracker light amplification would also be unnecessary. Besides, phototransistors are temperature sensitive, unidirectional and needs sophisticated circuit design.[6]

A photo-resistor or light-dependent resistor (LDR) or photocell is a light-controlled variable resistor. The resistance of a photo-resistor decreases with increasing incident light intensity or one can say it exhibits photoconductivity. A photo-resistor can be used in light-sensitive detector circuits and light and dark activated switching circuits. A photo-resistor is made of a

high resistance semiconductor. In dark, a photo-resistor can have a resistance as high as a few megohms ( $M\Omega$ ), while in light, a photo-resistor can have a resistance as low as a few hundred ohms. If incident light on a photo-resistor exceeds a certain frequency, photons absorbed by the semiconductor give bounded electrons enough energy to jump into the conduction band. The resulting free electrons (and their hole partners) conduct electricity, thereby lowering resistance. The resistance range and sensitivity of a photo-resistor can substantially differ among dissimilar devices. Moreover, unique photo-resistors may react substantially differently to photons within certain wavelength bands. A photoelectric device can be either intrinsic or extrinsic. An intrinsic semiconductor has its own charge carriers and is not an efficient semiconductor, for example, silicon. In intrinsic devices the only available electrons are in the valence band, and hence the photon must have enough energy to excite the electron across the entire band-gap. Extrinsic devices have impurities, also called dopant, added whose ground state energy is closer to the conduction band; since the electrons do not have as far to jump, lower energy photons (that is, longer wavelengths and lower frequencies) are sufficient to trigger the device. If a sample of silicon has some of its atoms replaced by phosphorus atoms (impurities), there will be extra electrons available for conduction. This is an example of an extrinsic semiconductor. The Characteristics of LDR with respect to solar radiation is shown in Figure 1.8. [7]

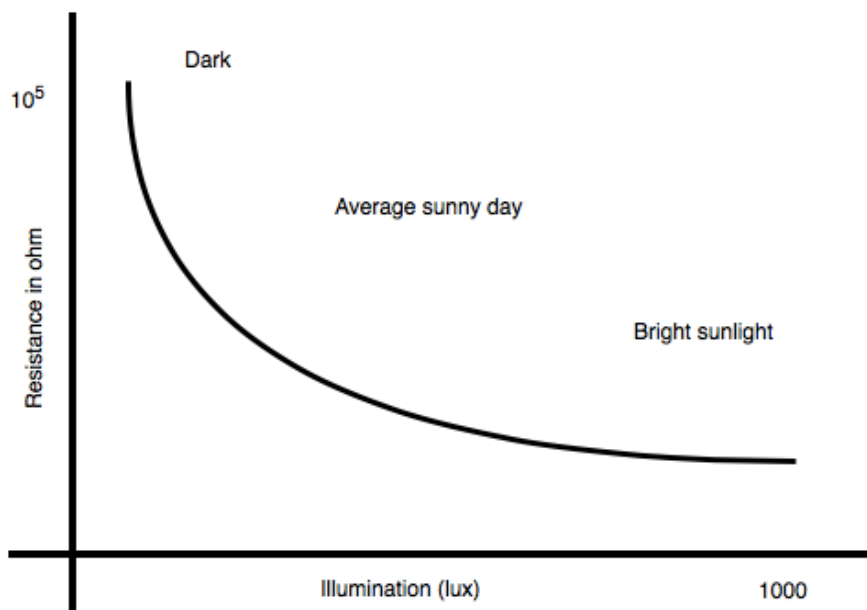


Figure 1.8: Variation of efficiency of LDR with solar radiation [6]

## 1.8.2 Motors

Motor is used to convert electrical energy into mechanical form. Motor is basically an actuator in solar tracking application which is used to provide motion to solar panel. In a dual axis tracker two motors are required to provide two degrees of freedom to solar panel. Different motors can be used in solar tracker viz. stepper motor, dc motor, dc geared motor etc. Selection of a particular motor depends on application in which it is to be used. In some applications where step movement is required stepper motor is used. Stepper motor can also be used in solar tracking mechanism by reducing its step size. Controlling of a stepper motor is bit complex by using a micro-controller. DC geared motor has continuous motion but its speed is much more which is not required in solar tracking application. DC geared motor is a good actuator which has optimum speed and its controlling is simple as compared to other motors. Figure 1.9 shows the diagram of DC geared motor and stepper motor.

A gear motor is a type of electrical motor. Like other electrical motors, it uses the magnetism induced by an electrical current to rotate a rotor that is connected to a shaft. The energy transferred from the rotor to the shaft is then used to power a connected device. In a gear motor, the energy output is used to turn a series of gears in an integrated gear train. There are different types of gear motors, but the most common are AC (alternating current) and DC (direct current). Gear motors have a speed rate of 100 to 3600 RPMs. This speed can be classified into categories: the normal and stall-speed torque. As the gear motor uses magnetic current, the gears in the gearbox or gear reduction equipment are turned. A secondary shaft is attached to the gears, resulting to the increase of torque that the motor produces as its output speed is reduced simultaneously. When this happens, the gear motor draws less current to operate and functions at slow speed, but gives more torque. [8]



Figure 1.9: DC geared motor and stepper motor

### 1.8.3 Motor Driver

It is an integrated circuit used to drive motor. Different motor drivers are required to drive different motors for example DRV8412, DRV8711, L298 are used for stepper motor. L293D is generally used for dc geared motor which is used in solar tracker. Figure 1.10 shows the IC of different motor drivers.

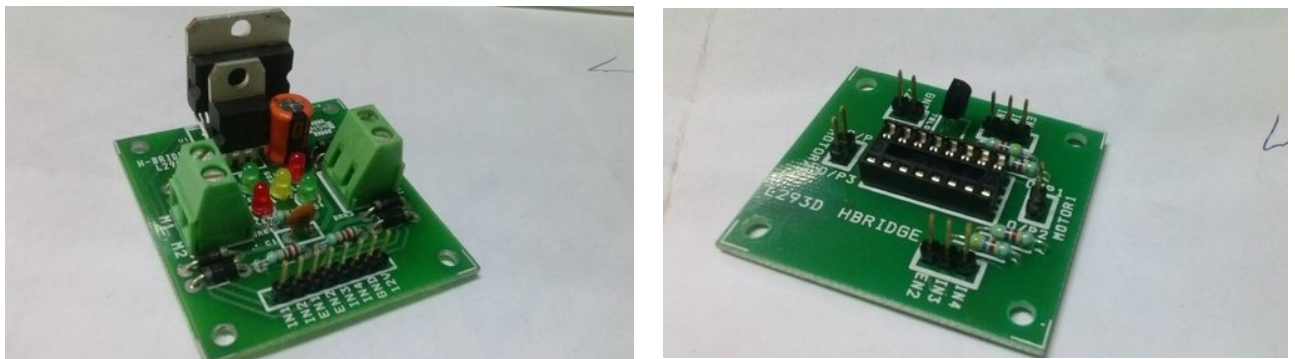


Figure 1.10: L298 and L293D motor drivers

### 1.8.4 Micro-controller

A micro-controller is a self-contained system with memory, peripherals and a processor that can be used as an embedded system. Most programmable micro-controllers that are used are embedded in consumer products or machinery including peripherals, phones, automobiles and other household appliances. Due to this, another name for a micro-controller is "embedded controller." Some embedded systems are more sophisticated while others have minimal requirements for memory and programming length and a low software complexity. [9] Figure 1.11 shows the basic block diagram of a micro-controller.

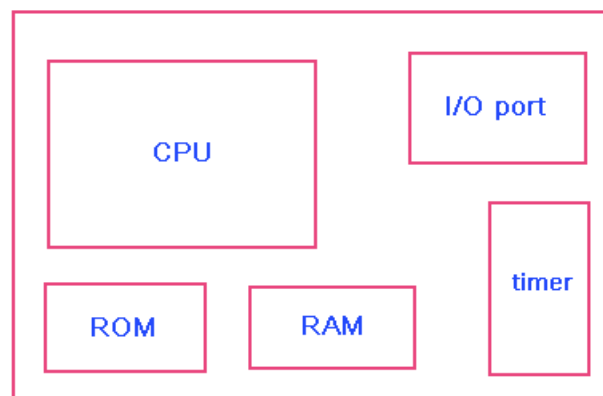


Figure 1.11: Block diagram of micro-controller

### 1.8.5 Potentiometer

A potentiometer is a 3 terminal device whose resistance can be manually adjusted. Two terminals are connected to both ends of a resistive element and third terminal is connected to a sliding contact known as wiper which moves over the resistive element. The position of the wiper is used to determine the output voltage of the potentiometer. The potentiometer essentially functions as a voltage divider. The resistive element can be seen as two resistors in series known as potentiometer resistance. The position of wiper determines the resistance ratio of the first resistor to the second resistor. A potentiometer is also commonly known as a pot or preset. It is named as preset when there is no rotating terminal in it rather than that it has a screw to adjust the wiper. The most common form of pot is the single turn rotary pot. This type of pot is used in audio volume control. Different materials are used to construct potentiometers including cermet, carbon composition, wire wound, metal film or conductive plastic. Table 1.3 shows different types of potentiometers with their applications. Figure 1.12 shows different types of potentiometers which are mentioned in table. [10]



Figure 1.12: Dual gang, concentric, multi-turn, Slide motorised and multi-turn linear potentiometers[10]

Table 1.3: Different types of potentiometer[10]

Type	Description	Application
Single-turn pot	Single rotation of approximately 270 degrees or 3/4 of a full turn.	Most common pot, used in applications where a single turn provides enough control resolution.
Multi-turn pot	Multiple rotations mostly 5, 10 or 20, for increased precision. They are constructed either with a wiper that follows a spiral or helix form or by using a worm-gear.	Used where high precision and resolution is required. The worm-gear multi turn pots are often used as trim pots on PCB.
Dual-gang pot	Two potentiometer combined on the same shaft, enabling the parallel setting of two channels. Most common are single turn potentiometers with equal resistance and taper. More than two gangs are possible but not very common.	Used in stereo audio volume control or other applications where 2 channels have to be adjusted in parallel.
Concentric pot	Dual potmeter, where the two potentiometers are individually adjusted by means of concentric shafts. Enables the use of two controls on one unit.	Often encountered in (older) car radios, where the volume and tone controls are combined.
Servo pot	A motorized potmeter which can also be automatically adjusted by a servo motor.	Used where manual and automatic adjustment is required. Often seen in audio equipment, where the remote-control can turn the volume control knob.
Slide pot	Single linear slider potentiometer, for audio applications also known as a fader. High quality faders are often constructed from conductive plastic.	For single channel control or measurement of distance.

Type	Description	Application
Dual-slide pot	Dual slide potentiometer, single slider controlling two potentiometers in parallel.	Often used for stereo control in professional audio or other applications where dual parallel channels are controlled.
Multi-turn slide	Constructed from a spindle which actuates a linear potentiometer wiper. Multiple rotations (mostly 5, 10 or 20), for increased precision.	Used where high precision and resolution is required. The multi turn linear pots are used as trimpots on PCB, but not as common as the worm-gear trimmer potentiometer.
Motorized fader	Fader which can be automatically adjusted by a servo motor.	Used where manual and automatic adjustment is required. Common in studio audio mixers, where the servo faders can be automatically moved to a saved configuration.

## CHAPTER 2

### LITERATURE REVIEW

[4] **Sukhraj Singh Cheema** devised mathematical simulation and control of dual axis solar tracking. The dual axis solar photovoltaic panel moves in horizontal and vertical directions. Altitude angle and azimuth angle are taken as reference for vertical and horizontal motion of the panel. The fuzzy controller has been used to control the position of DC motors. The mechanical design consists of rotary joints and two DC motors. This tracking system makes the solar photovoltaic array more efficient by keeping the panel's face perpendicular to the sun and therefore extracts maximum solar energy resulting into increased overall efficiency. The proposed control has the capability to be installed in different regions with minor modifications.

[5] **Oleksandr Veligorskyi et al.** proposed an active 2-axis solar tracker with control system which is verified on the developed prototype. The efficiency of the proposed tracker is calculated on three specific days of the year that allows to determine the PV system efficiency increasing range taking into account PV panel orientation losses. The efficiency of solar panel with tracker is then compared with the same panel installed at an angle of 45 degrees to the horizon. It is found that the efficiency of latter is 27% less than the former. The maximum efficiency improvement from tracker usage reaches 76% under the same conditions in summer.

[6] **Twisha Titirsha et al.** puts forward a proposal for using a dual axis solar tracker with reflector instead of simple solar panel to receive maximum sunlight. In their work they consider the increasing energy demands of Bangladesh which cannot be fulfilled by conventional sources of energy. They proposed a design of ideal solar house model using azimuth-altitude dual axis solar tracker on rooftop. Apart from this, the paper presents a application and structure of a micro-controller based azimuth-altitude dual axis solar tracker which tracks the motion of sun during the day. Comparison of LDR and other sensors is also shown in this work which concludes that LDR is best sensor for solar tracker. Six LDR's have been used in this work. A built-in ADC converter is used to drive motor circuit. To minimize the power consumption two stepper motors are used especially during the seasonal

change. In this work a fixed reflector is used on the front part of the tracker to make the best use of diffused rays of the sun. The analysis shows that the proposed tracking system with reflector increases the output of the PV cell significantly in comparison with solar panel without reflector. For industrial development of country it can contribute the surplus energy to the national grid during peak hour. 50% increase in energy efficiency is recorded in this work. Optimal generation of solar energy can bring about positive change both in micro and macroeconomics.

[11] **Dimitrija Angelkov *et al.*** presented a description of an active solar tracking system, which computes the position of sun as a function of topocentric position and time. A design of an automatic solar tracker based on micro-controller is presented in this paper. The Sun positioning testing procedures conducted included two primary motor calibration tests and a heliostat positioning test with two micro switches. The measured errors from the motor positioning tests were in the range of  $0.22^\circ$ , whereas solar positioning tests conducted showed an error of  $0.21^\circ$  which are enough to satisfy the decreased cost and increased accuracy. The sun positioning testing procedures conducted included two primary motor calibration tests and a heliostat positioning test with two micro switches. This system can be used to track every kind of object in the sky. With small amendments, it can be used in telescopes to watch the objects in the sky.

[12] **A. Nadjah *et al.*** proposed a new design and construction of a solar tracking system based on dsPIC30F6014A micro-controller. This project develops a new and efficient design of a micro-controller operated two-axis Sun tracker which is driven by only one motor. The advantages of this design deals with the low cost of realisation and low power consumption. It uses only two LDR's. Limit switches have been used to take the solar panel to its home position. The mechanical structure is very reliable and simple, it was designed in such manner to allow the control of two degree of freedom (azimuth and altitude) by only one driving DC motor. The controller circuit has been designed with multiple sensors units like radiation, temperature, angle and limit edge with possibility to store daily data measurements on MMC support which can be useful for evaluating the performances of the designed sun tracker.

[13] **A.B. Afarulrazi *et al.*** presented the design and development of an automatic Solar Tracker Robot (STR) which is capable to track maximum light of sun. The efficiency of the solar energy conversion can be optimised by receiving maximum light on the solar panel. The main components of the robot consist of micro-controller namely PIC16F877A, sensors, servo motors and digital compass. This robot is programmed to detect sunlight by using two Light Dependent Resistors (LDR). Servo motor gives motion to the solar panel to receive maximum light. Digital compass is used to detect the error in position of the robot. Two modified DC servo motors will move the robot back to the original position once the robot is out of position. Analysis on the power conversion of solar panel is being carried out by using Fluke 1750 power quality recorder. The robot is programmed using MPLAB IDE v8.30. This work includes the use of limit switches to bring the panel back to its home position. Only east-west direction is taken into account in this project.

[14] **Salih Fadil *et al.*** designed and realized two axis solar tracking system by using LDR sensors and DC motors with gear arrangements. The tracking of both azimuth angle and altitude angle has been implemented by micro-controller. Important points of this design are using minimum energy while tracking,,maximum energy efficiency with gear arrangements, stability of trajectory and cheaper than the other tracker systems. A PV panel with 40x90 cm is used. Maximum output voltage from the PV panel is 24 volts. The output voltage from the PV panel has been measured during a sunny day at fixed position toward south-east and with the solar tracker in Eskisehir. The average output voltage from the panel is 16.32 volts when the panel is at the fixed position. However, it is 21.48 volts when the position of the panel is controlled by the solar tracker. Especially, the efficiency of the PV panel is minimum in the morning and sunset times. Reflection rate of the PV panel is also greater than that of PV panel with tracker system. Two axis solar tracker remains normal to sun rays. Thus, most of the received sun rays are absorbed by the PV panel. Reflection is also reduced. Different motor types have been tried for tracker system. Stepper motor has been used but, too much power has been needed to provide the stability of tracker positions. Since using stepper motors has decreased the efficiency of system, DC motors with gear arrangements have been used instead.

[15] **Prabodh Bajpai *et al.*** proposed an automatic solar tracking system using LDR sensors and DC geared motors on a mechanical structure. Two-axis solar tracking has been designed through micro-controller based control logic. Performance of the proposed system over the important parameters like maximum hourly electrical power, solar radiation received on the collector, short circuit current, open circuit voltage, efficiency gain and fill factor has been calculated and compared with the fixed solar collector. The average gain in the maximum power and efficiency obtained with dual axis tracking system is 5.0423 W/hour and 28.87% respectively compared to the fixed PV system. However in the proposed system with an increase in received solar irradiation, losses in the PV module increases and therefore performance declines. This behaviour has been seen in all the performance parameters around noon time however fill factor remains low for most of time during the day.

[16] **Lwin Lwin Oo *et al.*** developed and implemented a prototype of two-axis solar tracking system using a PIC micro-controller. The parabolic reflector is constructed around two feet diameter to capture the sun's energy. The focus of the parabolic reflector is theoretically calculated to a very small point to get extremely high temperature. The assembly programming language is used to interface the PIC with two-axis solar tracking system. The temperature at the focus of the parabolic reflector is measured with temperature probes. Two 12V, 6W DC gear box motors have been used in this project. 5 LDR's are used to track the sun and to start the operation. Time Delays are used for stepping the motor and reaching the original position of the reflector. The two-axis solar tracking system is constructed with both hardware and software implementations. The designs of the gear and the parabolic reflector are carefully considered and precisely calculated. The parabolic reflector is placed to face the sun by manual before the experiment. And then this reflector traces the sun whole day until the reflector touches the limit switches. Limit switches are placed at 30° in the East-West of the reflector. The parabolic reflector moves one time in 5 minutes.

[17] **M. Amir Abas *et al.*** presented in their work a new mechanical structure for solar tracker. Two stepper motors have been used on X and Y axis. The rotation controlled by a pre-programmed micro-controller device PIC 18F4560 through C language. The algorithm is based on the measurement of intensity of solar radiation which is captured by Pyranometer which is a ultra violet sensitive device. The system has been tested and the results show very

vital impact on the design, controlling mechanism and also the cost. In this work some initial manual calibrations are required to start the tracking. Tracking has been done on the basis of time which is a big drawback of this work. Costly sensors have been used to detect sun light and complex circuitry has been installed for tracking. Real time clock has been installed to for time check.[14]

[18] **S.B.Elagib *et al.*** presented the design and development of a Microcontroller based solar tracker, based on solar maps, which depends on apparent position of the Sun, which is detected by latitude's location. GPS technology has been used in this work. The program calculates the azimuth and zenith angles using the Solar Position Algorithm for 30 days therefore regardless of changes in motion of sun for the next 30 days this tracker tracks the sun. Dependency on location of sun at a particular time is the major drawback in this work.

[19] **J. F. Lee *et al.*** proposed a low cost prototype dual- axis solar tracking system. Designed by using a low cost micro-controller and light sensors to detect the sun's movement and follow it accordingly throughout the year. Analysis of performance of dual-axis tracking system and fixed-position system has been done and discussed qualitatively and quantitatively based on outdoor environment under Malaysia climate. Comparative results depicted that performance in terms of irradiance and energy gain of static solar system thrives by dual-axis tracking system. Proper explanation of tracking has not been explained in this work. Homing mechanism is not considered in designing of dual axis solar tracker. Main focus is on the performance difference of dual axis tracker and fixed panel models.

[20] **Wang Wei *et al.*** focuses on the MPC control method of dual-axis solar tracking system. SIMULINK of MATLAB and typical mathematical model for simulation of stepper motor object have been combined to conduct a simulation analysis. Good speed and stability of solar panels in tracking process has been achieved. This work is based on latitude and longitude of a particular location which limits the use of this type of tracker.

[21] **Pardeep Singh** performed an experimental study to investigate the effect maximum temperature obtained for different tracking mechanisms viz. manual, fixed position and automatic on the parabolic trough collector. It includes design, fabrication and

characterisation of different tracking mechanisms. This work does not include the concept of homing mechanism. Therefore tracker needs to be adjusted during sunrise.

## **2.1 Gaps in Literature**

Most of the research work done on automatic solar tracking includes limit switches to attain homing position of solar panel or based on location and time which makes the system complex and unreliable. Therefore there is a need to daily readjust the solar panel in morning towards the rising sun. The work done in this field did not include the concept of micro-controller based homing mechanism except as described by Sukhraj Singh Cheema. But the system is still not suitable for all seasonal variations and needs to be reprogrammed with changing seasons and geographical locations. Earlier works used various types of sensors like pyranometer, digital compass which makes the project costly to use it for domestic purposes. Complexity of solar trackers builds a reluctant nature in the minds of customers to use it as it complicates the man-machine interface. Some works include the use of large storage devices to store and calibrate the tracker according to geographical data of a particular location which again increases the cost and complexity. In many dual axis solar trackers two motors move simultaneously at a time leads to power loss. Stepper motor used in many trackers requires precise controlling mechanism.

## **2.2 Objective**

Objective of present work is to design a micro-controller based real time automatic solar tracking system. The objective includes the real time control of solar panel for any location of sun during the day and throughout the year, without using any geographical data of that location. It also includes automatic homing of solar panel towards the rising sun in morning.

**3.1 Methodology Followed**

The methodology includes the design of the solar tracker and its electromechanical control system. Parts of solar tracker are then designed in part modelling software CREO. After designing all the parts and electronic circuitry, actual prototype is developed in sheet metal shop and carpentry shop. The control mechanism also involves programming of a controller to control dc geared motor as per the feedback of light sensors. Electronics part includes the various electronics components required which are light sensors, potentiometers, motors, motor driver and micro-controller. Layout of methodology is illustrated in figure 3.1.

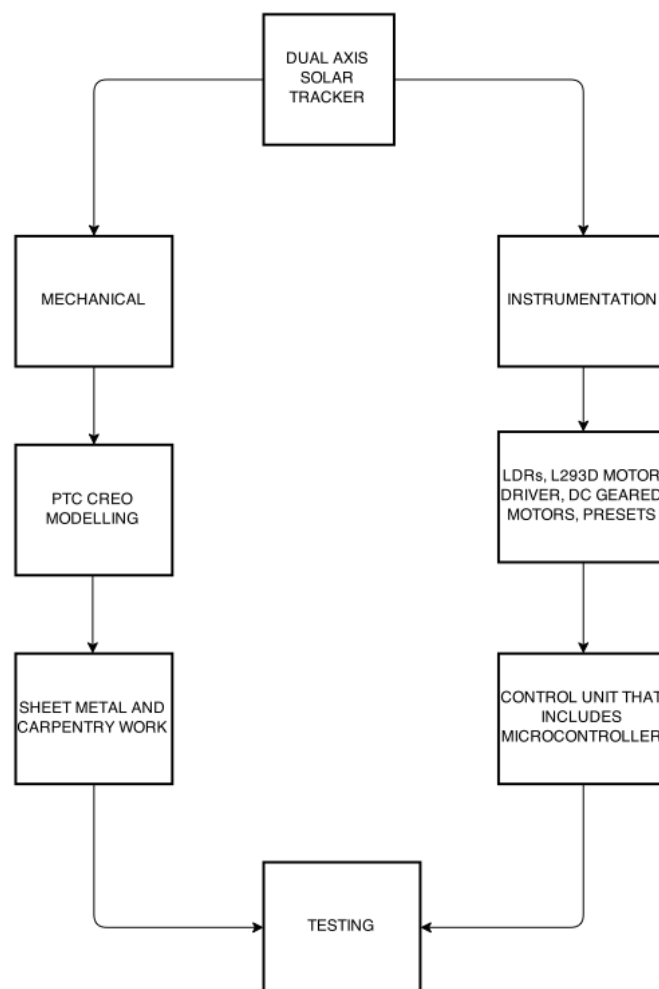


Figure 3.1: Methodology

In this work a rectangular stainless steel sheet is assumed as a solar panel as the main objective is only to develop a tracking mechanism. Block diagram of the whole project is shown in figure 3.2 . 4 LDR's are used on panel to control its motion, 1 LDR is used separately to provide homing mechanism. Two slits are used to separate 4 LDR's. 2 DC geared motors are used to provide two degrees of freedom to the panel. L293D motor driver has been used to drive two motors. MC9S12XDT512 a Freescale micro-controller has been used to control the whole tracker. 12V power supply is given to motor driver with the help of adaptor. USB power supply is given to the micro-controller. 5 potentiometers have been used in series with each LDR to calibrate their output voltages.

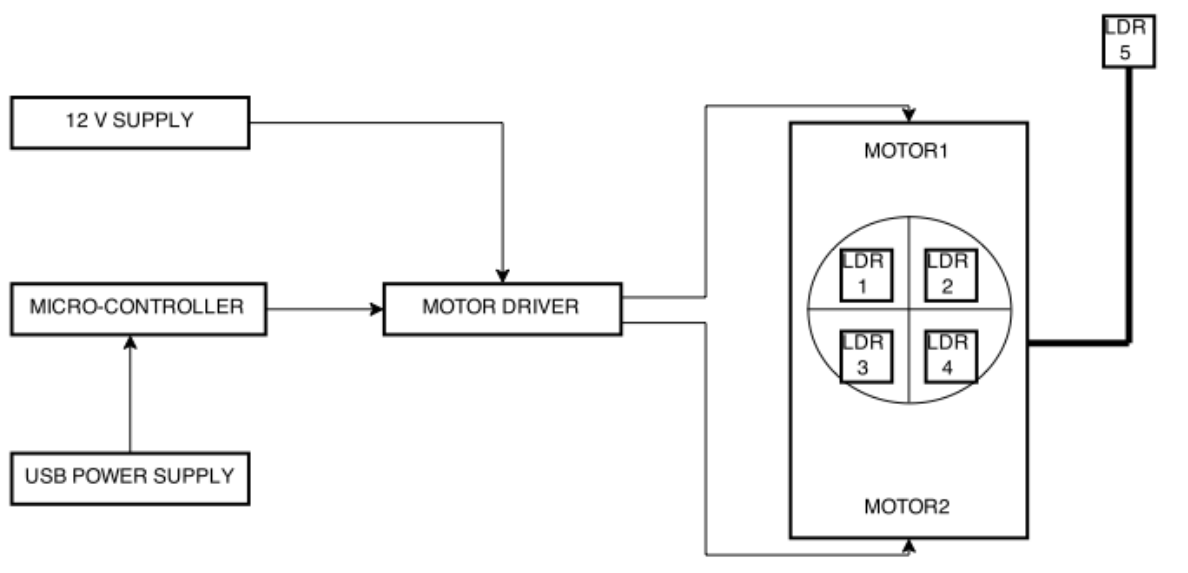


Figure 3.2: Block diagram of solar tracker.

**MODELLING AND FABRICATION OF SOLAR TRACKER**

**4.1 Modelling**

CREO modelling is a modelling software used to create analyse and view product design using 2D CAD, 3D CAD, parametric and design modelling. It is created by parametric technology corporation. Before actually making prototype of project it is necessary to check its feasibility by modelling it in this software. Figures given below show different steps followed in the formulation of complete model of dual axis solar tracker.

**Step 1:** Wooden base with slit is developed.

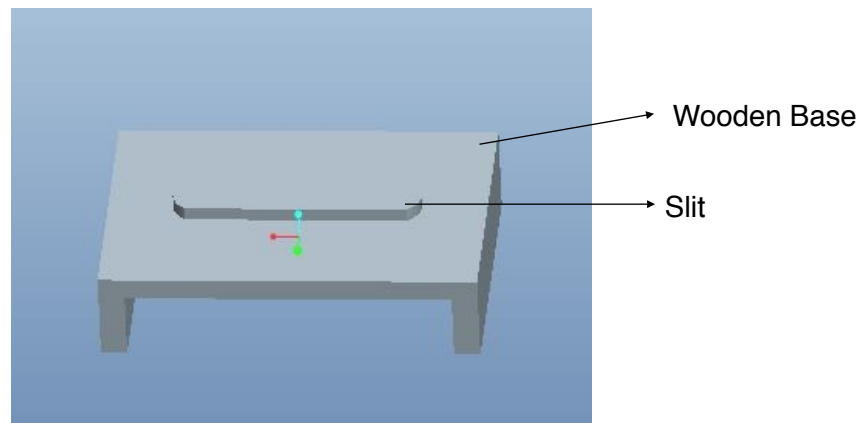


Figure 4.1: Base of solar tracker model

**Step 2:** A vertical rod with motor casing is developed in this step to fix motor into it.

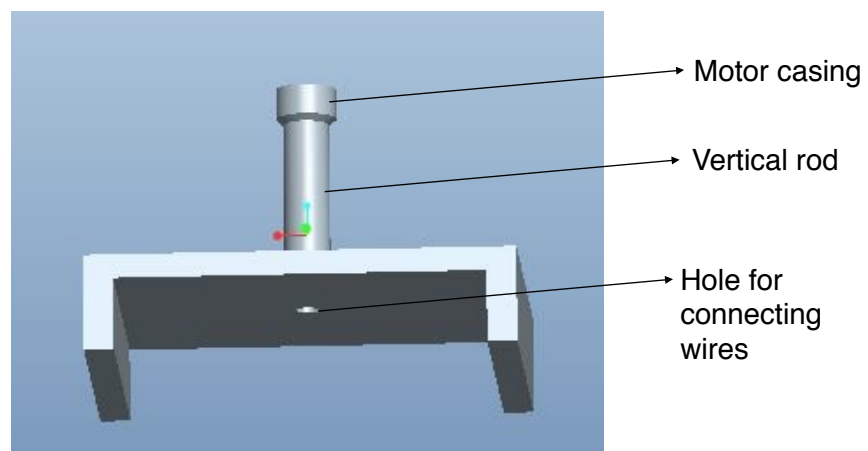


Figure 4.2: Support structure to fix solar tracking assembly

**Step 3:** Motor structure is developed and fixed in motor casing.

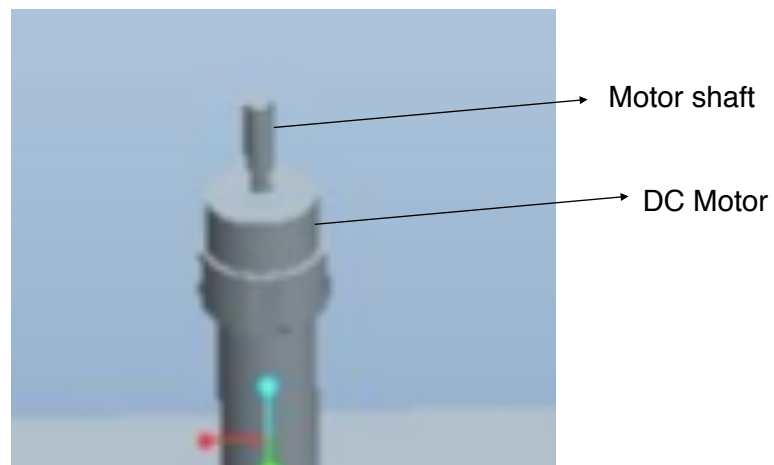


Figure 4.3: DC Motor fitted in motor casing casing

**Step 4:** Fixtures to support motor and stainless steel platform is fixed over the motor shaft.

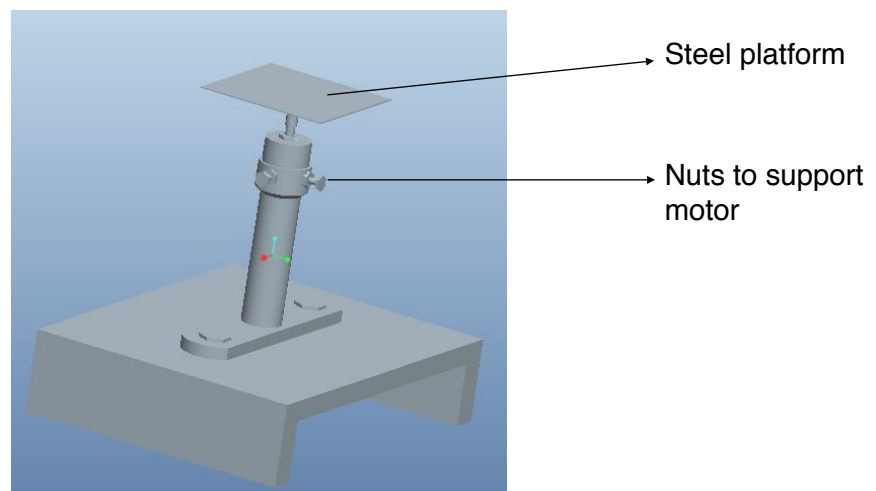


Figure 4.4: Fixture and platform to place trough motor over it

**Step 5:** Trough motor placed on platform in this step. Panel is to be attached with this motor.

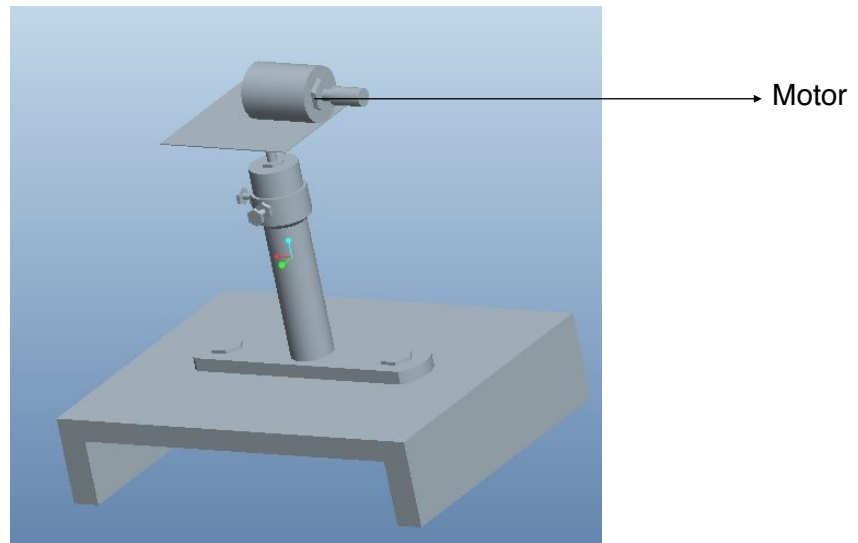


Figure 4.5: Motor fixed on platform

**Step 6:** Panel is attached with the shaft of trough motor.

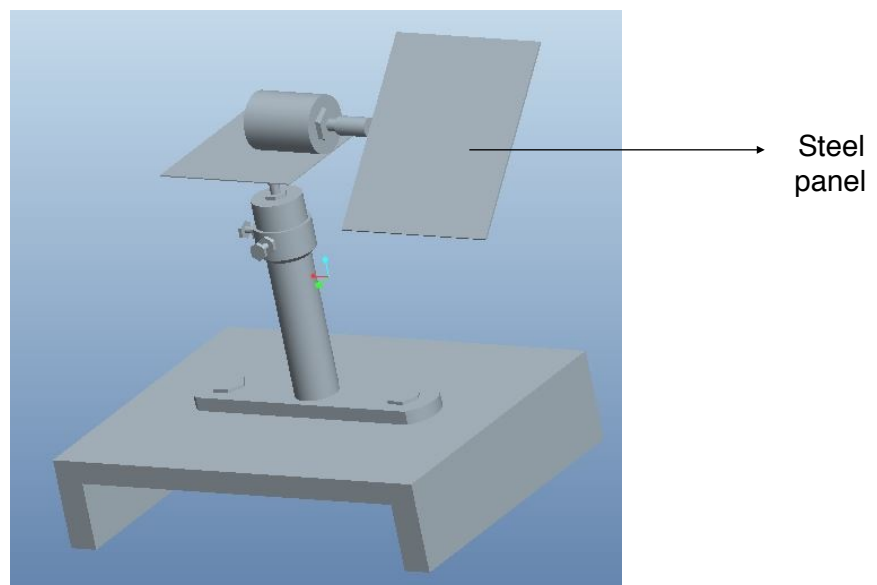


Figure 4.6: Panel attached with motor shaft

**Step 7:** LDR sensors on panel and a tower splitting these LDRs is developed in this step.

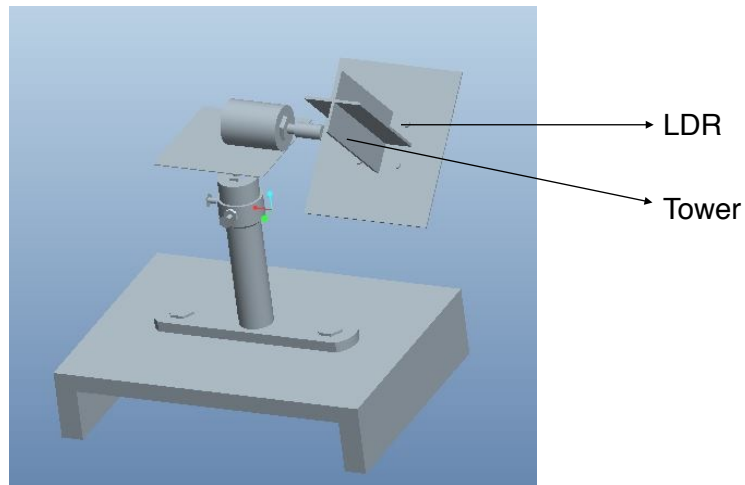


Figure 4.7: LDRs and tower

**Step 8:** A hollow structure is developed besides the trough motor to support master LDR.

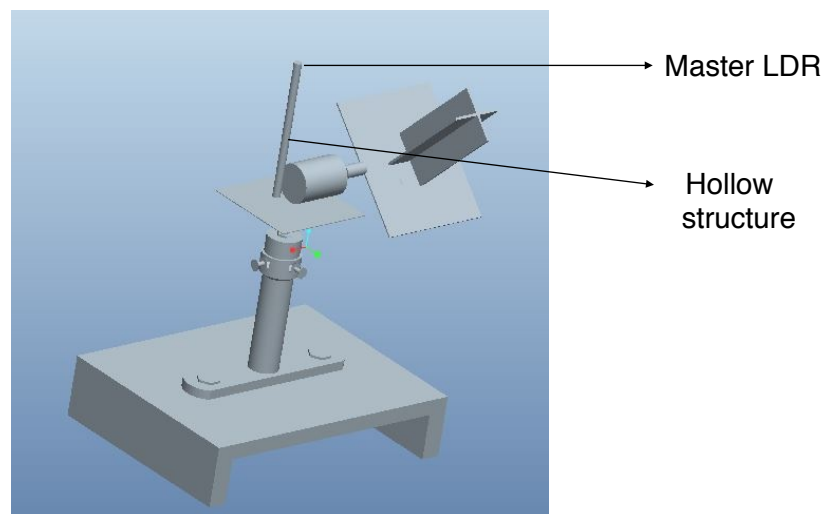


Figure 4.8: Hollow structure with master LDR

## 4.2 Development of Prototype

Prototype of solar tracker has been developed which involves mechanical and electrical works. Its structure has been developed in mechanical lab and electronic circuit implementation has been done in electronics department. In mechanical part it includes the work of sheet metal shop and carpentry shop. Electronics section includes the circuit used and the control unit.

### 4.2.1 Mechanical Work

A wooden base is made in carpentry shop with the help of hacksaw and nails. A hole is drilled on this base for the connection of wires. Using lathe machine a hollow iron rod is cut out of proper dimension. This rod is fixed vertically on the wooden base over the drilled hole with the help of a nuts and bolts. On the top opening of this vertical rod a hollow cylindrical shaped block is welded whose dimension is equal to the dimension of DC geared motor. A DC geared motor is taken and a stainless steel plate is attached to its shaft with the help of drilling. This motor is designated as motor 1 in this work.

A small metal bit is taken and its been made hollow with the help of lathe machine. This bit is attached to the shaft of a DC geared motor by using nut and bolt. With this attached bit a rectangular steel plate is welded which acts as solar panel in this work. This second DC motor is named as motor 2 in this work. Figure 4.9 shows cutting drilling and welding work.

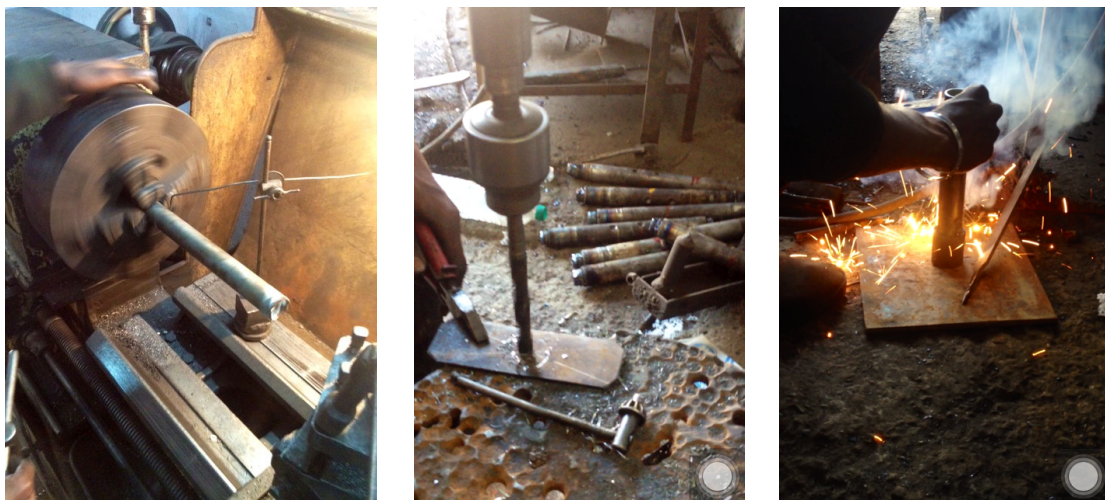


Figure 4.9: Cutting, Drilling and Welding works

Acrylic sheet has been used to cover the steel panel to provide electrical isolation with the electronics components used. A vertical tower used as partition between sensors is made of two slits of acrylic sheets and pasted over the panel so as to get 4 sections on the panel to attach 4 LDRs in them. A plastic straw is fixed besides motor 2 for a LDR. The logics of doing such a work has been explained in further sections. Figure 4.10 shows the completed model of solar tracker.

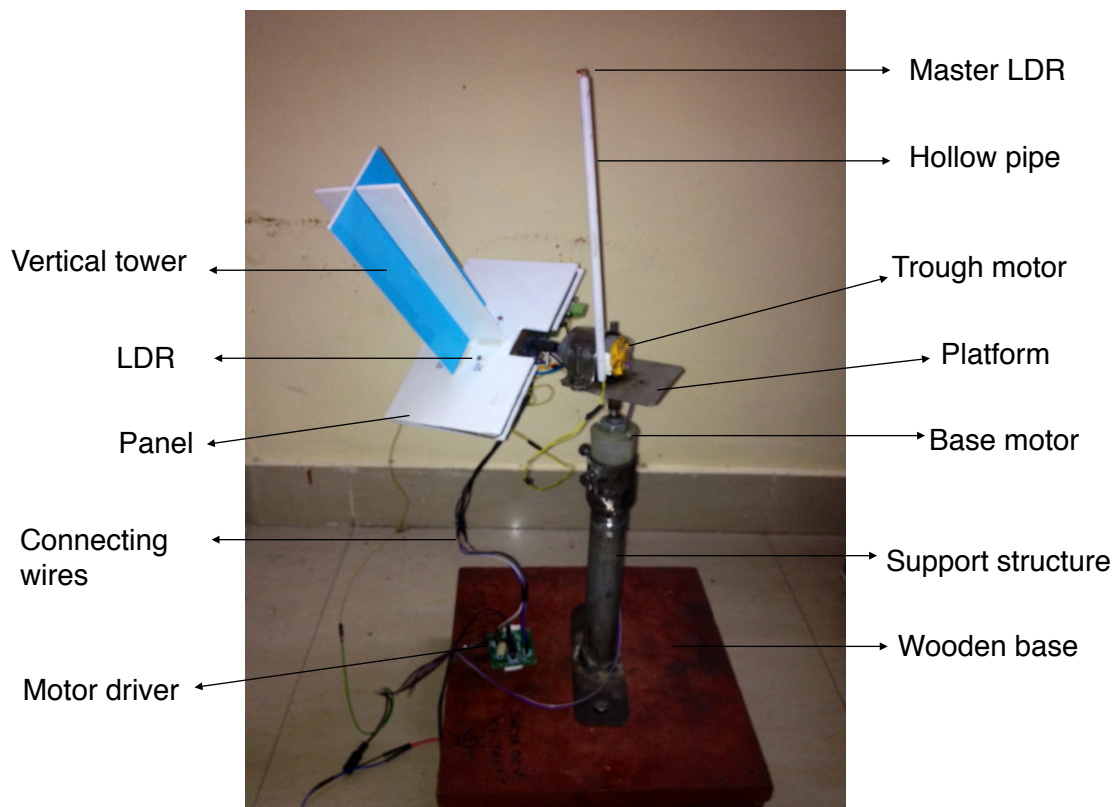


Figure 4.10: Model of solar tracker

## 4.2.2 Electronics Involved

This section includes various electronics components like light sensors, potentiometers, motors, motor drivers and micro-controller.

### 4.2.2.1 Light Sensor

Light dependent resistor(LDR) is used as light sensor in this work. 5 LDRs have been used, 4 at the panel in each section made by acrylic tower and 1 LDR is used as a master LDR attached at the top of plastic straw. LDRs attached on panel are used to control the motion of

panel in both horizontal and vertical plane i.e. azimuth and altitude angle of sun. Analog values of light falling on each LDR is converted in digital form with the help of inbuilt analog to digital convertor of micro-controller used. Depending on the light falling on LDRs motion of two motors has been controlled by the micro-controller. Master LDR is used to take the panel back to home position in the morning, when light falls on master LDR the motor 1 rotates till any one of the 4 LDRs on panel gets sunlight.

Potentiometers are used in series with each LDR to calibrate LDR's output voltage. Output voltage of LDR is set to 1.5V when no light is incident on it and it is 0.08V when light incidents on it. Figure 4.11 shows the arrangement of each LDR in the model

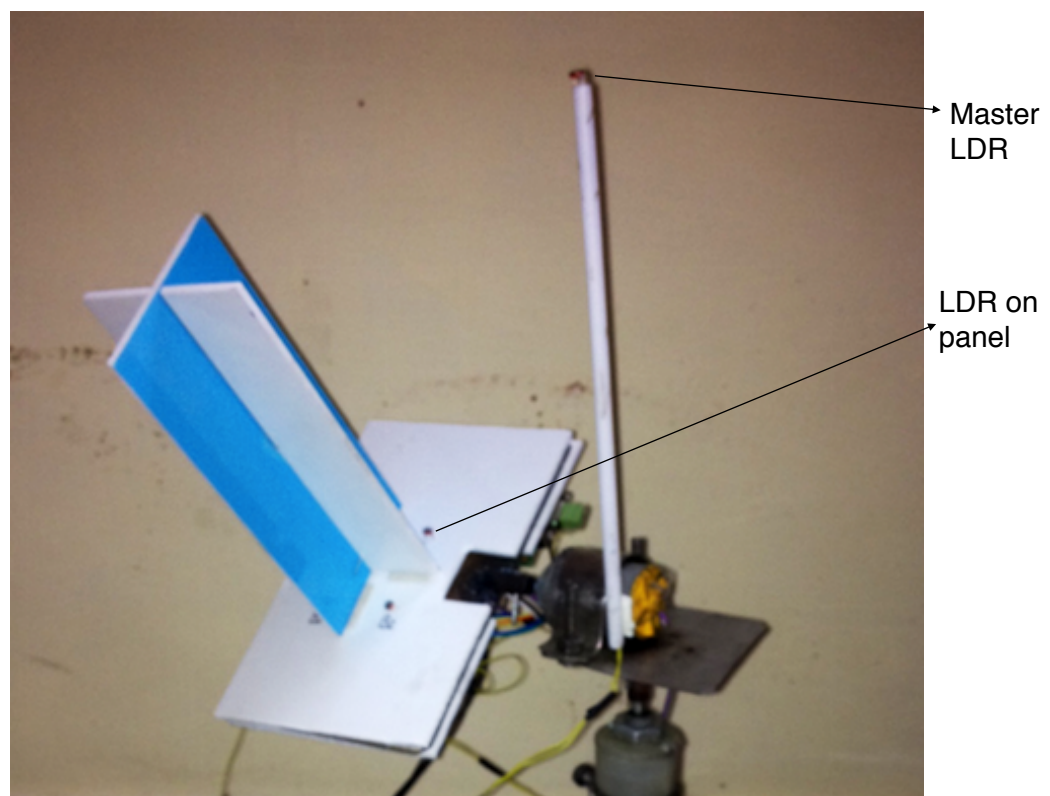


Figure 4.11: Arrangement of LDRs

#### 4.2.2.2 DC Geared Motor

Two 100RPM, 12V DC geared motors are used in the present work. One motor provides motion in horizontal plane which is designated as motor 1. Second motor provides motion in vertical plane which is named as motor 2. Clockwise and anticlockwise motion of each motor is controlled by the controller based on the light incident on each LDR. L293D motor driver

is used to activate the motors. In this work one motor is activated at a time leads to less power consumption. Figure 4.12 shows arrangement of DC geared motor. Figure 4.13 shows a open section of DC geared motor. A geared motor has a gear box in which 4-5 gears are present. It has a nut and shaft in which a hole is present.

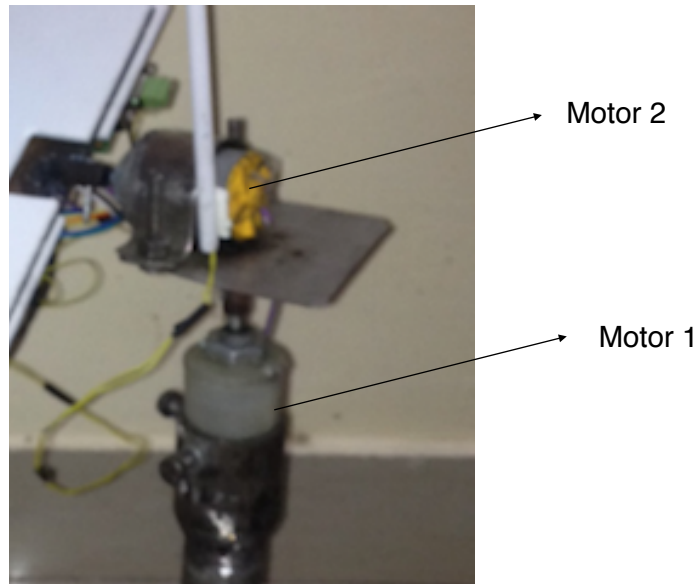


Figure 4.12: DC geared motor arrangement



Figure 4.13: DC geared motor inside view

These motors provide motion to the solar panel in two axis which is shown in figure 4.14

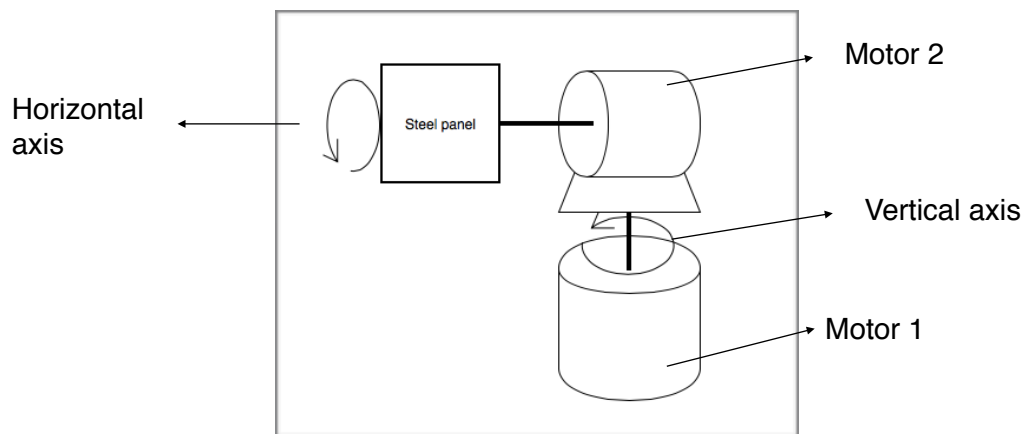


Figure 4.14: Motion Specification Of Two Motors

### 4.2.2.3 Motor Driver

L293D is motor driver IC by which one can drive DC motor in any direction. It is a 16 pin IC by which 2 DC motors can be controlled simultaneously in any direction. It has two H-bridge circuits in it to control two motors. H-bridge is combination of 4 transistors attached with each other forming letter H. H-bridge allows the voltage flow in either direction, change in polarity is required to change the direction of motion of motor. Due to its small size it is very much used in robotics where motors are used extensively. Figure 4.15 shows the overview of L293D PCB. [22]



Figure 4.15 L293D motor driver

Figure 4.16 shows the pin diagram of L293D motor controller. It has two enable pins for two motors. Pin 1 and pin 9 shown in figure 5.7 are the enable pins. These pins needs to be high to drive the motors. Therefore these pins are given 5V in the present work. To drive the motor

with left H-bridge pin 1 needs to be enabled and to drive the motor with right H-bridge pin 9 needs to be activated. There are 4 input pins on this chip, pin2 and 7 on the left side and pin 15 and 10 on the right side. Left input pins controls the motor connected on left side and right input pins control the motor connected on right side respectively. Motors are controlled according to the inputs provided to these input pins as LOGIC 0 or LOGIC 1. An example is shown here to control the motion of a motor connected on left side.

Pin 2 = Logic 1 and Pin 7 = Logic 0, then motor moves in clockwise direction.

Pin 2 = Logic 0 and Pin 7 = Logic 1, then motor moves in anticlockwise direction.

Pin 2 = Logic 0 and Pin 7 = Logic 0, then motor does not moves.

Pin 2 = Logic 1 and Pin 7 = Logic 1, then motor does not moves.

Vcc voltage is the voltage required by this IC for its own internal operations which is 5V. For driving motors it has separate supply pin Vss. In this work it is supplies by a 9V adaptor to drive motors. The maximum voltage for Vss motor supply is 36V. It can supply a maximum current of 600mA.

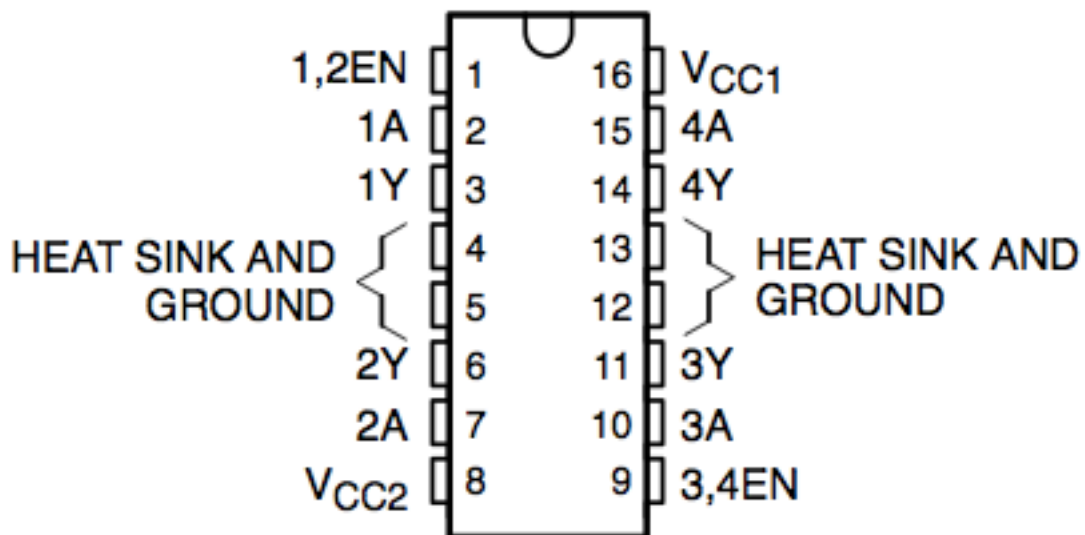


Figure 4.16: Pin diagram of L293D [23]

#### 4.2.2.4 Potentiometer

Single turn pot is used in this work as there is no requirement of extra number of rotations in the present work, the only need is to calibrate LDRs so that their output voltages should remain same. A PCB of 5 potentiometers has been used in the present work. Each potentiometer is used in series with each LDR to adjust the output voltages of each LDR. Figure 4.17 shows the diagram of the PCB of potentiometer.

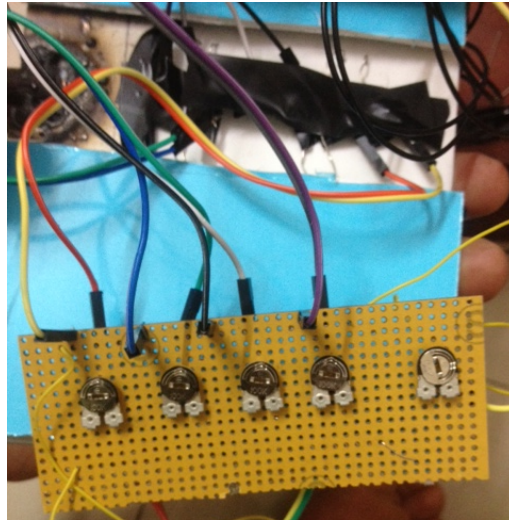


Figure 4.17: PCB of potentiometer

#### 4.2.2.5 Micro-controller

In the present work MC9S12XDT512 a Freescale micro-controller has been used to control the operation of two DC motors. It is a 16 bit micro-controller with 40 Mhz bus speed and high code density. It is a low cost controller with very less power consumption. It has a parallel processor for fast processing known as X gate. It operates in the voltage range of 3V to 5V. Figure 4.18 shows the block diagram of this micro-controller.

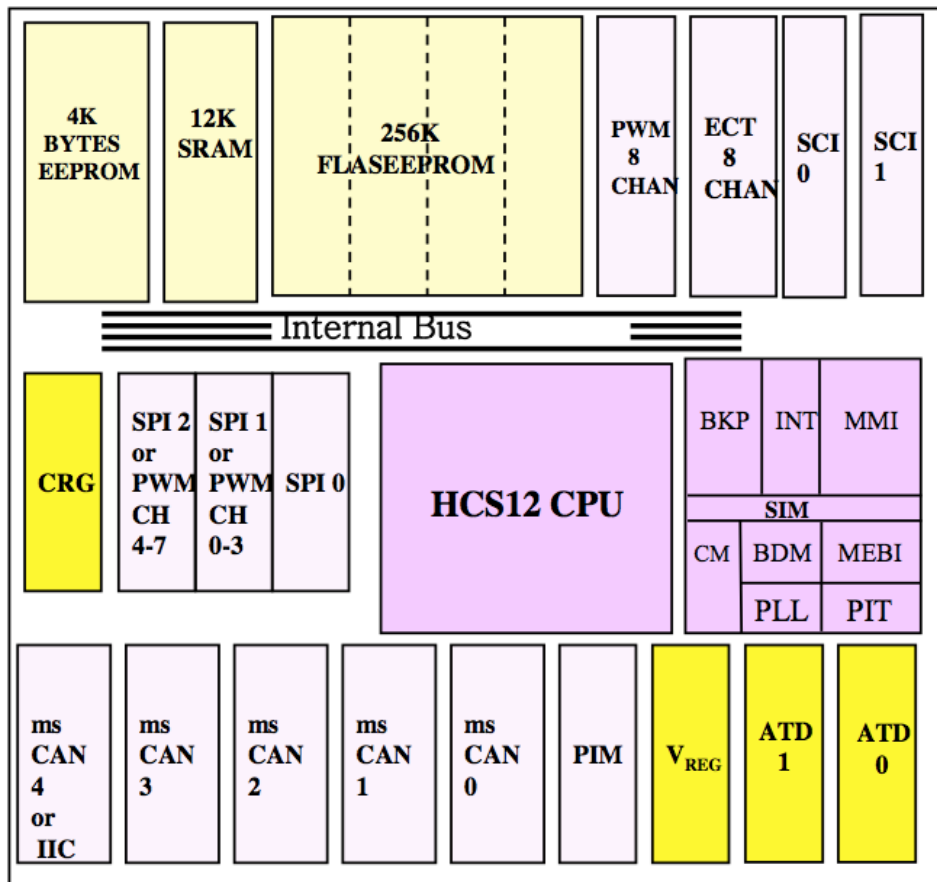


Figure 4.18 Block diagram of micro-controller

It is a IC with 80 pins. A number of input output ports are available in this micro-controller. It has 8 analog channels which are used to convert analog values into digital form. Advantage of this controller is that a number of times a code can be rewritten and burnt in it without any error. This controller is programmed using code warrior IDE. Figure 4.19 shows the image of micro-controller. Pin no. 18, 20, 22, 24 of port B in this micro-controller are used to connect 4 LDRs which are present on panel. These pins also worked as analog channel pins where analog data is converted to digital form. Output voltage of these LDRs are calibrated using potentiometers used in series with these LDRs. Their output voltage is set to 1.5V when no light incidents on them and it is equal to 0.05 when a 100 watt bulb light incident on these LDRs. 100 watt bulb is used in this work to test the solar tracker model. Master LDR is attached with pin no. 12 of this micro-controller which is named as analog channel 6 in this controller. Port P of this controller is made active by giving a value 1 to it so that it can be

used as a power source of 5V in this work. Pin no. 3 is used as ground. Input lines 1, 2, 3 and 4 from the motor driver are connected to pin no. 47, 45, 43, 41 of the controller respectively. It is powered up with USB power supply of laptop. ADC setting of 5 registers which has been done in this controller which are mentioned in table 4.1



Figure 4.19: MCU9S12XDT512 Freescale micro-controller

Table 4.1: ADC settings of micro-controller

ADC register name	Value	Remarks
ATD0CTL0	0X06	Wrap around after 6th channel
ATD0CTL2	0X80	Power up register
ATD0CTL3	0X60	8 conversions per sequence
ATD0CTL4	0X80	Resolution=8 bit, Sample period=2
ATD0CTL5	0XB0	Data right justified, continuous and multiple scan

### 4.3 Block Diagram of Solar Tracker

Circuit diagram shown in figure 4.20 illustrates the connection specifications of each component used in solar tracker.

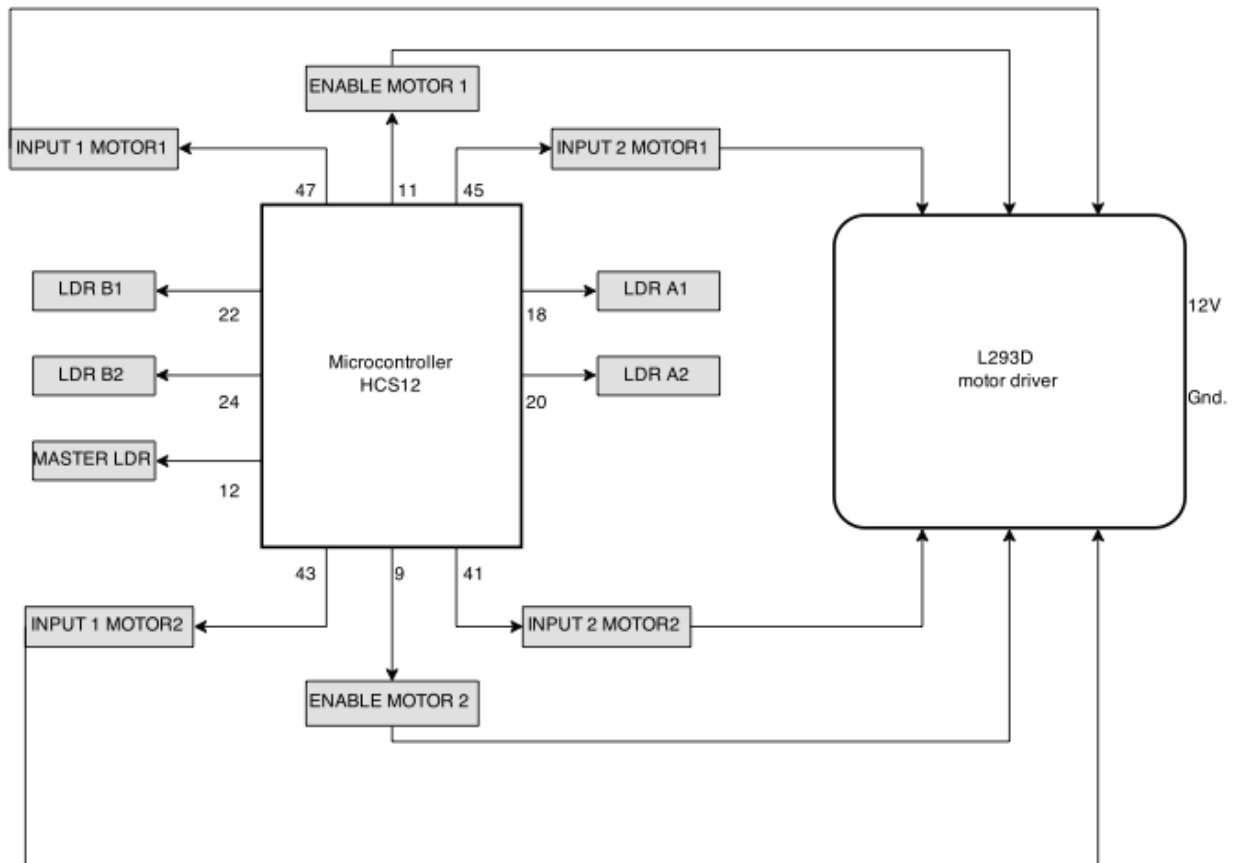


Figure 4.20: Block diagram of solar tracker

## CHAPTER 5

### PROGRAMMING AND ALGORITHM

#### 5.1 Code Description

Programming of micro-controller is done in C++ language using code warrior IDE software. Programming includes the initialisation of header files which are hdef,h and derivative.h. Then initialisation of ports required in the work has been done. After that analog to digital convertor settings are done. Then based on the light falling on LDRs various cases have been made. According to the output voltages of LDRs different rotating directions have been given to the two motors used to adjust the position of panel. The final aim of this controlling section is to get equal light on all the 4 LDRs which are present on panels. Whole code includes the while loop for the execution of each case.

Tracker starts tracking when there is light on master LDR. Two major cases are considered while controlling the motion of motors which are whether the light is falling on 1 LDR at a time or it is falling on 2 LDRs at a time. Table 5.1 and 5.2 shows behaviour of motors according to the mentioned cases. Motor 1 is base motor and motor 2 is trough motor in the below mentioned tables. Figure 5.1 shows the arrangement and designation of each LDR in this work. In this figure A1, A2, B1 and B2 are the 4 LDRs which are present on steel panel.

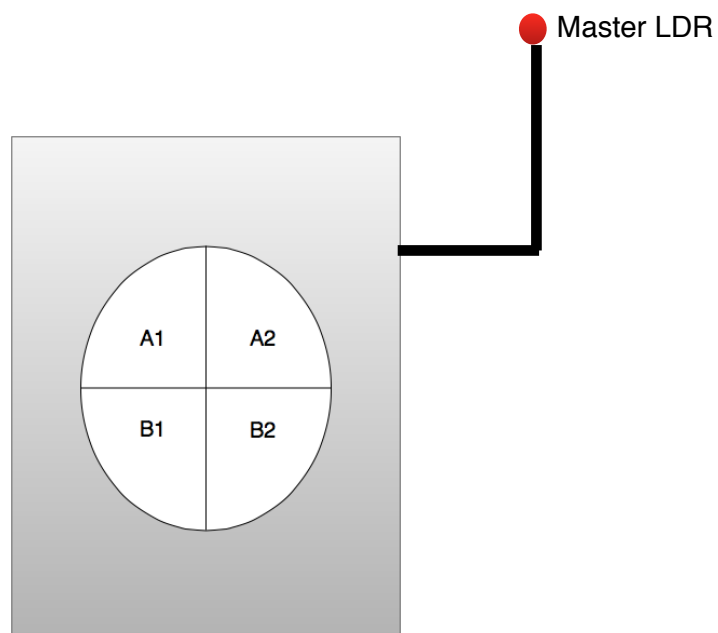


Figure 5.1: Arrangement and designation of LDRs

Table 5.1: When light on single LDR

<b>LDR</b>	<b>Motion of motor</b>
A1	Motor 1 = Anticlockwise
A2	Motor 1 = Clockwise
B1	Motor 1 = Clockwise
B2	Motor 1 = Anticlockwise

Table 5.2: When light on two LDRs

<b>LDRs</b>	<b>Motion of motors</b>
A1 and A2	Motor 2 = Clockwise
B1 and B2	Motor 2 = Anticlockwise
A1 and B1	Motor 1 = Clockwise
A2 and B2	Motor 1 = Anticlockwise

## 5.2 Algorithm

Figure 5.2 shows the algorithm followed to control the motors. Initially it checks whether there is light on master LDR, if this condition is true the motor 2 rotates in clockwise direction to get light on 2 LDRs. If light does not incidents on two LDRs then motor 1 rotates to get light on two LDRs otherwise motor 2 keeps on rotating to get light on all LDRs which is the final state where the tracker has to stop.

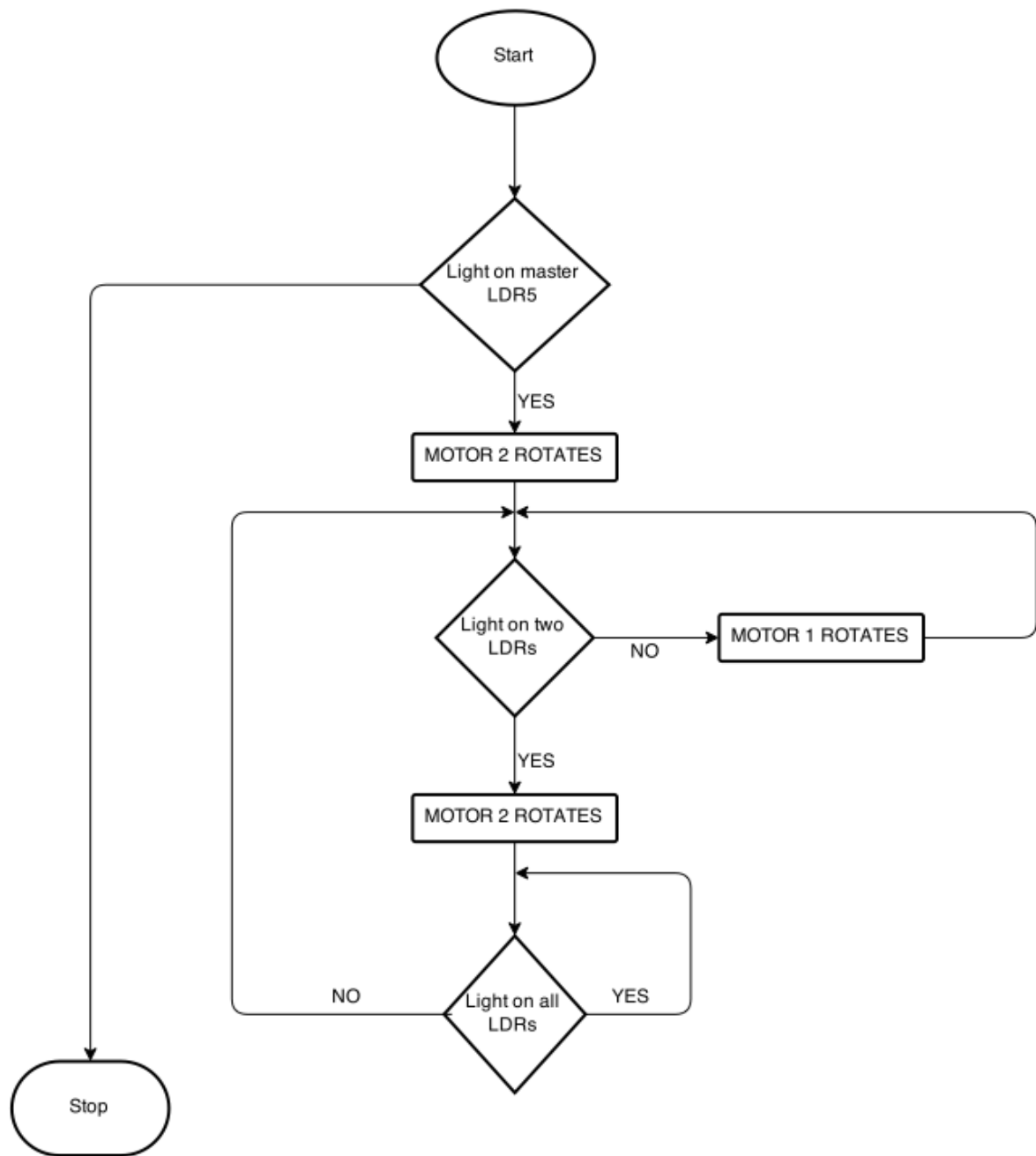


Figure 5.2: Algorithm

## CHAPTER 6

### RESULTS AND DISCUSSION

#### 6.1 Execution of Solar Tracker

Different positions of solar tracker are possible to track the sun from morning to evening and again back to home position. Position of sun is considered at all locations from east to west, from morning to dawn and motor actions are explained with the help of figures. Lighted portion on the panel is shown with yellow colour. With each possible case rotation of each motor is mentioned in figures and final position after tracking sunlight is shown.

Case 1: When sunlight is falling on LDR A1 then at first base motor i.e. motor 1 rotates anticlockwise and then trough motor i.e. motor 2 rotates clockwise.

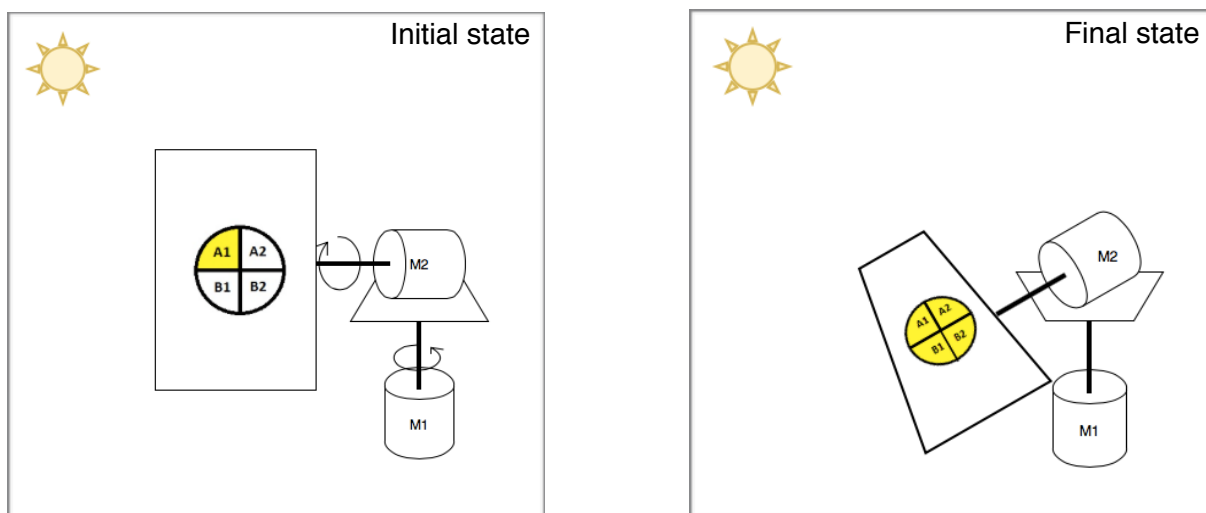


Figure 6.1: Case 1 when sunlight on LDR A1

Case 2: When sunlight is falling on LDR A2 then at first base motor i.e. motor 1 rotates clockwise and then trough motor i.e. motor 2 rotates clockwise.

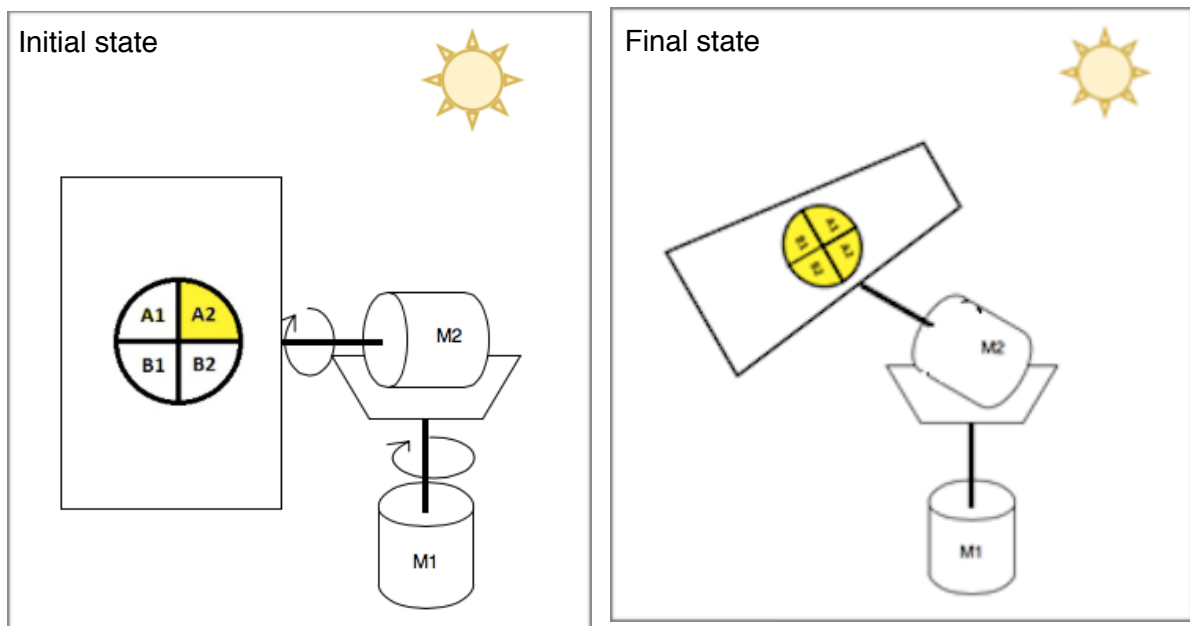


Figure 6.2: Case 2 when sunlight on LDR A2

Case 3: When sunlight is falling on LDR B1 then at first base motor i.e. motor 1 rotates clockwise and then trough motor i.e. motor 2 rotates anticlockwise.

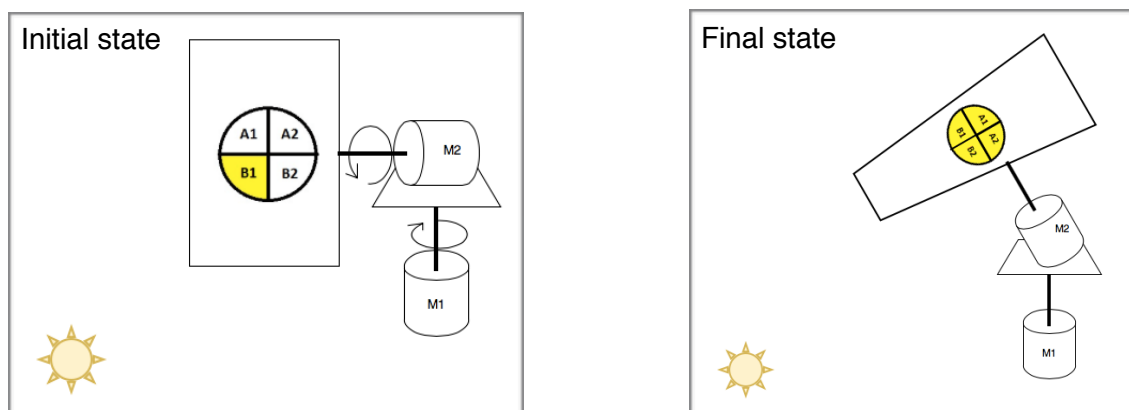


Figure 6.3: Case 3 when sunlight on LDR B1

Case 4: When sunlight is falling on LDR B2 then at first base motor i.e. motor 1 rotates anticlockwise and then trough motor i.e. motor 2 rotates anticlockwise.

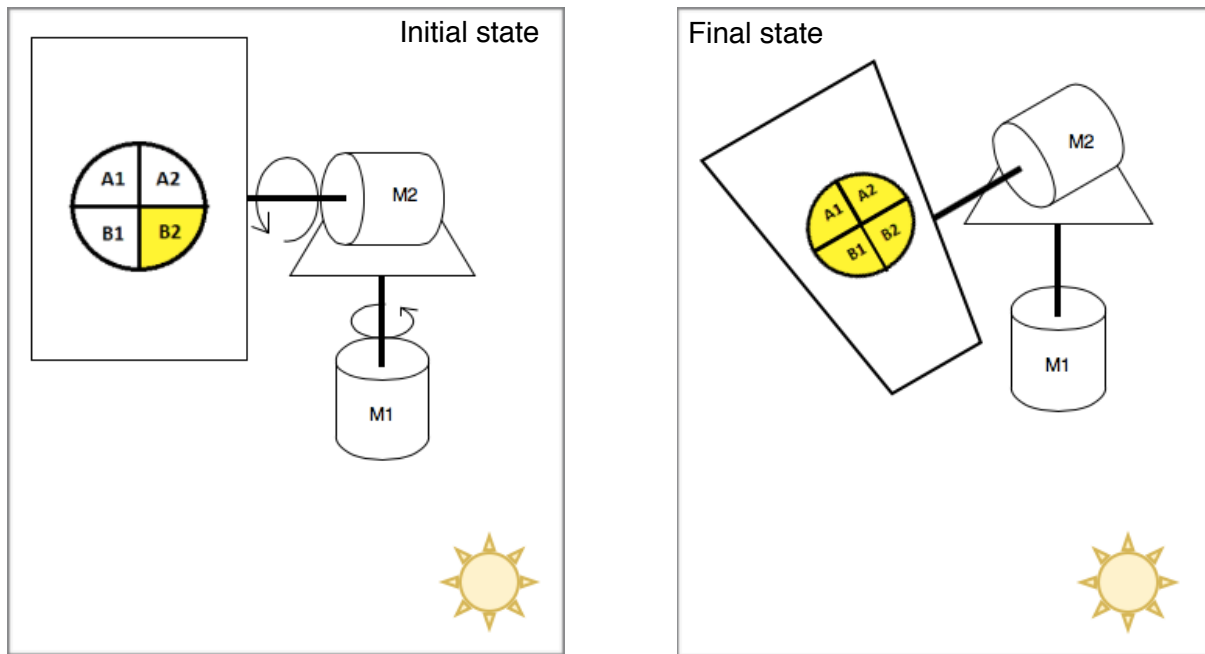


Figure 6.4: Case 4 when sunlight on LDR B2

Case 5: When sunlight is falling on LDR A1 and A2 then only trough motor i.e. motor 2 rotates clockwise.

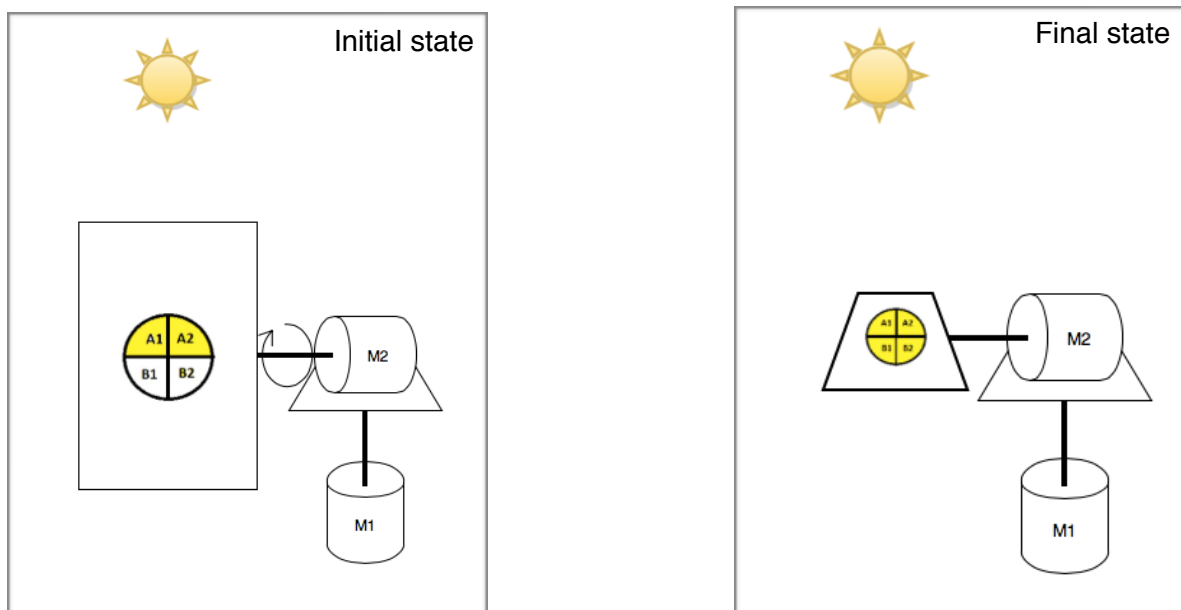


Figure 6.5: Case 5 when sunlight on LDR A1 and A2

Case 6: When sunlight is falling on LDR B1 and B2 then only trough motor i.e. motor 2 rotates anticlockwise.

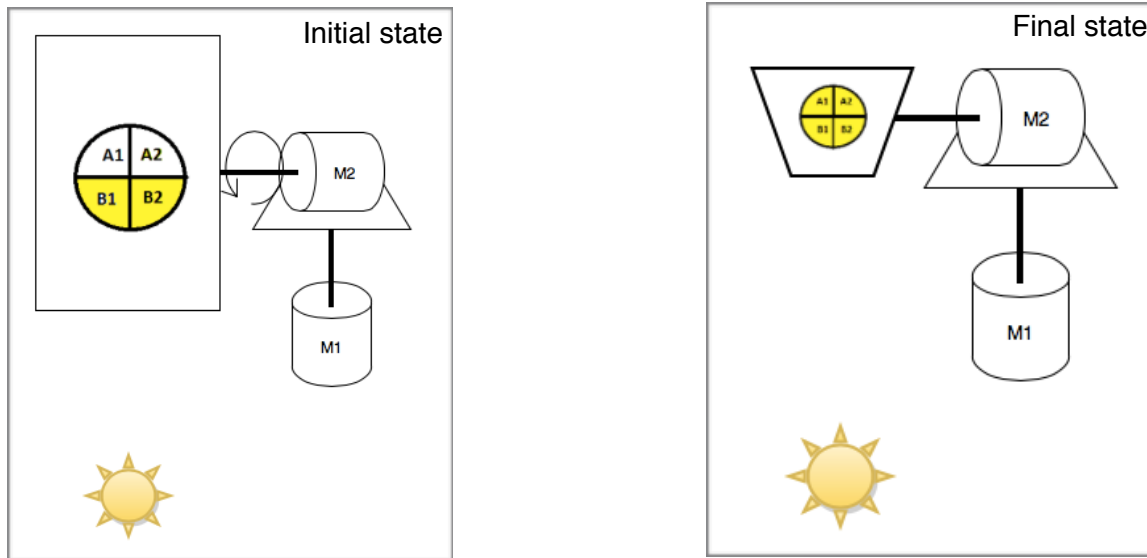


Figure 6.6: Case 6 when sunlight on LDR B1 and B2

Case 7: When sunlight is falling on LDR A1 and B1 then only base motor i.e. motor 1 rotates clockwise.

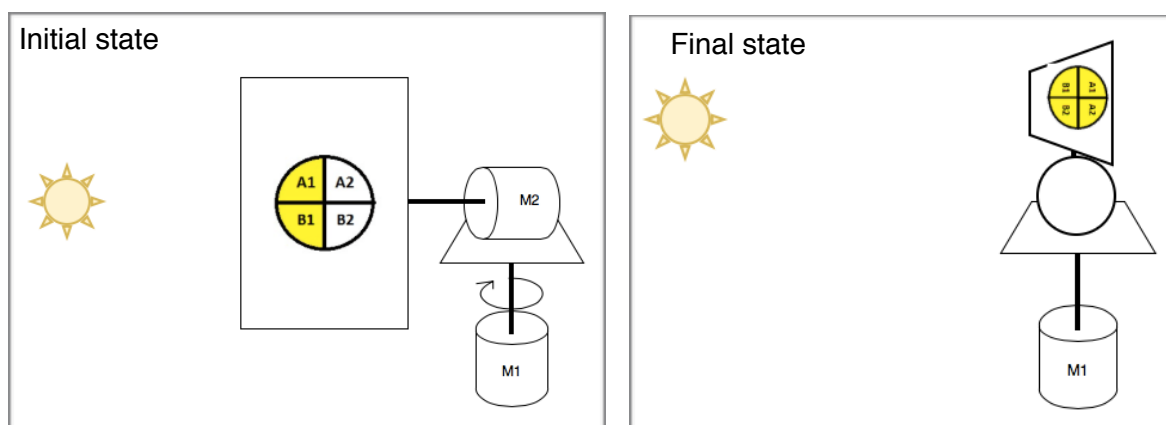


Figure 6.7: Case 7 when sunlight on LDR A1 and B1

Case 8: When sunlight is falling on LDR A2 and B2 then only base motor i.e. motor 1 rotates anticlockwise.

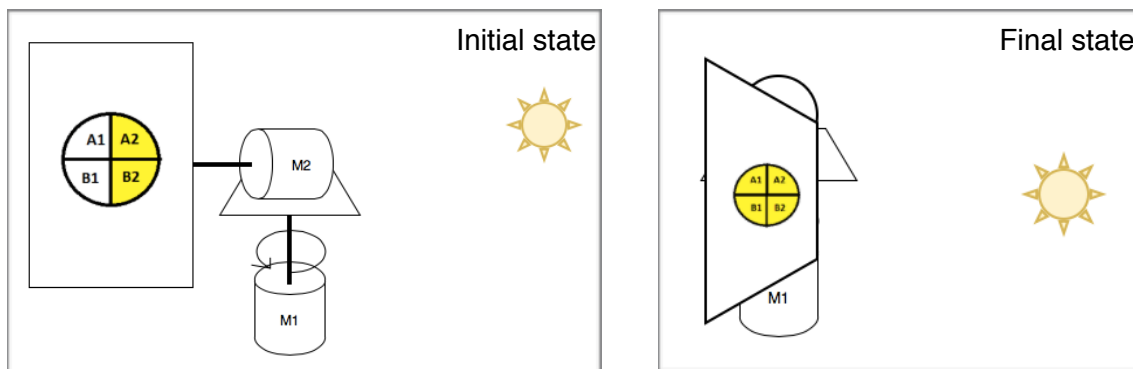


Figure 6.8: Case 8 when sunlight on LDR A2 and B2

## 6.2 Homing Mechanism

Homing mechanism is the main objective of this work which is fulfilled by using a master LDR. This LDR is placed isolated at a height much greater than all the components of tracker with the help of a plastic pipe. The whole solar tracker functioning activates only when master LDR is illuminated. During sunrise when light falls on master LDR there is motion in steel panel due to trough motor i.e. motor 2 which rotates clockwise so as to get sunlight on any LDR present on panel. As soon as any LDR on panel gets illuminated the control action takes place according to the above mentioned cases. During sunset master LDR does not get light therefore no control action occurs. Figure 6.9 shows the placement of master LDR.

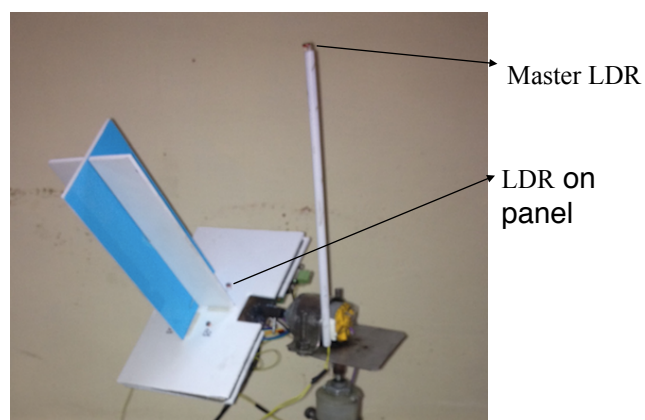


Figure 6.9: Placement of master LDR

## **CHAPTER 7**

### **CONCLUSION AND FUTURE SCOPE**

#### **7.1 Conclusions**

Based on the experimental analysis for real time solar tracking mechanism, following conclusions are made:

1. A micro-controller based real time automatic solar tracking system with homing mechanism has been developed.
2. Power consumption of tracking system is low as one motor operates at an instant, hence power source required for self sustainability of system is simple, cheap and energy efficient.
3. Present system uses real time data of solar radiation for the location where it is placed. Hence there is no need to attach memory storage device or computer to store bulky geographical data.
4. Present system is not affected by any seasonal variation and temporary climate variation during the day.
5. Control mechanism is operated using DC geared motor which is cost effective alternate to the costly and more complicated stepper motor or servo motor mechanism.
6. Many sensors like angle sensors, digital compass, pyranometer have not been used to control the motion of motors which makes it simple and easy to implement.

#### **7.2 Future Scope**

At the completion of the work of solar tracking system it has been observed that there is scope to implement this model in actual domestic and industrial use by using large motors and simply increasing the dimensions of model in a proper ratio. The work can be improved by eliminating the power supplies but using a solar panel and a battery to drive motors so that the whole system can become self sustained and eco-friendly. Design can be further optimised by using lighter materials for the fabrication.

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