"Design and development of a computer controlled electromechanical mount for maneuvering a telescope"

Submitted in partial fulfillment of the requirements

of the degree of

Master of Technology in Mechatronics

by

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Date: Sanket Garade

CERTIFICATE

This is to certify that the Dissertation entitled **"Design and development of a computer controlled electromechanical mount for maneuvering a telescope"** submitted by **Sanket Garade** MIS No. **121394007** in partial fulfillment of the requirement for the award of the Degree of **Master of Technology in Mechatronics** of College of Engineering, Pune affiliated to Savitribai Phule Pune University, is a record of his own work.

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Date:

Place: Pune

Dissertation Approval for M. Tech.

This dissertation entitled

DESIGN AND DEVELOPMENT OF A COMPUTER CONTROLLED ELECTROMECHANICAL MOUNT FOR MANEUVERING A TELESCOPE

By

Sanket Pandit Garade

(MIS no. 121394007)

is approved for the degree of

Master of Technology with specialization in Mechatronics

of

Department of Production Engineering and Industrial Management

College of Engineering Pune

(An autonomous institute of Govt. of Maharashtra)

Examiners	**Name**	**Signature**
1. External Examiner	______________________________	
2. Internal Examiner	______________________________	
3. Supervisor (s)	______________________________	
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Date:

Place: Pune

Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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ABSTRACT

It is essential requirement in area of astronomical research to develop a machine (known as a mount) with which it will be helpful to track and view astronomical objects. The purpose of this dissertation is to develop such a mount which will be of help amateur astronomy enthusiasts. It will help in maneuvering a telescope and controlling it to point to the desired object in the sky. The control will be done from software running on a computer connected to this mount. Computer software will send slew commands (for movement) to the mount which will in turn maneuver the telescope using the electronic motors and mechanical assembly of the mount. The mount can be operated in 2 modes – Normal and Scanning. In Normal mode, the mount will simply move the telescope according to the arrow keys (up/down/left/right) selected on the software. In Scanning mode, the telescope will perform a line by line scan of the area of the sky selected in the software.

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Alt-az	-	Altitude-Azimuth
EQ	-	Equatorial
HW	-	Hardware
FW	-	Firmware
SW	-	Software
PCB	-	Printed circuit board

1. Introduction

1.1. Background

1.1.1. Telescope

A telescope is an instrument that gathers light and focuses that light into an image. In turn, this image can be magnified for viewing. A telescope is mounted in such a way that allows you to swing it freely from one object to another in the sky.

An astronomical telescope is used to observe celestial objects such as planets, stars, deep-sky-objects such as galaxies, nebulae, comets etc.

1.1.2. Telescope Mounts

The mechanism which supports the telescope and is used to maneuver it is called a mount. Mounts come in various types. The most two common types are equatorial mounts and alt-az (altitude-azimuth) mounts.

Equatorial mounts are more complex to design but are ideal for astronomical viewing as it allows movement aligned to the celestial objects i.e. about the polar axis.

Alt-az mounts are comparatively simpler to design and are primarily meant for terrestrial viewing. However these mounts are also used for astronomical viewing. The mount designed in this project is an alt-az mount.

1.1.3. Need of an automated mount

– An automatic mount facilitates fast navigation of the sky when doing night sky observations.

- Compared to manual navigation of the telescope, an automatic mount requires less physical efforts as well, which can be very high especially when using heavier telescope (larger than 8 inch scopes)

- In cold regions, staying out in the cold for an entire night doing observations can be a problem. In such cases, the observation can be done by sitting inside a room and controlling the scope using a computer.

- For long exposure photographic observations, a mount is used to avoid star trails which occur due to the rotation of the earth.

- Sky survey is done by many amateur astronomers around the world. In this, they scan an area of the sky looking for possibly new comets/meteors etc. This scanning can be done with minimum efforts when using a automated mount

1.2. Aim and scope of project

The one line aim of the project is to –

Build a device (mount) which can be used to maneuver a telescope and point it to the desired object in the sky.

The detailed problem statement, scope of work and the requirement specifications are explained below.

1.2.1. Problem statement

A mount is to be built which can hold a telescope and can be controlled from a computer to point to a desired object in the sky. It should operate in two modes:-

- In the Normal mode, the user should be able to maneuver the telescope through the arrow keys on the computer software.
- In the Scanning mode, it should perform a line by line scan of the area of the sky selected in the software.

1.2.2. Scope of work

Following table shows the different modules of the project and the scope of work in each.

Module	Scope of work
Electronics hardware and firmware – Power supply – Remote control – Motor driver	To be designed, implemented, integrated and tested.
Mechanical parts and assembly – Mount frame – Gears	To be designed, fabricated, assembled and tested.
Software – Stellarium (Astronomy software)	To be used as it is with minor modifications in the backend script.
Communication (between remote control and Stellarium)	To be implemented, integrated and tested.
Telescope	To be procured and integrated with the mount.

Table 1: Scope of work

1.2.3. Requirement specifications

Following are the technical requirement specifications of the project.

1. Load specifications: The mount must be able to maneuver a telescope which is maximum 1kg in weight and has maximum dimensions: length = 18 inches and diameter = 3 inches

2. Performance specifications: The mount should have an angular resolution of 0.1°.

3. Power specifications: The mount must be powered by 12v dc voltage either through a power supply or a battery.

4. Dimensions: the mount (excluding the telescope) must fit in a box of 30cm x 30cm x 60cm.

5. Communication specifications: It should communicate with an external device like PC/laptop over serial port. This communication will be used to carry the motion commands and information from PC to the mount and vice versa.

6. Functional specifications: It should operate in two modes, Normal and Scanning.

2. Literature study

To design a telescope mount, the basic of telescopes, celestial coordinate system and telescope mounts is to be studied. This will help in designing the mount efficiently and controlling in the best possible way.

2.1. Theory of telescopes

A telescope is an instrument that gathers light and focuses that light into an image. In turn, this image can be magnified. This instrument is also mounted in such a way that allows you to swing it from object to object.

A telescope's ability to gather light is dependent on:

Aperture: The larger the primary optics (the largest lens or mirror) the more light is captured.

Optical quality: The more reflective a mirror and the more a lens allows light to pass through it, the more light is transmitted to your eye.

Collimation (alignment): Even if you have the best optics, if they are not properly aligned, your light gathering capacity will be diminished.

Below diagram shows a basic telescope and how it focuses light.

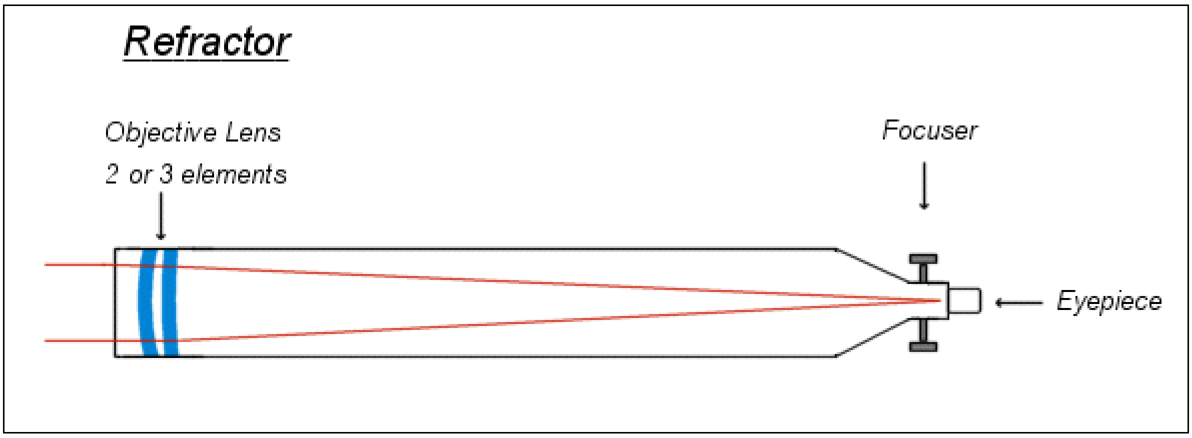


Figure 1.00 : Basic telescope working

2.2. Theory of celestial coordinates

In astronomy, a celestial coordinate system is a system for specifying positions of celestial objects: satellites, planets, stars, galaxies etc. Coordinate systems can specify a position in 3-dimensional space, or merely the direction of the object on the celestial sphere.

There are 2 main types of celestial coordinate systems:

1. Alt-az coordinate system
2. Equatorial coordinate system

2.2.1. Altitude azimuth system

The horizontal, or altitude-azimuth (alt-az), system is based on the position of the observer on Earth, which revolves around its own axis once per sidereal day (23 hours, 56 minutes and 4.091 seconds) in relation to the "fixed" star background. The positioning of a celestial object by the horizontal system varies with time, but is a useful coordinate system for locating and tracking objects for observers on earth. It is based on the position of stars relative to an observer's ideal horizon.

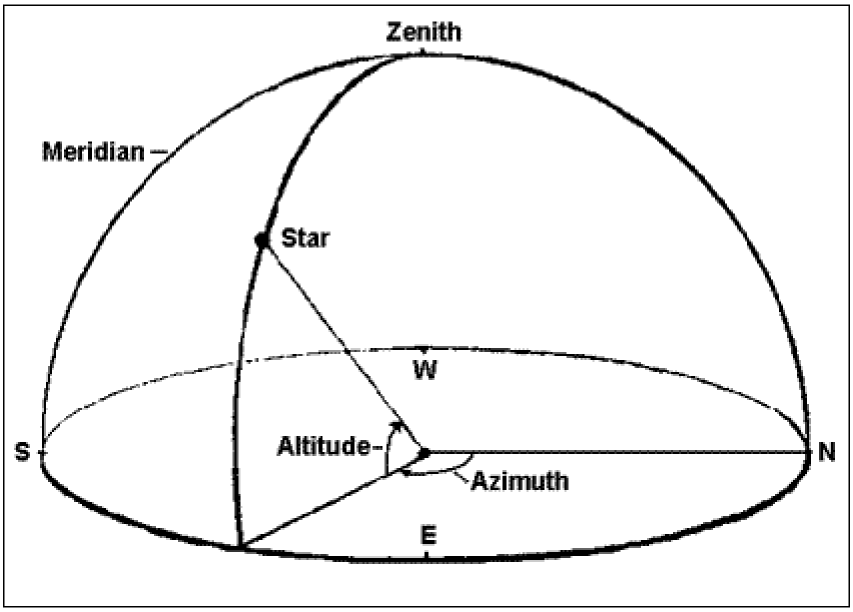


Figure 2.00 : Coordinate system - Alt-az

2.2.2. Equatorial system

The equatorial coordinate system is centered at Earth's center, but fixed relative to distant stars and galaxies. The coordinates are based on the location of stars relative to Earth's equator if it were projected out to an infinite distance. The equatorial describes the sky as seen from the solar system, and modern star maps almost exclusively use equatorial coordinates.

The equatorial system is the normal coordinate system for most professional and many amateur astronomers having an equatorial mount that follows the movement of the sky during the night. Celestial objects are found by adjusting the telescope's or other instrument's scales so that they match the equatorial coordinates of the selected object to observe.

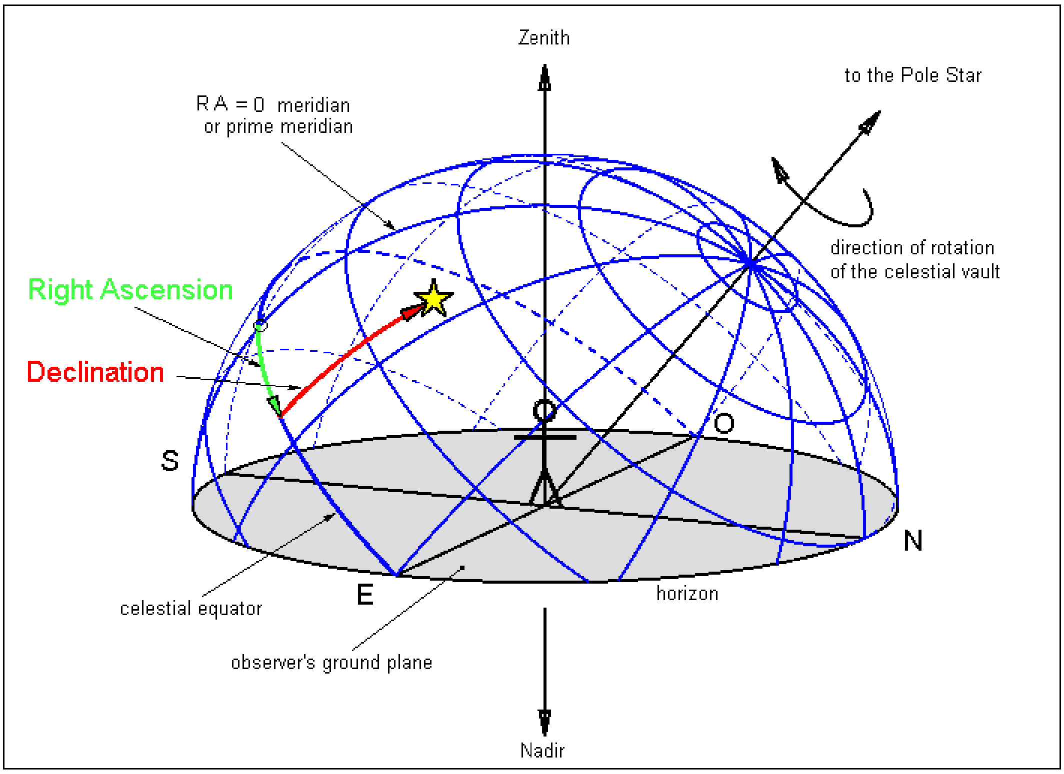


Figure 3.00 : Coordinate system – Equatorial

2.3. Theory of telescope mounts

A telescope mount is a mechanical structure which supports a telescope. Telescope mounts are designed to support the mass of the telescope and allow for accurate pointing of the instrument. Many sorts of mounts have been developed over the years, with the majority of effort being put into systems that can track the motion of the stars as the Earth rotates.

Functions of a telescope mount:

1. It should provide a system for smooth controlled movement to point and guide the instrument.
2. It should support the telescope firmly so that you can view and photograph objects without having the image disturbed by movement.

Main types of telescope mounts:

1. Alt-azimuth mounts (alt-az)
2. Equatorial mounts

2.3.1. Alt-az mount

An alt-az mount is the simplest type of mount. It has two motions, altitude (up and down, vertical to the horizon) and azimuth (side-to-side, along the horizon). Good mounts will have slow-motion knobs to make precise adjustments, which aid in keeping tracking motion smooth. These mounts are good for terrestrial observing and for scanning the sky at lower power but are not for deep sky photography. Certain alt-az mounts (GoTo mounts) are now computer-controlled and allow a telescope to track the sky accurately enough for visual use but are still not accurate enough for long exposure photography.

2.3.2. EQ mount

As the Earth rotates around its axis, the stars appear to move across the sky. If you are observing them using an alt-az mount, they will quickly drift out of view. A telescope on an equatorial mount can be aimed at a celestial object and easily track the daily motion, keeping it in your eyepiece. It works by inclining it at an angle equal to your latitude and pointing one axis (called either the polar axis or right ascension (RA) axis) in the same direction as the Earth's rotational axis (towards the celestial pole). Once the polar axis is parallel to the Earth's axis and turned at the same rate of speed as the Earth, but in the opposite direction, objects will appear to stand still when viewed through your scope. There is no rotation of the field of view and tracking can be extremely accurate, making the equatorial mount perfect for astrophotography. It has two motions: in RA (east-west) and in declination (north-south).

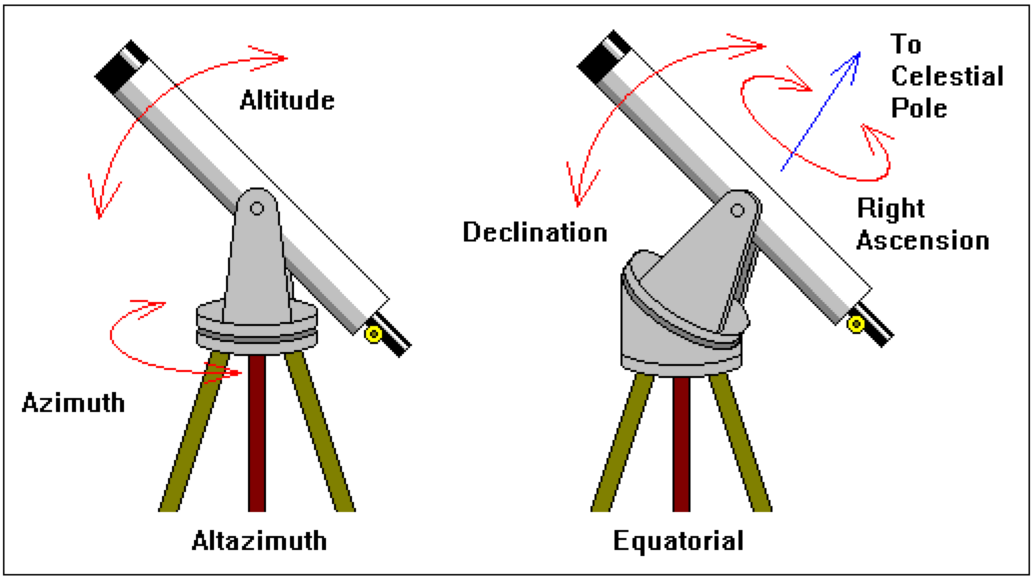


Figure 4.00 : Telescope mount - types

3. Project Plan

The project activities and the schedule for the same are described below.

3.1. Activities

The project, being a mechatronics project and hence inter-disciplinary in nature, has a mix of various activities. These are listed below in brief:-

Main activity	Sub-activities
Study	Telescope and mount study
	Electronics study – Stepper motor driving
	Mechanical study – Gear design, Assembly design
Electronics Hardware (HW)	Hardware design
	Component selection
	Component procurement
	Bread board testing and redesign
	Schematic (SCH) design
	PCB design
	PCB manufacturing
	Board assembly
	Board bring up and testing
Electronics Firmware (FW)	FW test stubs
	System architecture design
	Driver design
	Application design
	Implementation and testing
Mechanical (Mount)	Load and torque analysis
	Gear design
	Gear manufacturing
	Mount design
	Mount manufacturing and assembly
	Mount testing and corrections
Software (SW)	Windows application development and testing
Integration and testing	Testing of electronics with mount
	Final integration and testing
Other	Telescope selection and procurement

Table 2 : List of activities

3.2. Schedule

Below is the schedule for execution of the project.

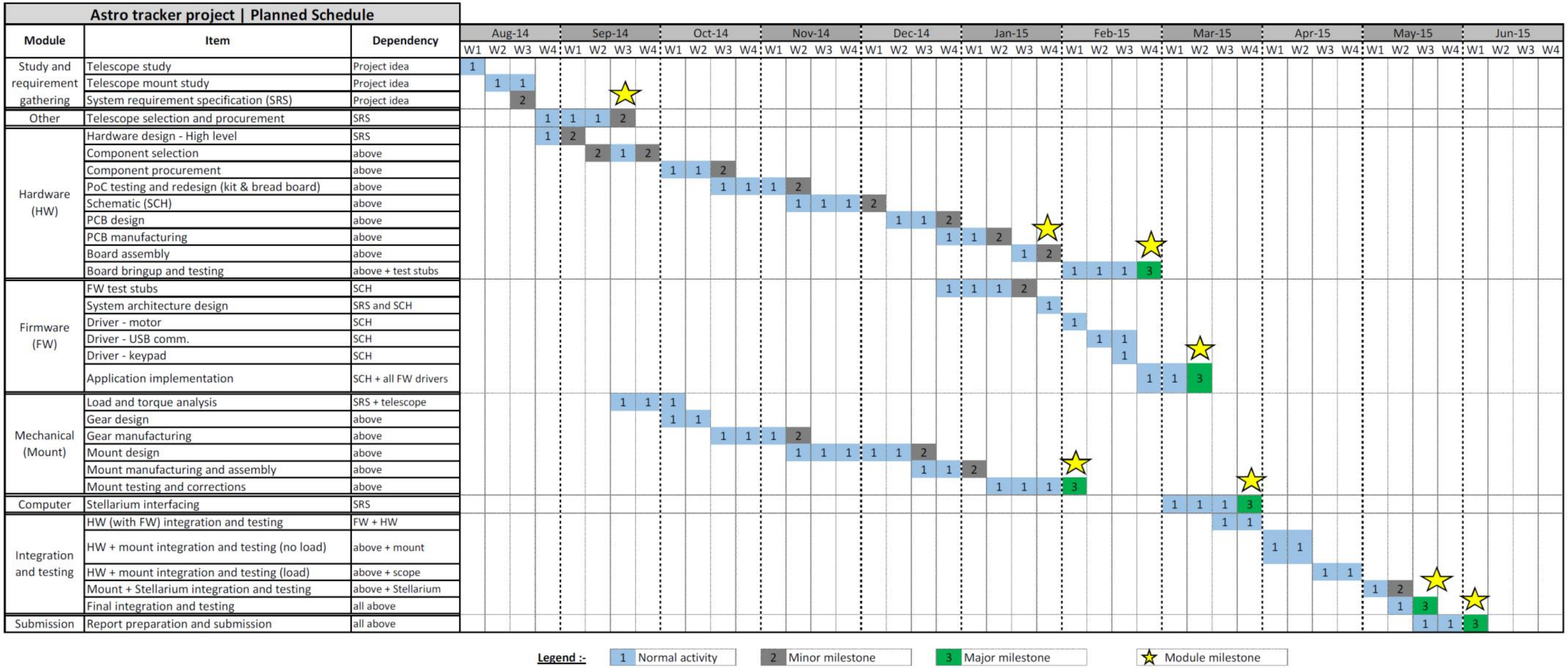


Figure 5.00 : Project Schedule

3.3. Tools

Below is the list of tools and software required for the project execution:-

- Mechanical:

  1. Catia - For part design and assembly simulation
  2. Epilog laser cutting machine - For manufacturing the mechanical parts

- Electronics:

  1. Express SCH and PCB - For schematic and PCB design
  2. AVR studio - For firmware design and implementation
  3. Sinaprog - For downloading firmware in the MCU
  4. DMM and Oscilloscope - For testing purpose

- Software:

  1. Visual Studio 2010 - For windows application development
  2. Bray's Terminal - For testing serial communication

4. System Operation

This section gives the overview of the working of the mount.

4.1. System Overview

The mount comprises of the following blocks shown in the diagram.

In this arrangement,

The computer software is the "master",

The mount is the "slave".

And the telescope is the "load".

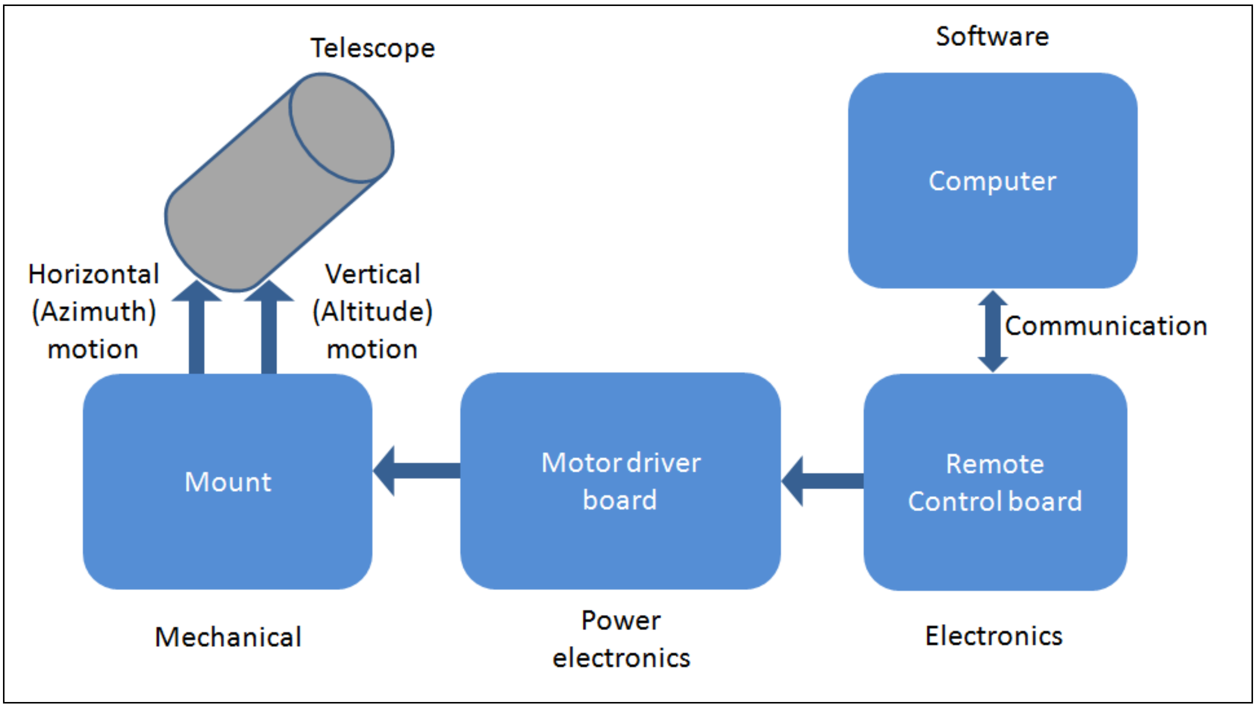


Figure 6.00 : System block diagram

As can be seen from the block diagram, the system is an open loop system. i.e. no feedback is given from the mount to the control board

4.2. Working of system

The system operation is described in this section. The system operates in 2 modes. Mode selection can be done from the computer software window. Below are the details of the 2 modes.

4.2.1. Normal mode

In this mode, the telescope will be simply moved up/down/left/right using the arrows keys on the software. The resolution of the movement can also be controlled from the software. Lesser resolution will be used in moving the telescope from one point to another when the points are far away. This will help faster movement. On the other hand, higher resolution will be used to perform very small changes in the telescope's position. This will result in slower but fine control when pin-pointing to objects in the field of view of the telescope.

4.2.2. Scanning mode

In this mode, the telescope will be used to scan a particular region of the sky. This kind of scanning activity, performed by amateur astronomers, is called "sky survey". Sky surveys result in observing and finding new celestial objects such as comets.

First, the arrow keys will be used to position the scope to a desired start point in the sky. Then, the area to be scanned (e.g. 5° x 3°) will be entered along with the desired quadrant. On pressing the "Scan" button, the mount will begin line-by-line scan of the selected quadrant and will cover the selected area of scan. The scan will be performed in a pattern where the scope will traverse the horizontal dimension first (i.e. 5°) and move up/down in a small vertical increment of 0.5° (fixed). It will again cover the horizontal distance followed by another vertical increment and keep on doing this till the vertical dimension (3°) is fully covered.

5. System Design

The system is divided into 4 parts for design purpose –

– Mechanical design
– Electronics design
– Software design
– Communication design

Each of these is explained in below sections.

5.1. Mechanical design

The high level mechanical design of the mount is shown in below diagram.

There will be 2 kinds of motions as shown –

1. Horizontal OR Azimuth motion
2. Vertical OR Altitude motion

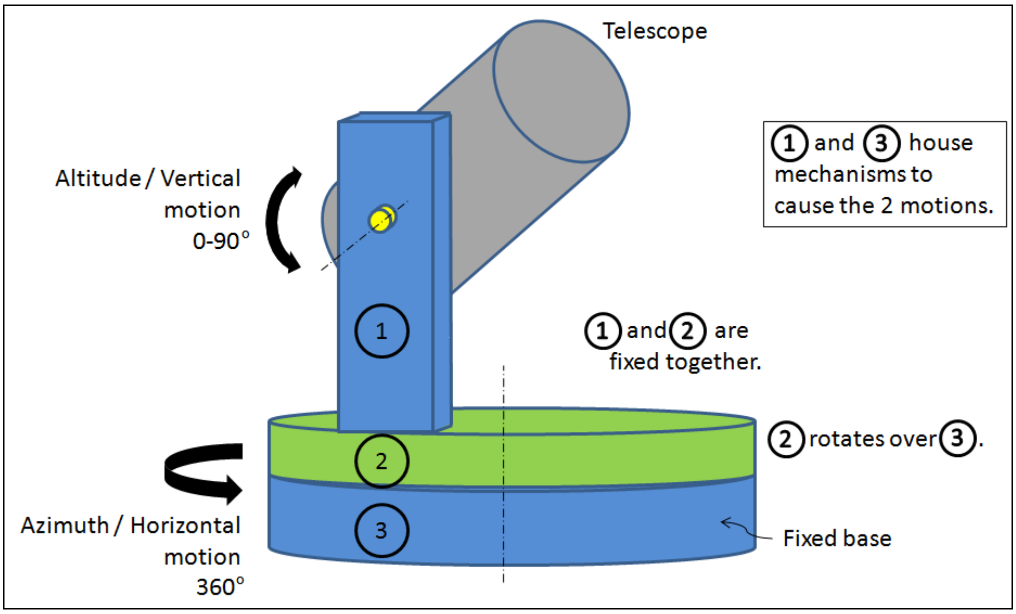


Figure 7.00 : Mount design overview

Each of these motions/drives will be driven by a worm and worm-wheel gear. The reason for choosing a worm drive for this application is because the angular resolution of the load is very small (0.1°). As a worm gear has a very high reduction ratio, this accuracy can be achieved along with satisfying the load torque.

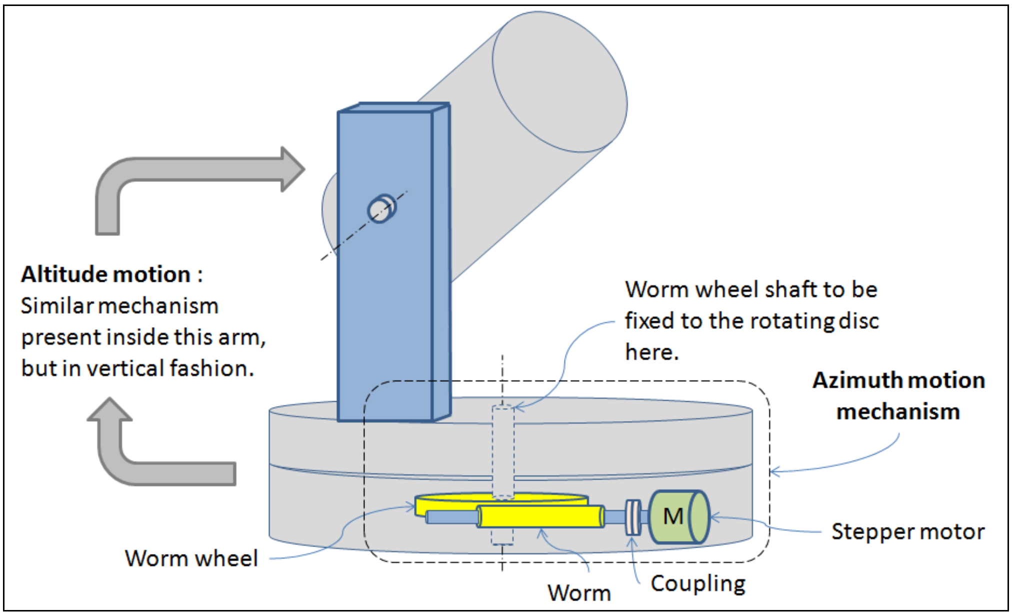


Figure 8.00 : Mount design virtual section view

The worm gear will be driven by a stepper motor. Detailed calculations of the load are given below.

5.1.1. Load calculations

The primary considerations for load are:-

1. Load torque (τ_{load})
2. Load angular accuracy (θ_{load}) = 0.1° fixed.

Gear ratio (a) and motor (τ_m and θ_m) is to be selected to satisfy this load.

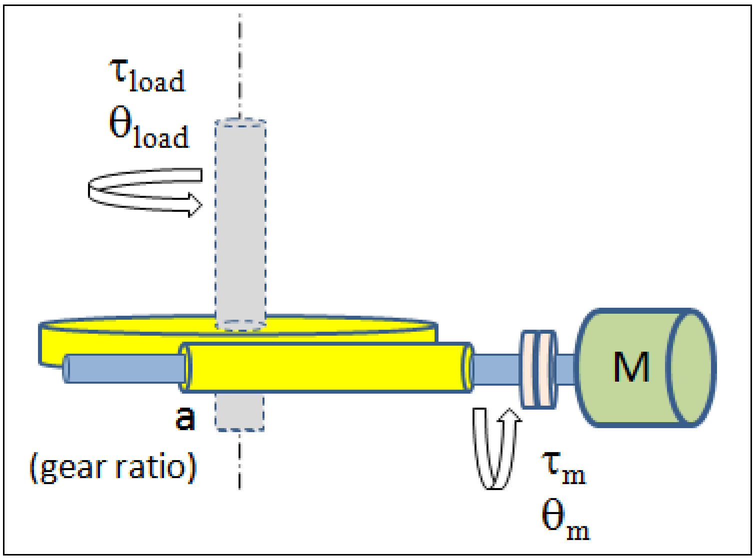


Figure 9.00 : Load consideration

Each of the 2 drives (altitude and azimuth) will have their own loads, details of which are given below.

5.1.1.1. Altitude drive load

The load for the altitude drive is only the telescope. Hence only the telescope weight and dimensions are used to determine the load torque in below calculations.

Load calculations for "Altitude motion"

Item	Value	Unit	Description
θ_{load}	0.1	degree	Req angular displacement resolution
τ_{load}	15.47	kg-cm	Required load
a	40		Gear ratio
θ_m	**1.8**	**degree**	Req motor step angle
τ_m	**0.39**	**kg-cm**	Req motor torque

Telescope load

Item	Value	Unit	Description
Wt	1	Kg	assume equal distribution along length
Len	16.5	inches	end to end max. length
	41.25	cm	
FOS	1.5		factor of safety
τ_{load} = Wt/2 x FOS x Len/2			Formula for Torque
τ_{load}	15.47	Kg-cm	

Note -
Input values in green cells
Output values in yellow cells

Table 3 : Load calculation - Altitude drive

Thus, as can be seen, the load torque requirement is 15.47 kg-cm.

Considering a gear ratio of 1:40, a stepper motor having:-

Torque = 0.39 kg-cm at least and

Step angle = 1.8° maximum

should be selected for the "altitude drive".

Note – Details of gear ratio selection is given in later section.

5.1.1.2. Azimuth drive load

The load for the azimuth drive is load of the telescope plus load of the mount frame. Hence weight and dimensions of both are used to determine the load torque in below calculations.

Load calculations for "Azimuth motion"

Item	Value	Unit	Description
θ_{load}	0.1	degree	Req angular displacement resolution
τ_{load}	22.50	kg-cm	Required load
a	40		Gear ratio
θ_m	**1.8**	**degree**	Req motor step angle
τ_m	**0.56**	**kg-cm**	Req motor torque

Telescope + mount load

Item	Value	Unit	Description
Wt	2	Kg	Total weight of scope and mount with altitude mechanism
Len	12	inches	end to end max. length of above mechanism.
	30	cm	
FOS	1.5		factor of safety
τ_{load} = Wt/2 x FOS x Len/2			Formula for Torque
τ_{load}	22.50	Kg-cm	

Note -
Input values in green cells
Output values in yellow cells

Table 4 : Load calculation - Azimuth drive

Thus, as can be seen, the load torque requirement is 22.5 kg-cm.

Considering a gear ratio of 1:40, a stepper motor having:-

Torque = 0.56 kg-cm at least and

Step angle = 1.8° maximum

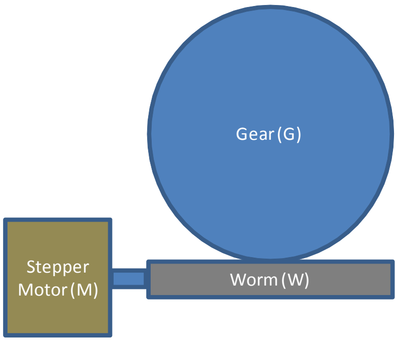
should be selected for the “azimuth drive”.

5.1.2. Gear calculations

Each of the drives will be driven by a worm and worm-wheel gear. The reason for choosing a worm drive for this application is because the angular resolution of the load is very small (0.1°). As a worm gear has a very high reduction ratio, this accuracy can be achieved along with satisfying the load torque.

A gear ratio of 40 was selected. Below is the calculation for the same.

Angular displacement Calculations



Enter values for gear ratio. Use standard gears.

Enter a step angle such that value of θload (yellow) should come less than the max θload (red)

Item	Value	Unit	Description
T_G	40		No. of teeth on gear "G"
T_W	1		No. of teeth/helix on worm "W"
a	40		gear ratio (Tg/Tw)
θ1	1.8	degree	Step angle of motor (assume)
θfull	360	degree	
	200		No of motor steps per revolution of worm (θfull/θ1)
	200		No of motor steps for displacing 1 tooth of Gear "G" (θfull/θ1)
T_x	0.005		No of tooth of "G" displaced in 1 motor step (θ1/θfull)
θ2	9	degree	Angle displcement by displacing 1 tooth of "G" (θfull/a)
θload	0.045	degree	Therefore, angle displcement by displacing Tx tooth of "G". Which is nothing but angle displaced of gear wheel "G" for 1 motor step. (θ1/a)
θload req	0.1	degree	Required angluar resolution
Result	OK		OK - ok and valid design ; NG - not good.

Table 5 : Gear calculations

As can be seen, with this gear ratio, the required angular accuracy of the load can be easily achieved.

5.1.3. Model design

The 3-D model of the mount was designed using CATIA v5 software. The parts were individually designed in the part designer module and were assembled together in the assembly module. The designed part files were used to fabricate the corresponding parts using a laser cutting machine. Below are some of the screenshots of the 3-D model.

Also shown later are drawings and assembly stages of the mount.

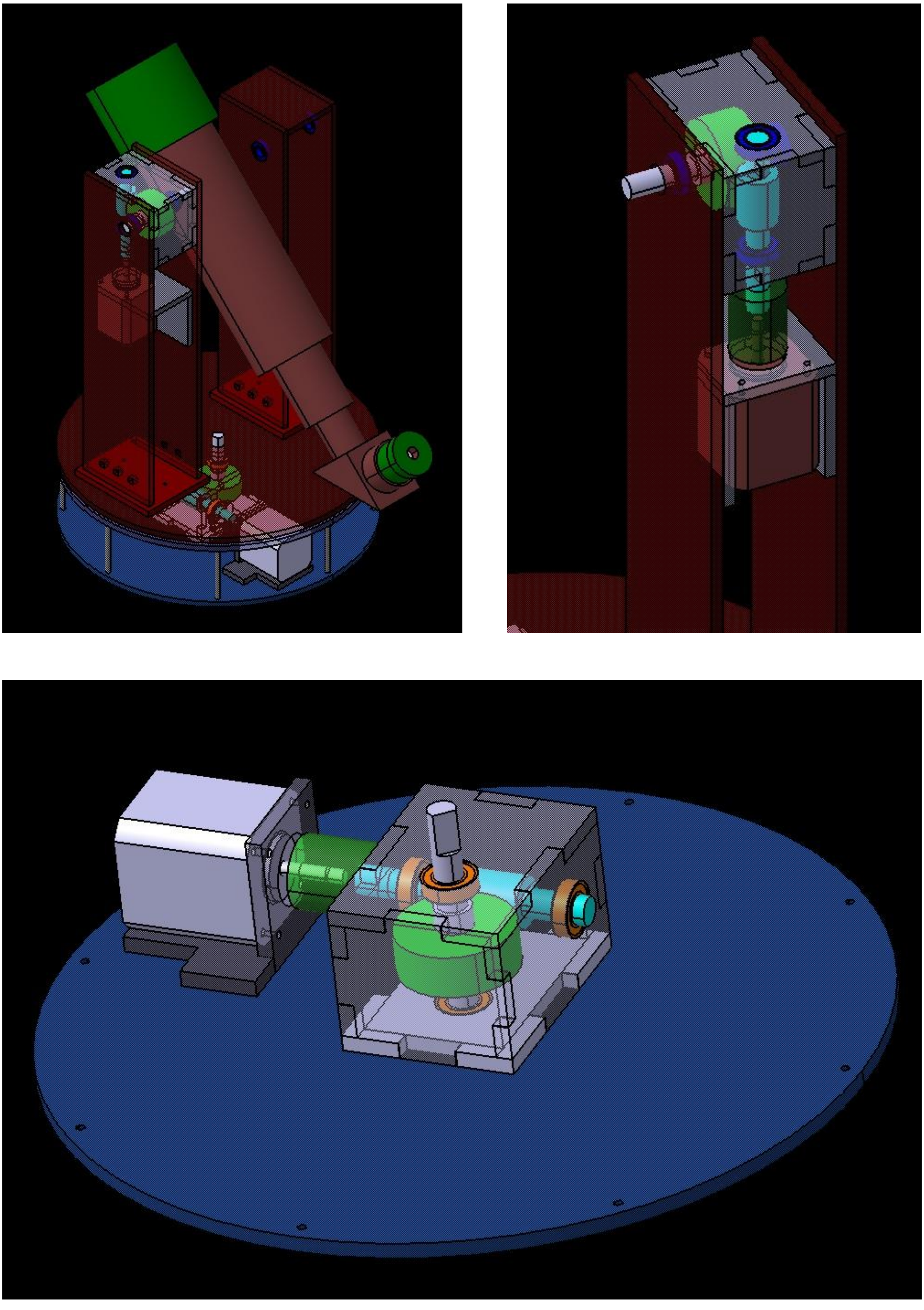


Figure 10 : Mount 3-D model

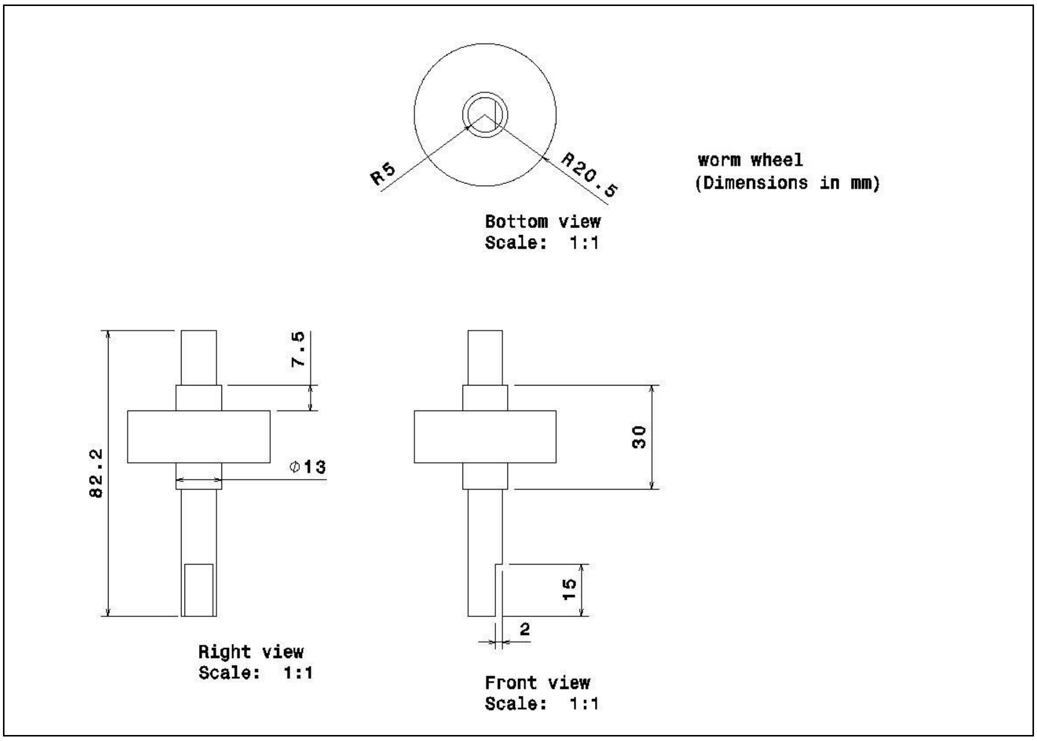


Figure 11 : Drawing - Worm wheel

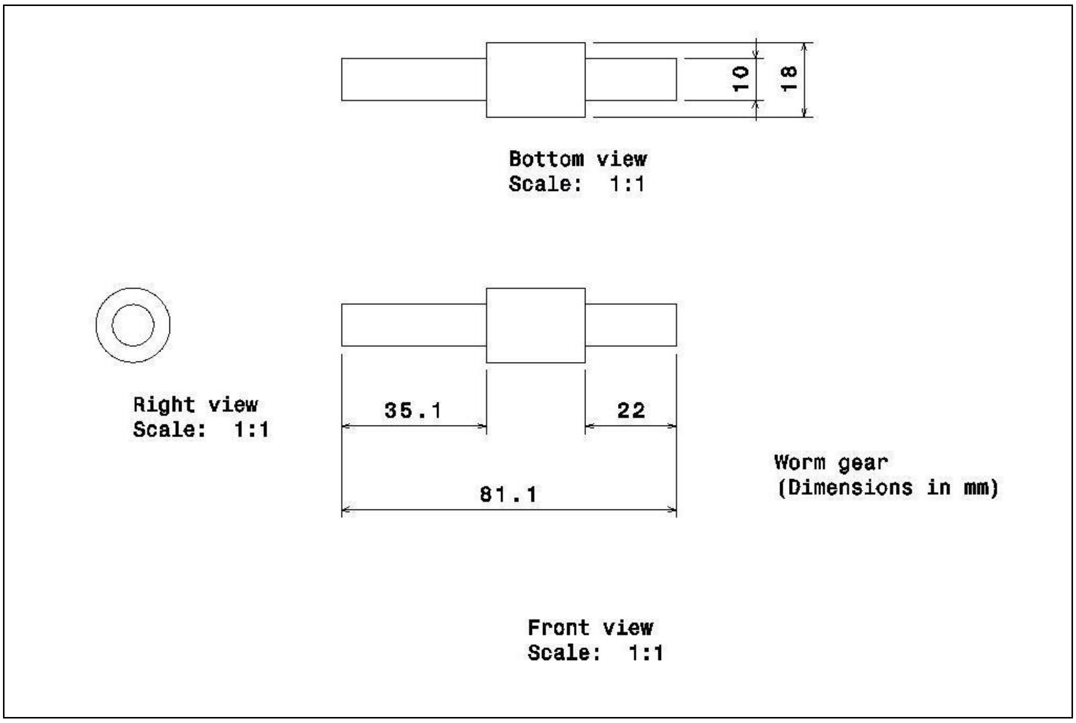


Figure 12 : Drawing - Worm

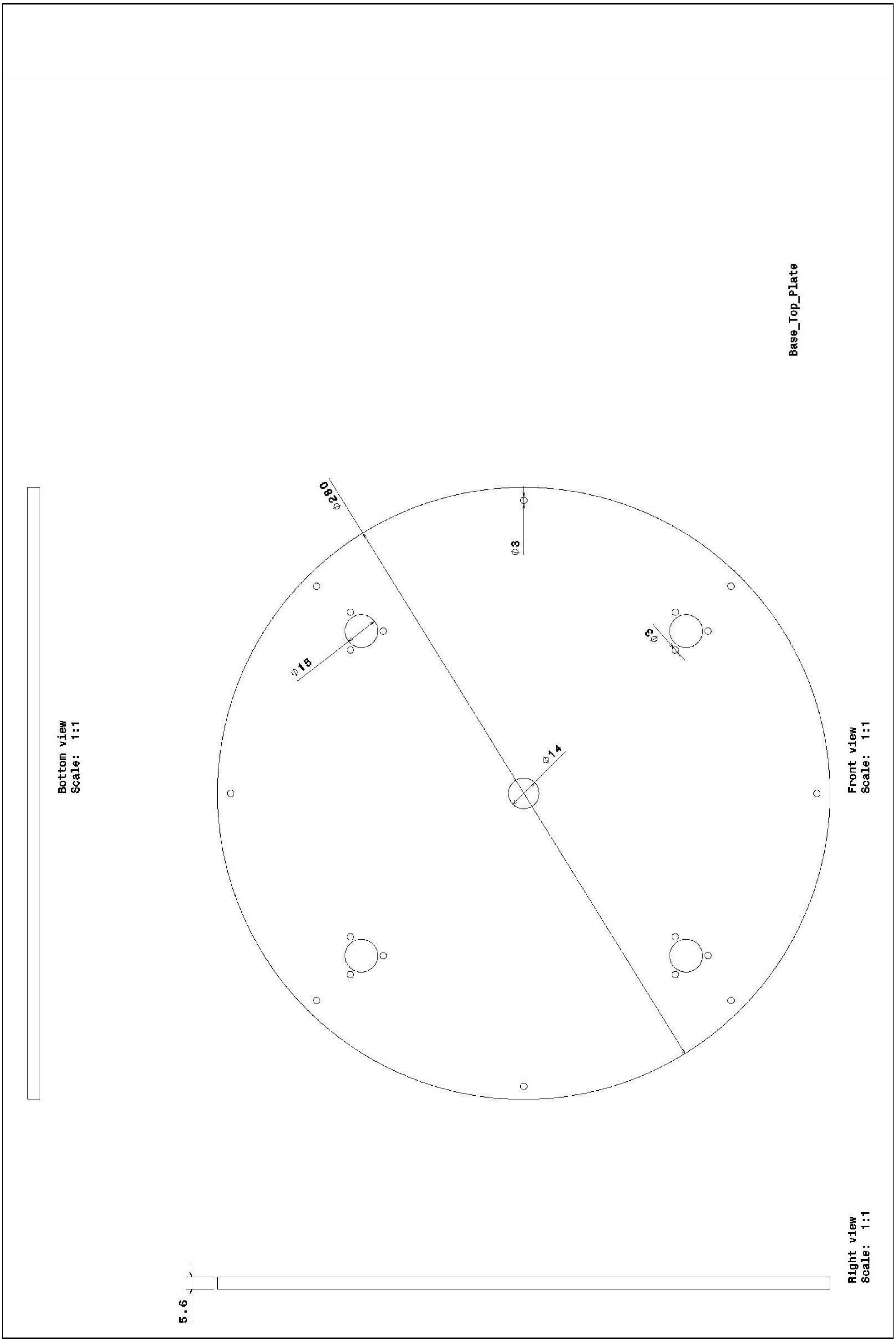


Figure 13 : Drawing - Base top plate

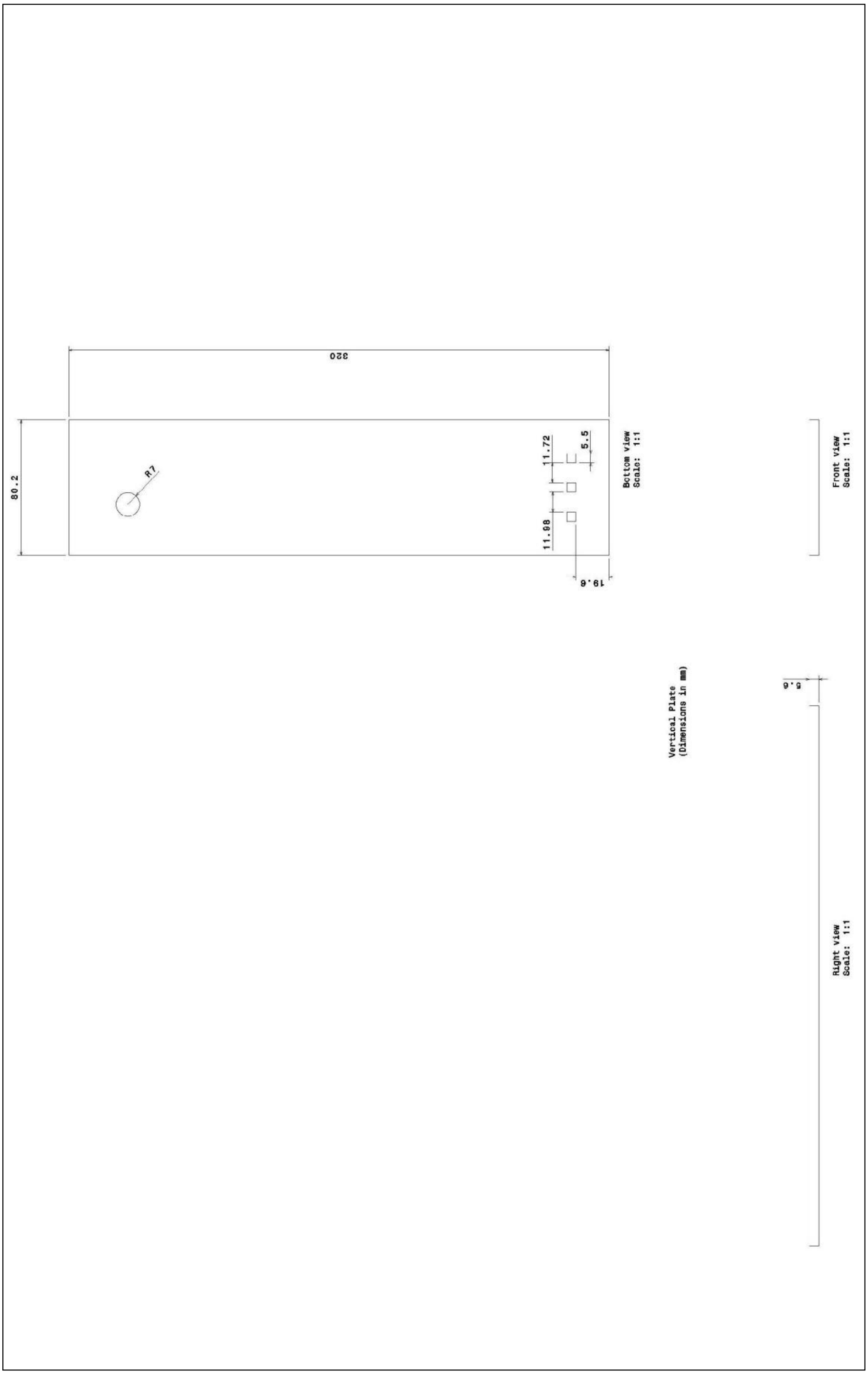


Figure 14 : Drawing - Vertical plate

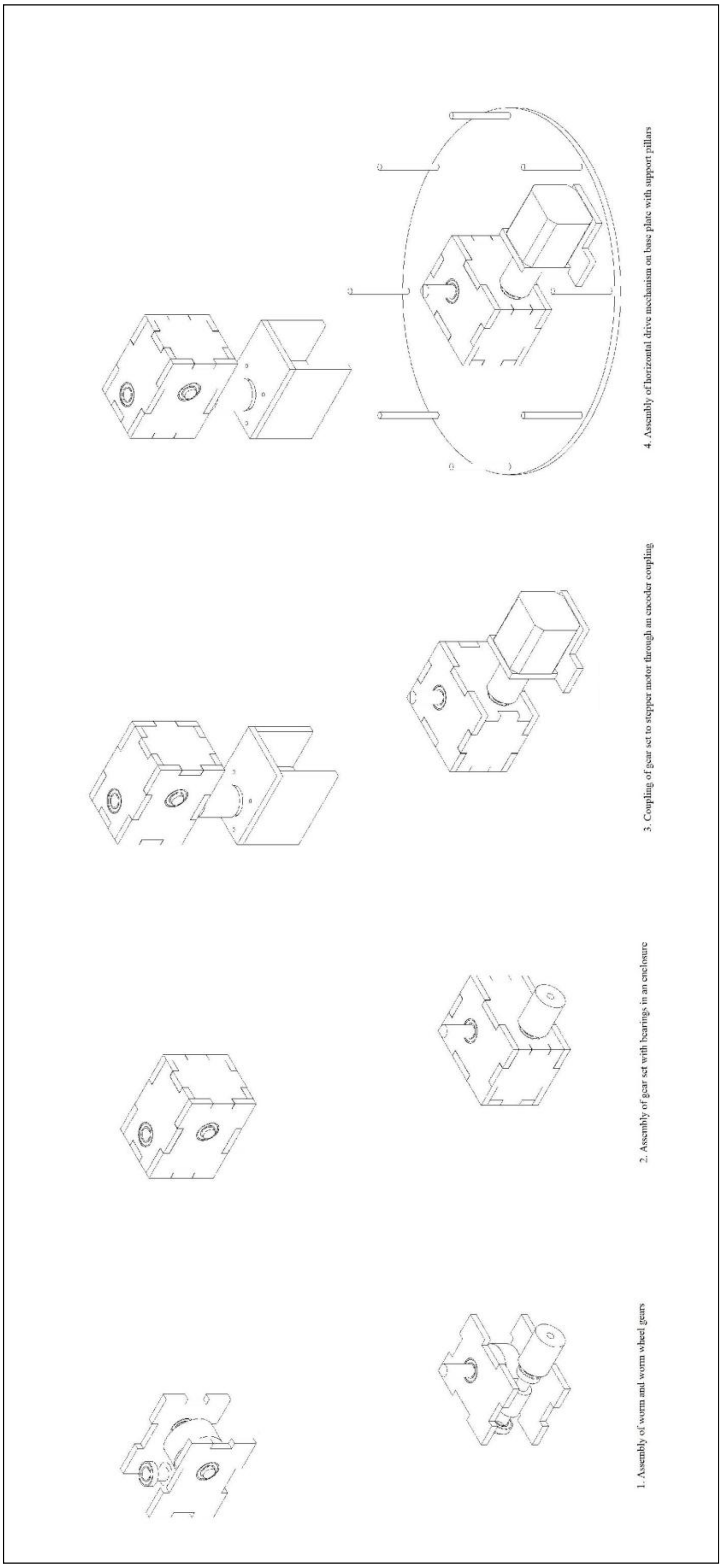


Figure 15 : Assembly - Stage 1

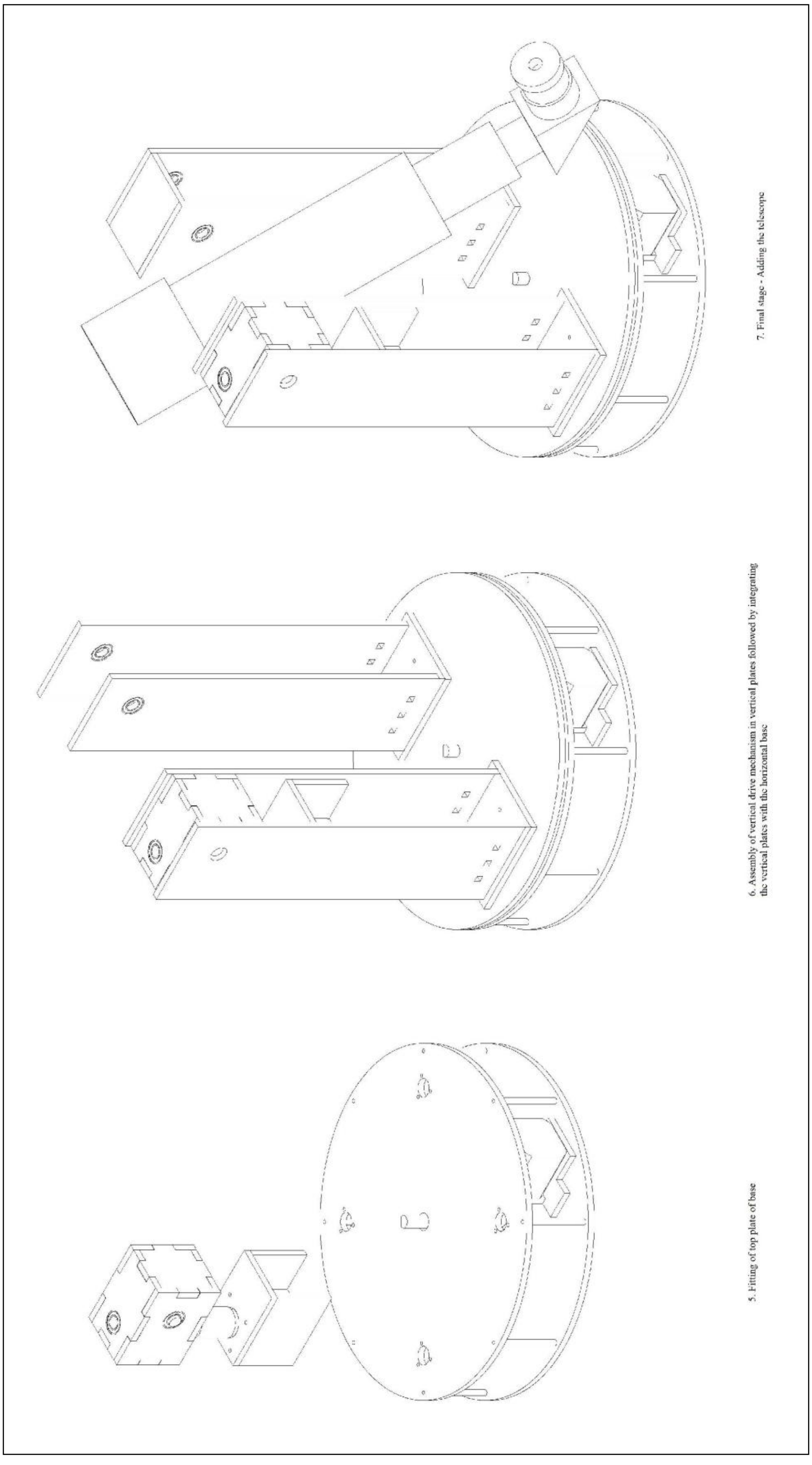


Figure 16 : Assembly - Stage 2

5.2. Electronic design

The electronics design is divided in 2 parts – hardware and firmware.

5.2.1. Hardware design

The hardware design consists of 3 main parts as shown in below block diagram:-

1. Power supply
2. Control board
3. Stepper Motor Driver

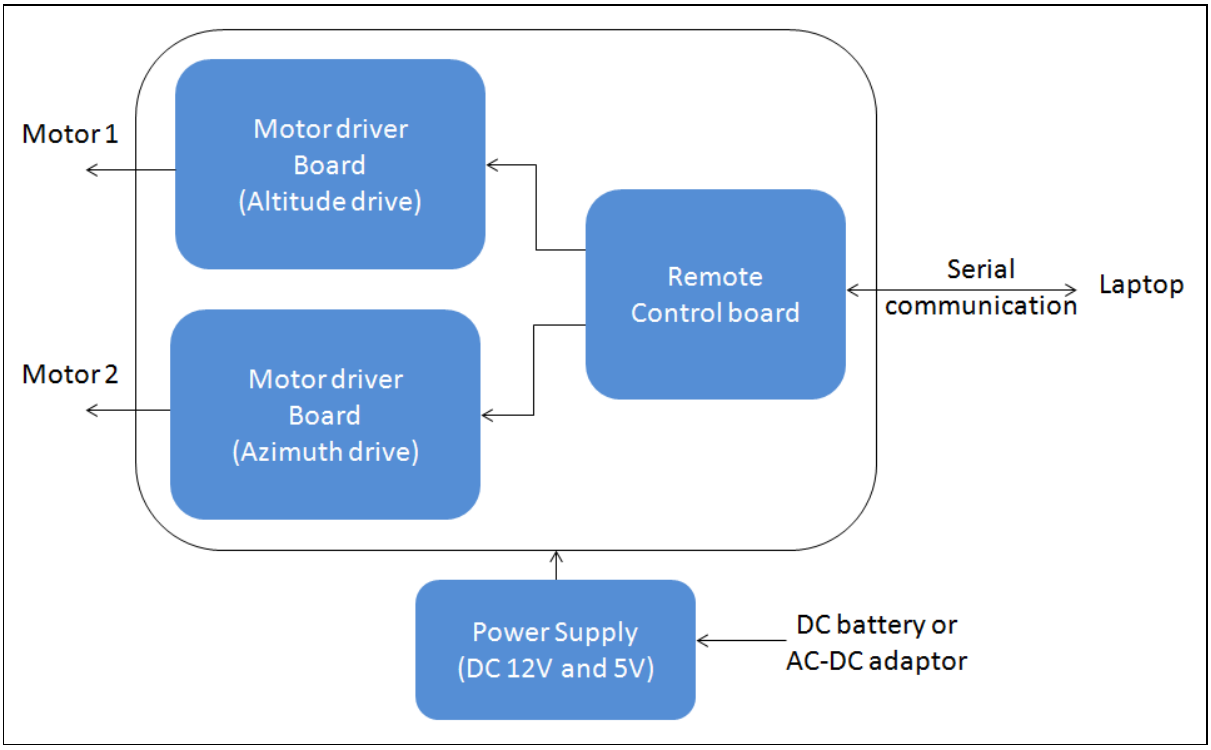


Figure 17 : Electronic design - block diagram

5.2.1.1. Motor driver design

The motor driver mainly consists of the following components:-

1. Stepper motor controller (IC L297) - For stepper motor sequencing
2. H bridge driver (IC L298) - For motor driver

Schematic of the motor driver board is shown below.

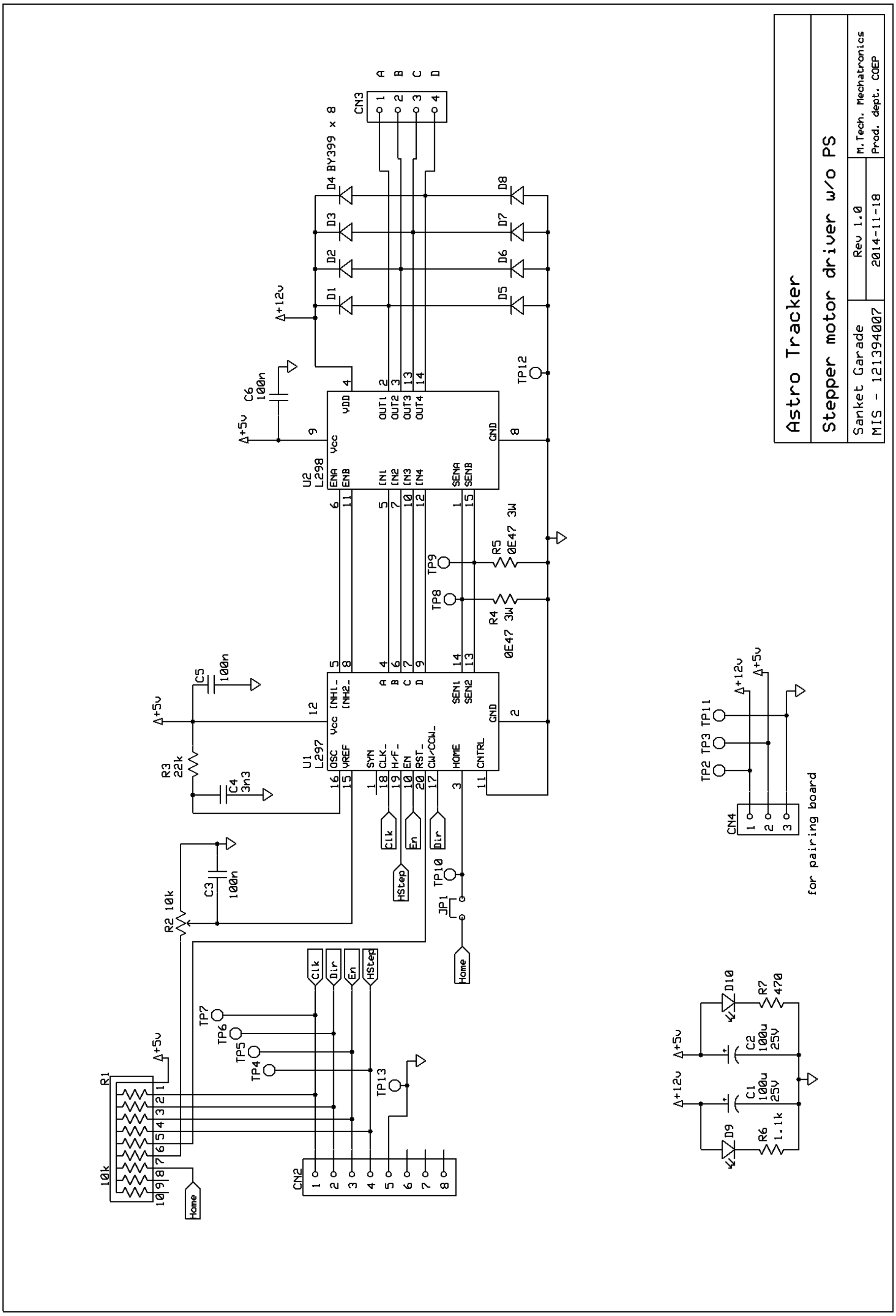


Figure 18 : Schematic – Stepper motor driver

5.2.1.2. Control design

The remote control mainly consists of the following components:-

1. Microcontroller - For system control
2. Serial to USB module - For communication with PC
3. Motor driver section - For sending motor control signals to the 2 motor driver boards.

Schematic of the control board is shown below.

5.2.1.3. Microcontroller (MCU) selection

Microcontroller selection is done depending on following requirements:-

1. Motor driver GPIO pins - 8 nos.
2. Programming port (SPI) - 1 nos.
3. Serial communication (UART) - 1 no.
4. Timer interrupts - 1 no.

All these can be achieved using Atmel ATmega16 MCU. Hence it is selected.

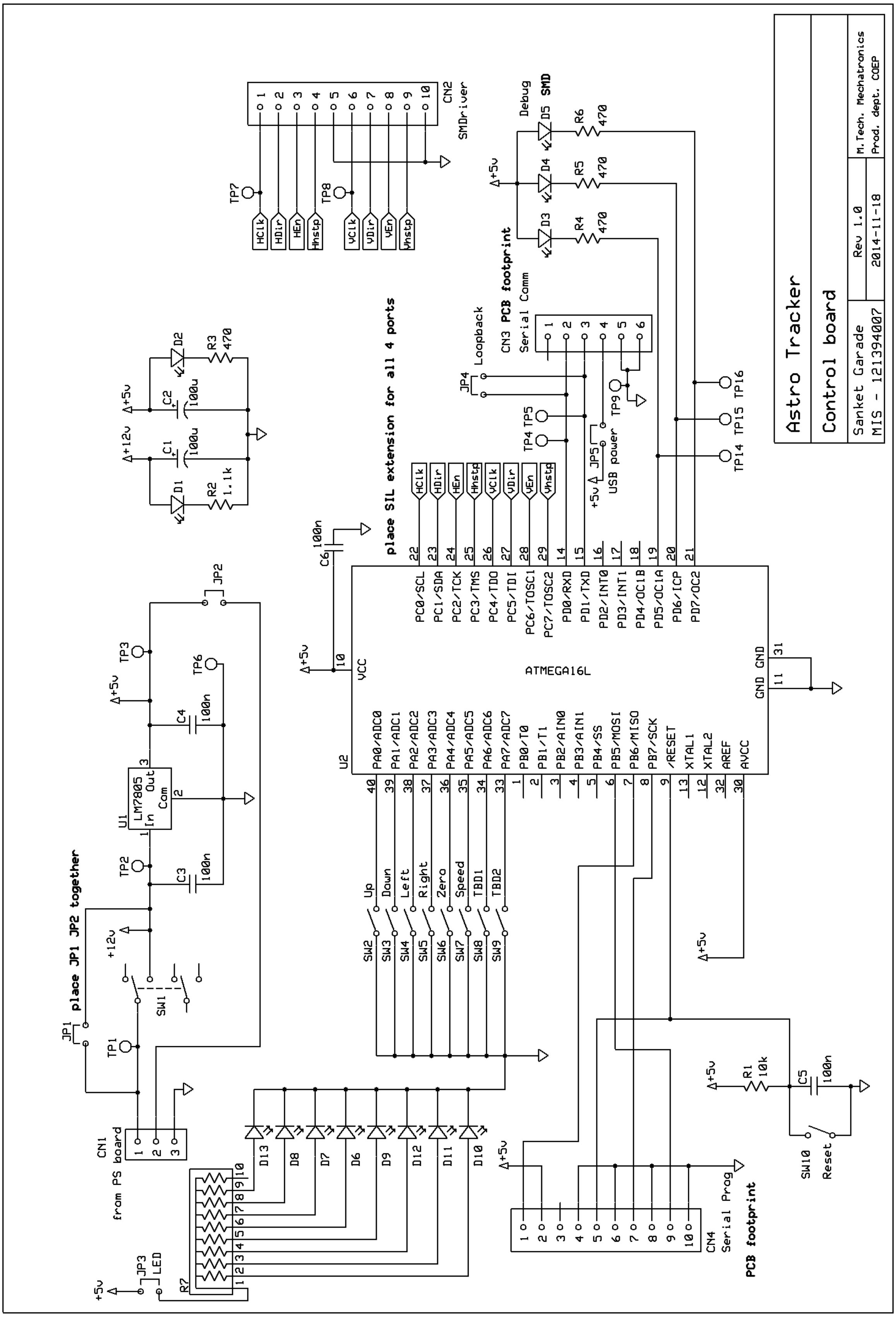


Figure 19 : Schematic – Control board

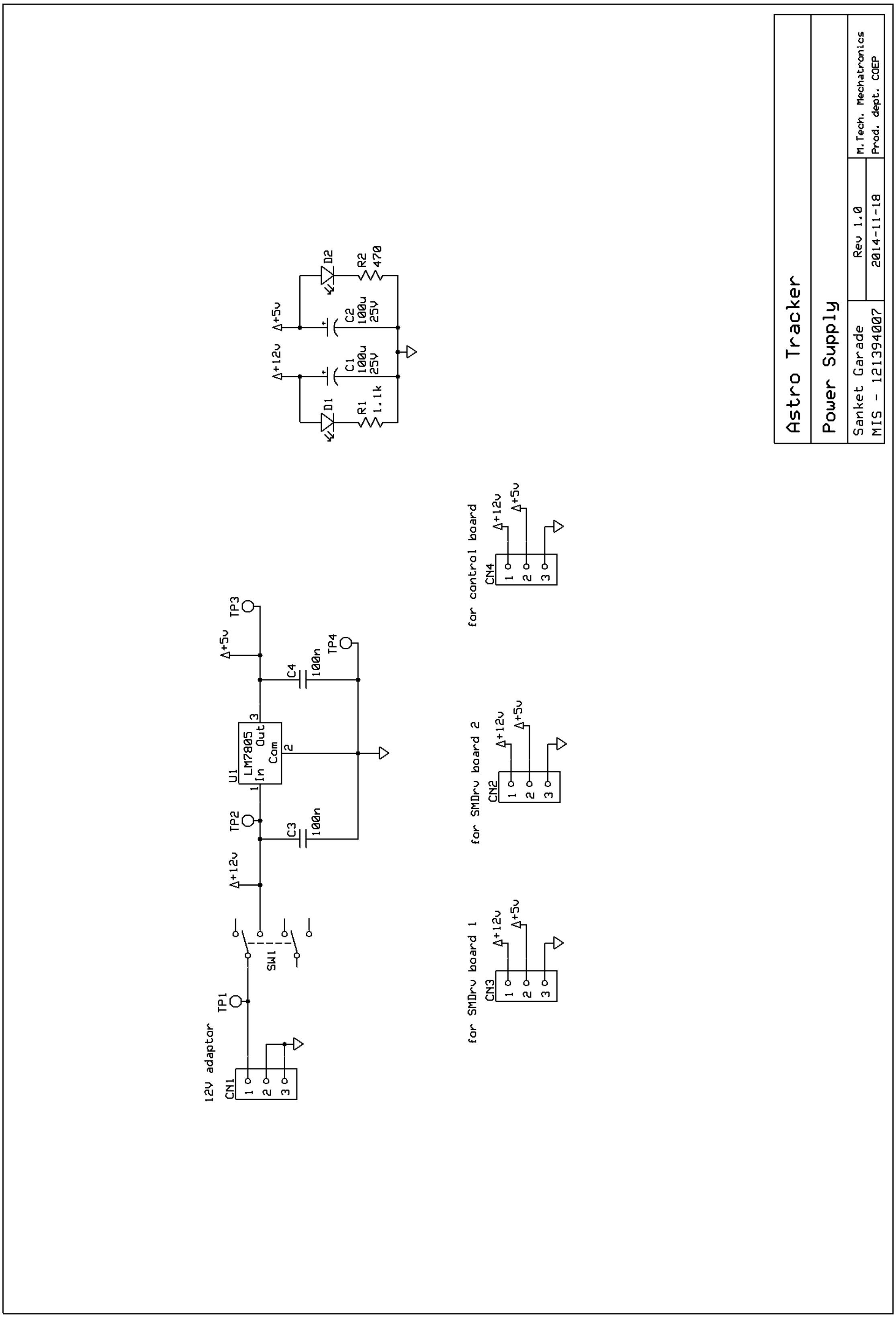


Figure 20 : Schematic – Power supply

5.2.2. Firmware design

The firmware in the Atmega16 MCU is designed as shown in below state diagram. A timer interrupt is configured to give timed clock pulses for the motor driver board. Interrupts are also configured for serial communication.

The pulse target command is received in the serial Rx interrupt and is used in the main loop.

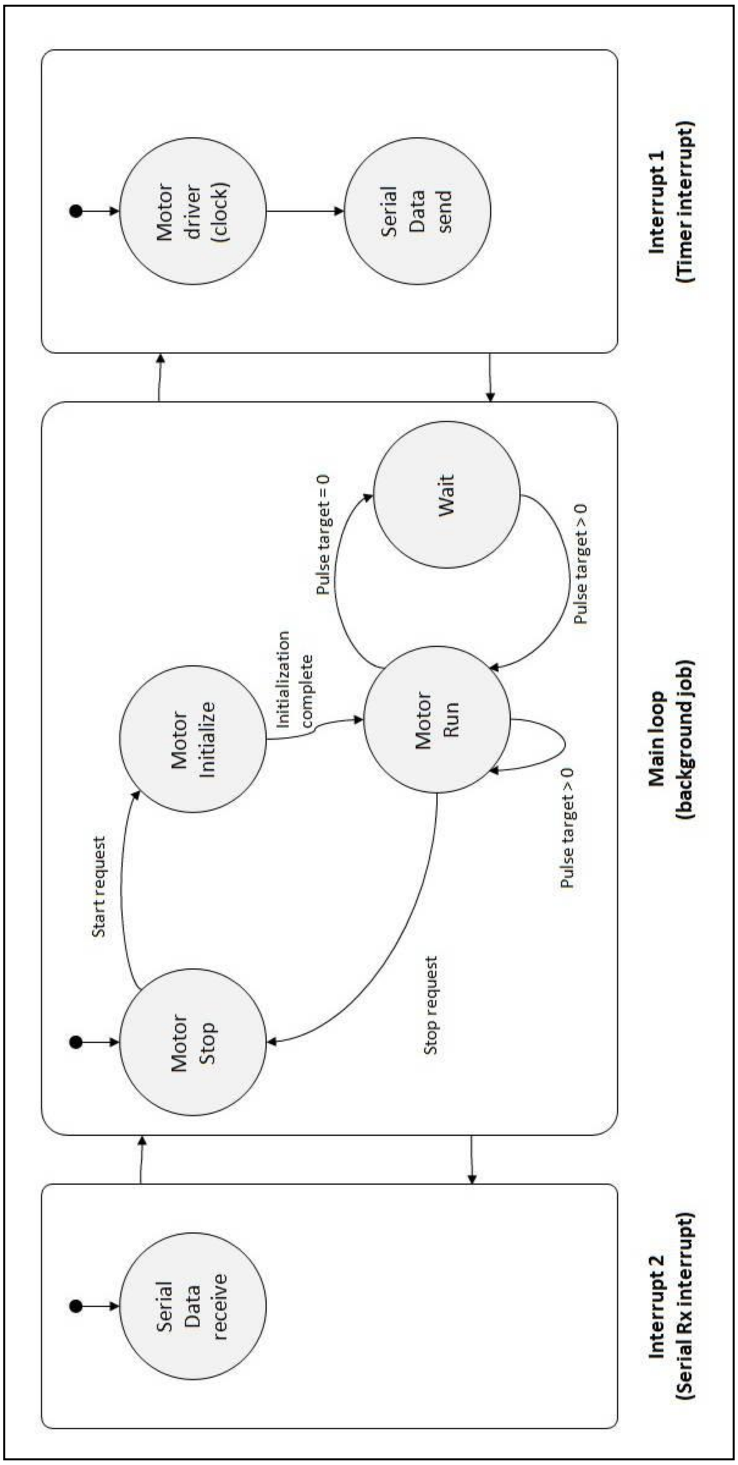


Figure 21 : Firmware design - State diagram

5.3. Software design

A windows application has been developed for the mount control. This application is the master of the entire system. Below is the screen-shot of the same. The application has been developed using MS Visual Studio 2010 software.

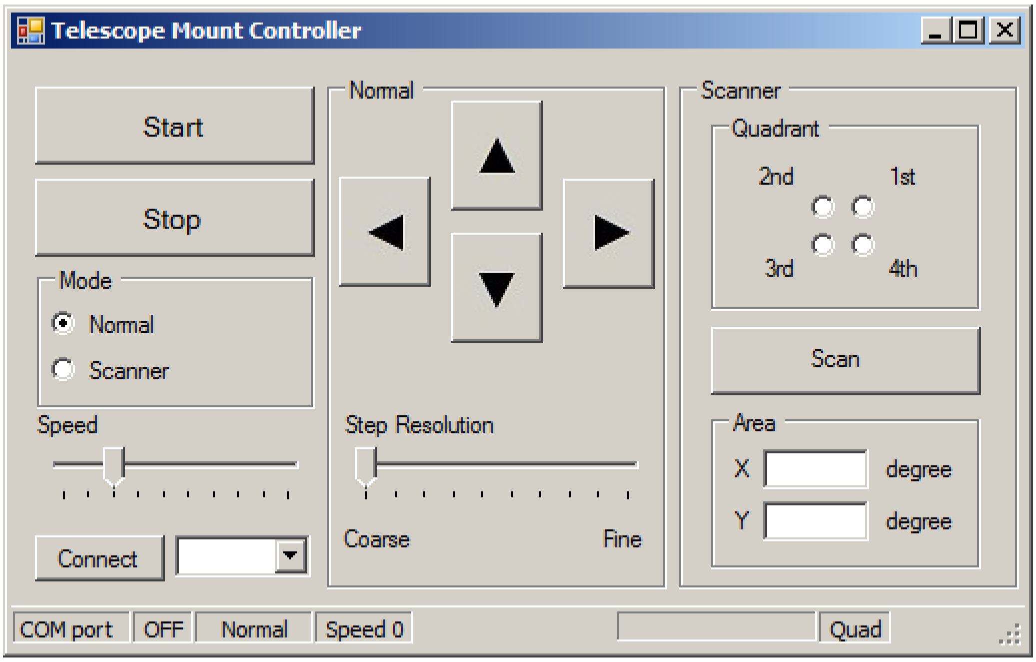


Figure 22 : Software - Windows application

User can control the mount using the arrow keys in the “Normal” section of the application. In the “Scanner” section, the user can set the scan area as X degrees by Y degrees; select either of the 4 quadrants and click on “Scan” button to start the scan. The window also displays the feedback received from the mount such as the status of the mount – whether it is on or off; mode set in the mount; speed etc. in the status bar at the bottom.

5.4. Communication design

A communication protocol was designed to enable error free and reliable communication between the application software and the mount. The protocol was built upon serial communication as a base protocol. Below is the table showing the frame format for the designed protocol. It shows the different types of information and commands exchanged between the application and the mount.

Frame Type	Command	Direction	Mode	SOF	Frame#	DLC	Data (L = DLC, MSB 1st)				Check Sum	EOF
							D3	D2	D1	D0		
Req01	Start Stop	PC → Mount	-	0x55	0x11	1	-	-	-	0 - Stop 1 - Start	0xXX	0x5A
Req02	Speed	PC → Mount	-	0x55	0x12	1	-	-	-	Speed Divider	0xXX	0x5A
Req03	Mode	PC → Mount	-	0x55	0x13	1	-	-	-	0 - Normal 1 - Scan	0xXX	0x5A
Req04	Direction	PC → Mount	Normal	0x55	0x14	1	-	-	-	B7-B4 : V Direction 0 - CW 1 - CCW B3-B0 : H Direction 0 - CW 1 - CCW	0xXX	0x5A
Req05	Pulse Count	PC → Mount	Normal	0x55	0x15	4	Vertical pulse count (0 - 65536) (D3 - MSB ; D2 - LSB)		Horizontal pulse count (0 - 65536) (D1 - MSB ; D0 - LSB)		0xXX	0x5A
Req06	Zero	PC → Mount	Scan	0x55	0x16	1	-	-	-	0 - Normal 1 - Set Zero	0xXX	0x5A
Req07	Quadrant	PC → Mount	Scan	0x55	0x17	1	-	-	-	1 - 1st quad 2 - 2nd quad 3 - 3rd quad 4 - 4th quad	0xXX	0x5A
Req08	Degrees	PC → Mount	Scan	0x55	0x18	4	Vertical degrees count (0 - 65536) (D3 - MSB ; D2 - LSB)		Horizontal degrees count (0 - 65536) (D1 - MSB ; D0 - LSB)		0xXX	0x5A
Res01	System Status	Mount → PC	-	0x55	0x21	4	B7-B4 : V Direction 0 - CW 1 - CCW B3-B0 : H Direction 0 - CW 1 - CCW	Reserved 0x00	Speed Divider	B0 : Sys Status 0 - Stop 1 - Start B1 : Mode 0 - Normal 1 - Scan	0xXX	0x5A
Res02	Pulse Count	Mount → PC	Normal	0x55	0x25	4	Vertical pulse elapsed (0 - 65536) (D3 - MSB ; D2 - LSB)		Horizontal pulse elapsed (0 - 65536) (D1 - MSB ; D0 - LSB)		0xXX	0x5A
Res03	Quadrant	Mount → PC	Scan	0x55	0x27	1	-	-	-	1 - 1st quad 2 - 2nd quad 3 - 3rd quad 4 - 4th quad	0xXX	0x5A
Res04	Degrees	Mount → PC	Scan	0x55	0x28	4	Vertical degrees elapsed (0 - 65536) (D3 - MSB ; D2 - LSB)		Horizontal degrees elapsed (0 - 65536) (D1 - MSB ; D0 - LSB)		0xXX	0x5A

Table 6 : Communication protocol - Frame format

The protocol is designed to ensure that corrupted data is discarded. This is done by implementing a redundancy check in the form of checksum. The “checksum” byte in the frame format is the sum of all the bytes in that frame before it. When the frame is received at the other entity, a fresh checksum is calculated of the received bytes and he result is compared with the received “checksum” byte. If the results match, only then the data is processed, else the entire frame is discarded.

6. Testing and Results

6.1. Test observations

The requirement specifications which were set at the start of the project were tested to check if they were achieved. Below are results of the same.

Requirement	Observations	Remarks
Load	The telescope mounted on the mount is of 1.2Kg which the mount is able to control.	Ok
Performance	The mount is theoretically designed to achieve 0.1° angular resolution, however due to some mechanical inaccuracies in assembly the mount is only able to achieve 0.2° resolution.	Though the resolution specification was not met, it is still very good for the purpose of astronomical observation.
Power	The mount is able to perform perfectly on a 12V DC supply.	Ok
Dimensions	The mount fits well within the required dimensions.	Ok
Communication	The mount and the computer application communicate with each other using an error free protocol.	Ok
Functional	The mount is able to perform as expected in the two modes for which it was designed.	Ok

Table 7 : Test observations

6.2. Setup Photos

Below are some photos of the mount and the overall system.

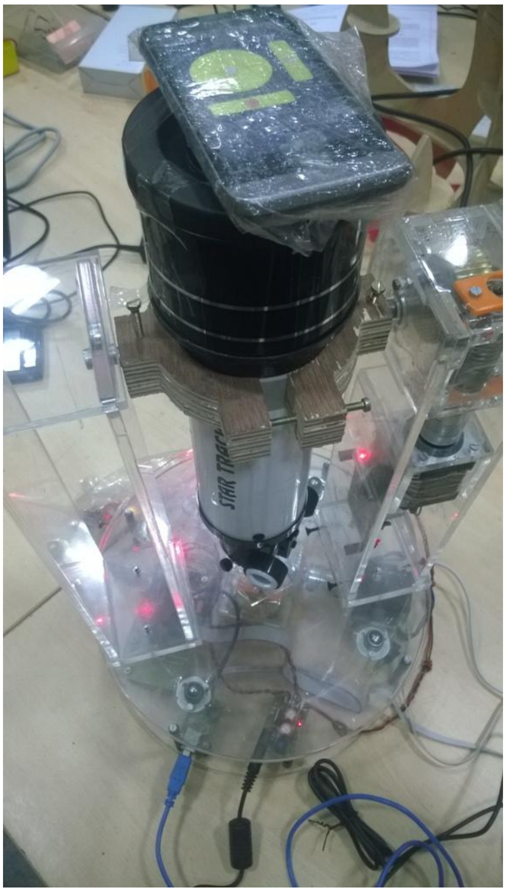


Figure 23 : Photo - Setup under test

Figure 24 : Photo - Test measurements

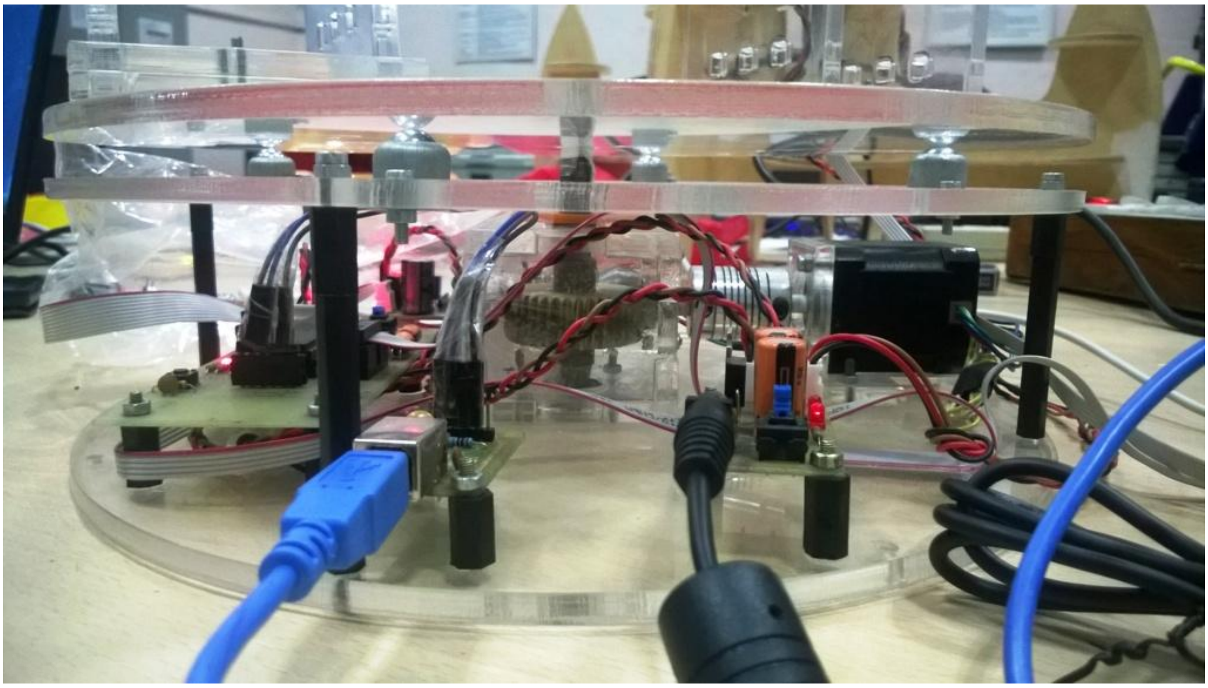


Figure 25 : Photo - Horizontal drive assembly

Above photo shows the base of the mount which houses the horizontal drive assembly. The gears, coupling and motor can be seen. Also can be seen are the control board on the left, the communication connector with the blue cable, and the power supply board on the right with the black cable.

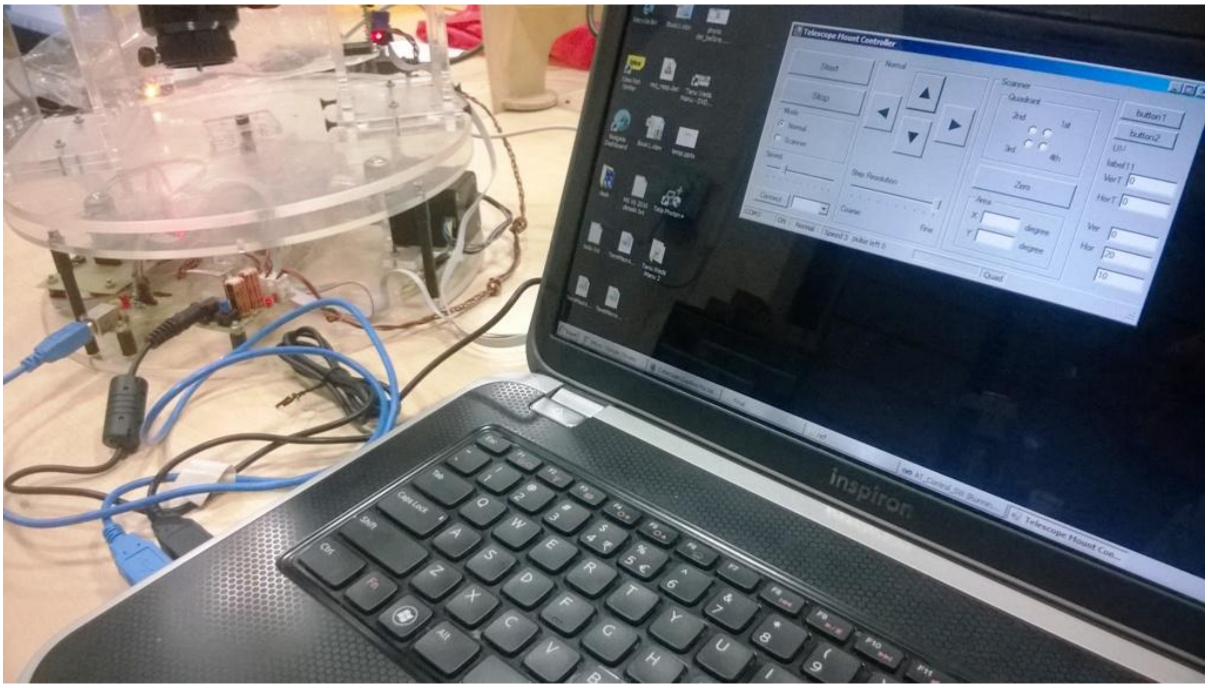


Figure 26 : Photo - Mount interfaced with application software

7. Conclusion

As per the initial requirement, a mount for guiding a telescope was successfully designed and developed. It was able to bear the load of the telescope and maneuver it. The mount was working as expected in both the functional modes – Normal and Scanner. The mount was also sufficiently good in angular resolution. As a result it was able to position the telescope very accurately as the user desired.

The entire system is a good example of a "Mechatronics" system as it incorporates concepts from various engineering fields like mechanical, electronics, software and communication. Various challenges were faced while working in each of these fields and also during their integration and testing. Having an inter-disciplinary approach was the key for successful execution and completion of the project.

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