Design and development of a computer controlled electro-mechanical mount for maneuvering an astronomical telescope

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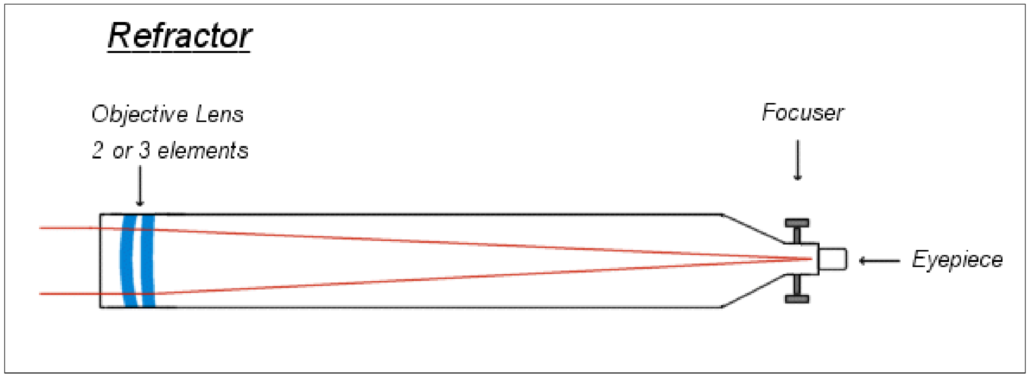
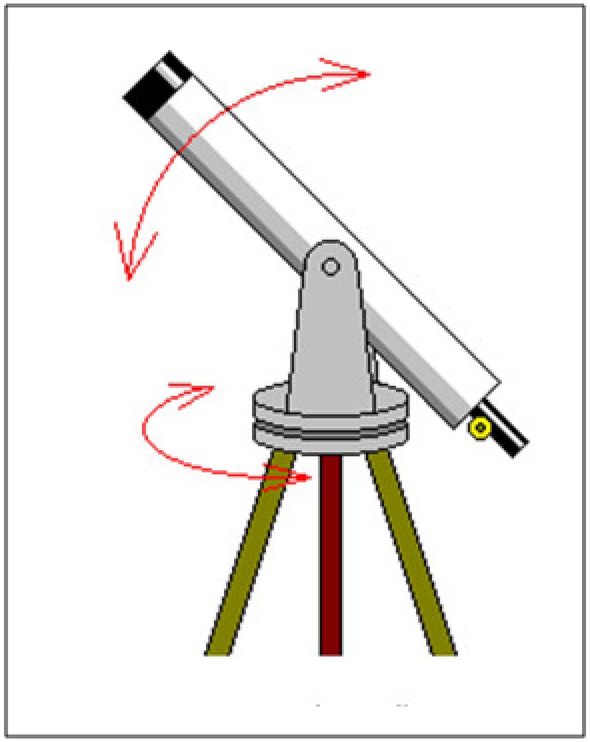
Introduction

- **Telescope –**

  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.

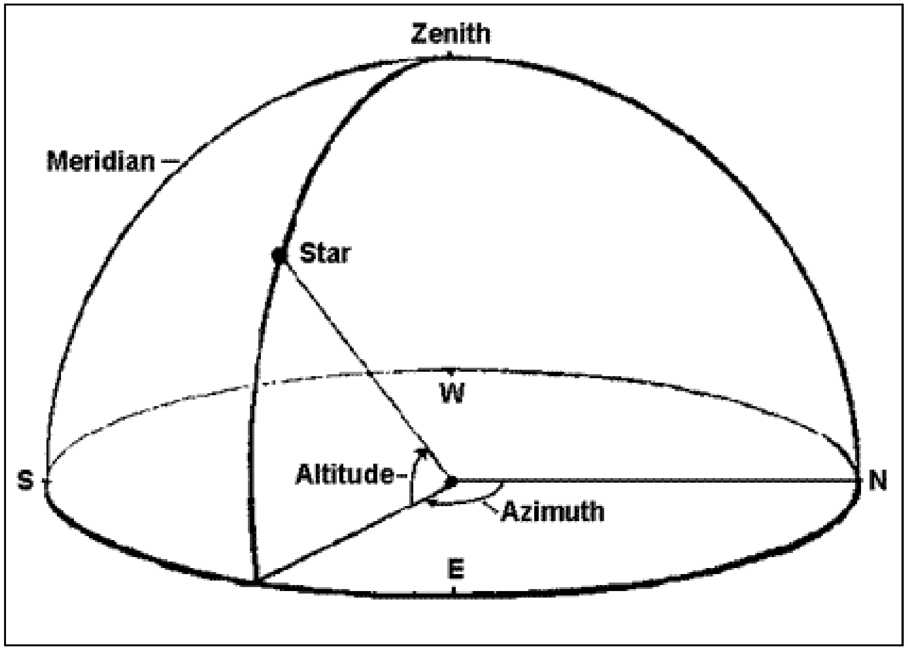
  An astronomical telescope is used to observe celestial objects such as planets, stars, deep-sky-objects such as galaxies, nebulae, comets etc.





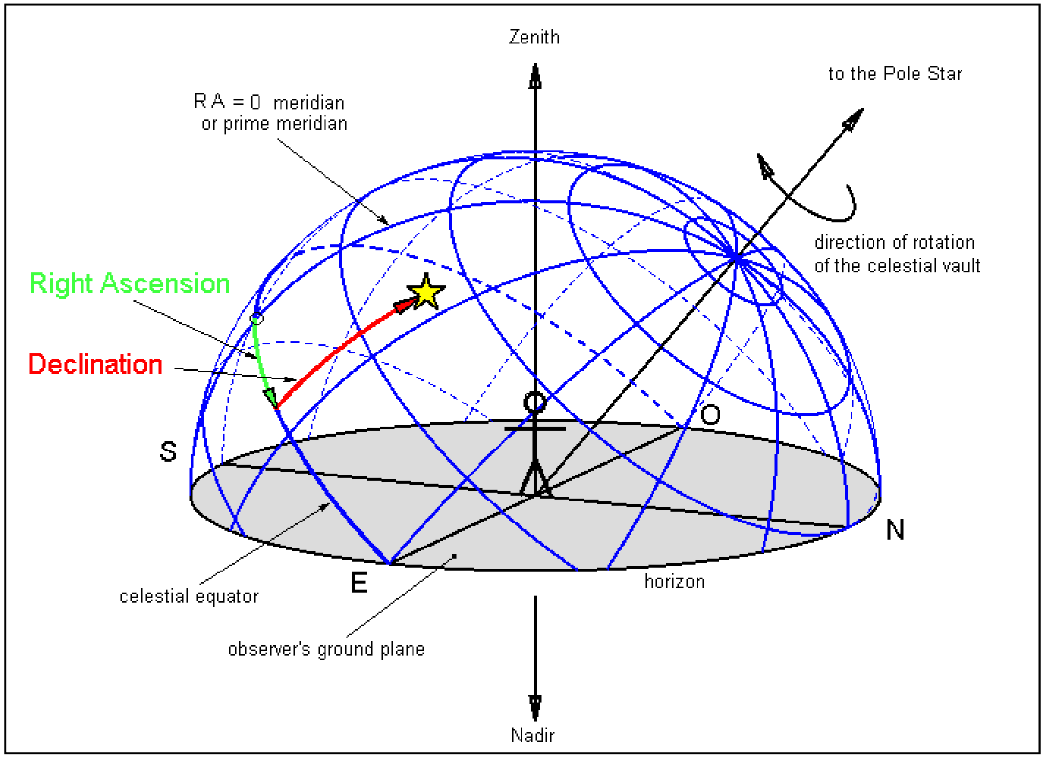
Introduction

- **Celestial Co-ordinate systems**
  - A system for specifying positions of celestial objects.
- **Alt-az coordinate system**
  - In this system, the positioning of a celestial object 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.
  - This system is not the best for astronomical purposes, but is still used by people as it is simpler than the equatorial system.



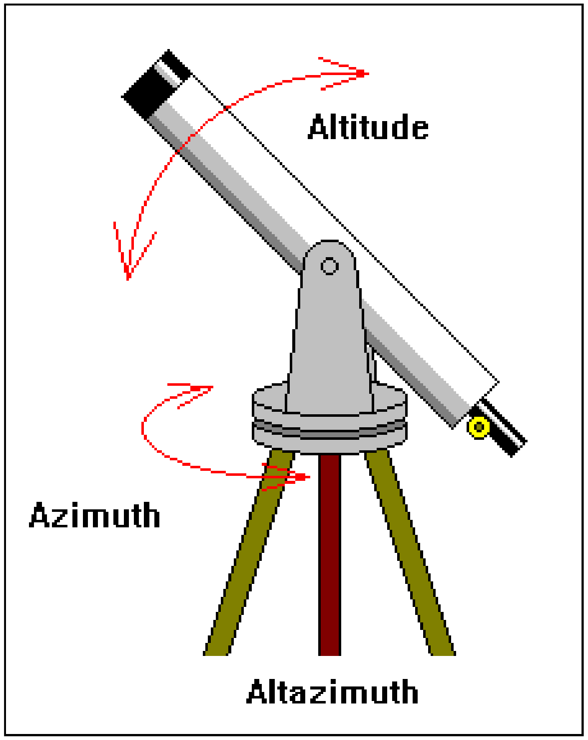
Introduction

- **Equatorial coordinate 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
  - This system is popularly used for astronomical purposes, but it is more complex than the alt-az system.

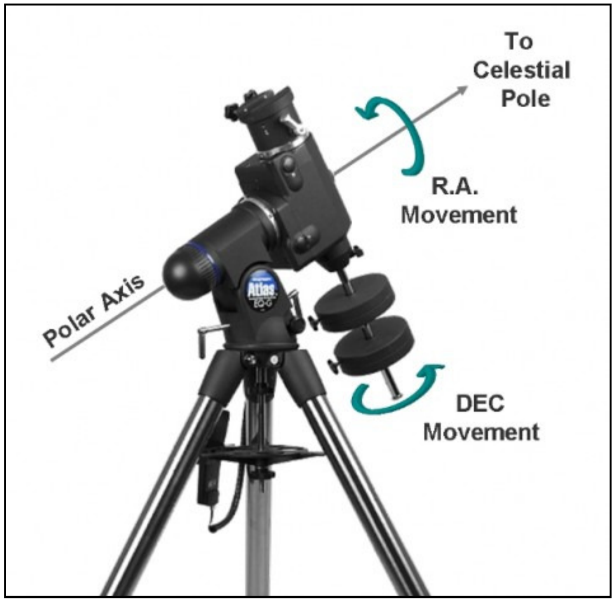


Study of mount

- **Alt-azimuth mount (alt-az)**
  - Simplest type of mount
  - It has 2 motions
    - Horizontal / Azimuth / Side to side
    - Vertical / Altitude / Up and down
  - Good for terrestrial observing and for scanning the sky at lower magnification.
  - Not good for deep sky photography.



- **Equatorial mount (EQ)**
  - Complex type of mount
  - It's 1 axis is tilted such that it passes through the celestial pole (Pole star).
  - It has 2 motions
    - Right ascension (RA) – about the polar axis
    - Declination (DEC) – about an axis perpendicular to the polar axis
  - Best for astronomical observation and deep sky long exposure photography.



Need for an automatic mount

- An automatic mount facilitates fast navigation of the night 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 higher especially when using heavier telescope (larger than 8 inches)
- Also 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.
- Also, 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.

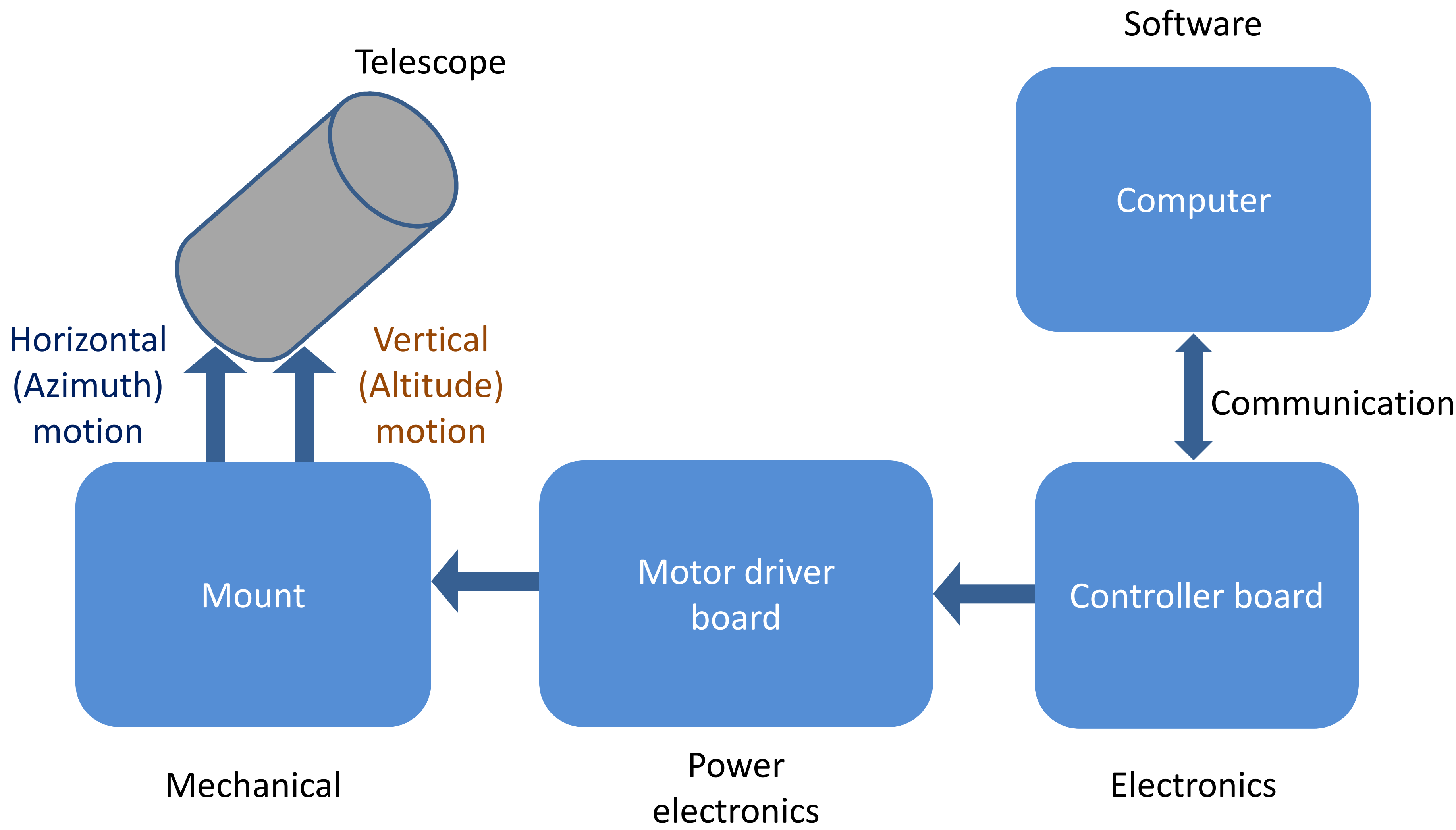
Problem statement

- Problem Statement –
  - A machine (called "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 do the following 2 tasks :-

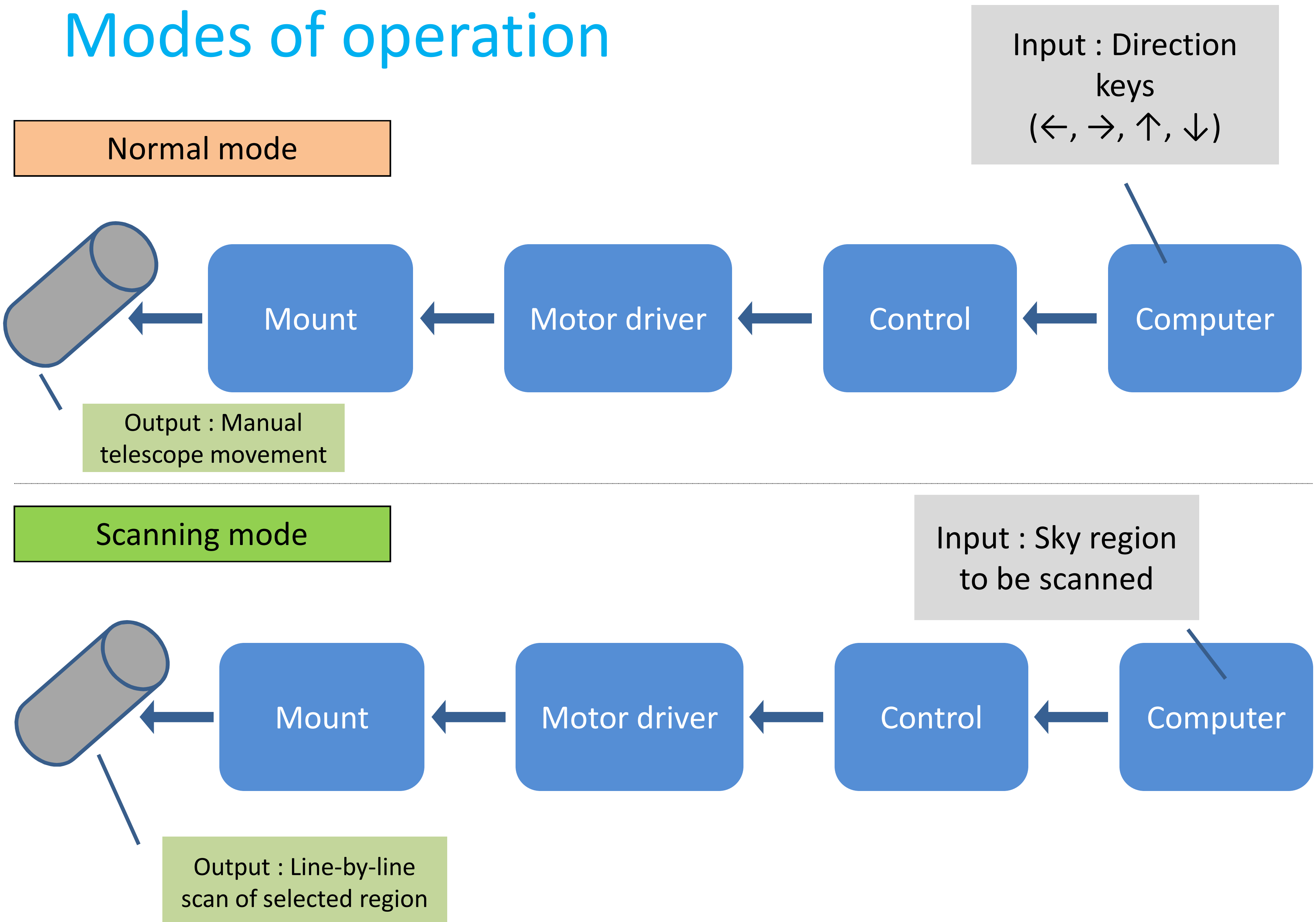
1. In normal mode, the user should be able to maneuver the telescope using the direction control keys on the computer software.
2. In scanning mode, the area of the sky to be scanned will be given as input from the computer software. The mount will perform a line-by-line scan of the selected region of the sky. This technique is commonly used for sky survey activities by various astronomers.

- Specifications –
  - Load specifications : The mount must be able to maneuver a telescope which is maximum 1Kg in weight and has max dimensions : Length = 18 inches and diameter = 3 inches
  - Performance specifications : The mount should provide an angular resolution of 0.1°, at least, in both its' axes.

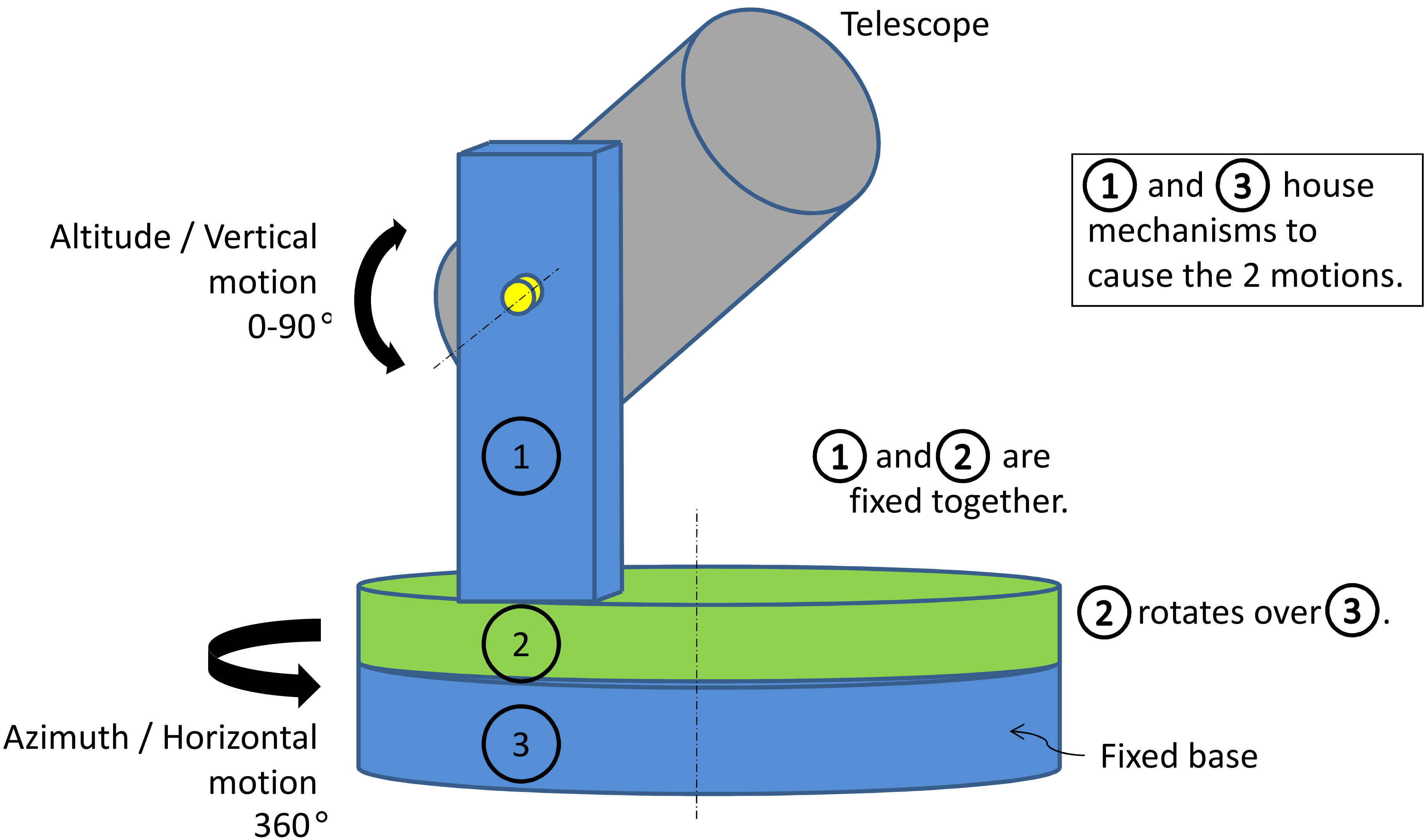
Block Diagram



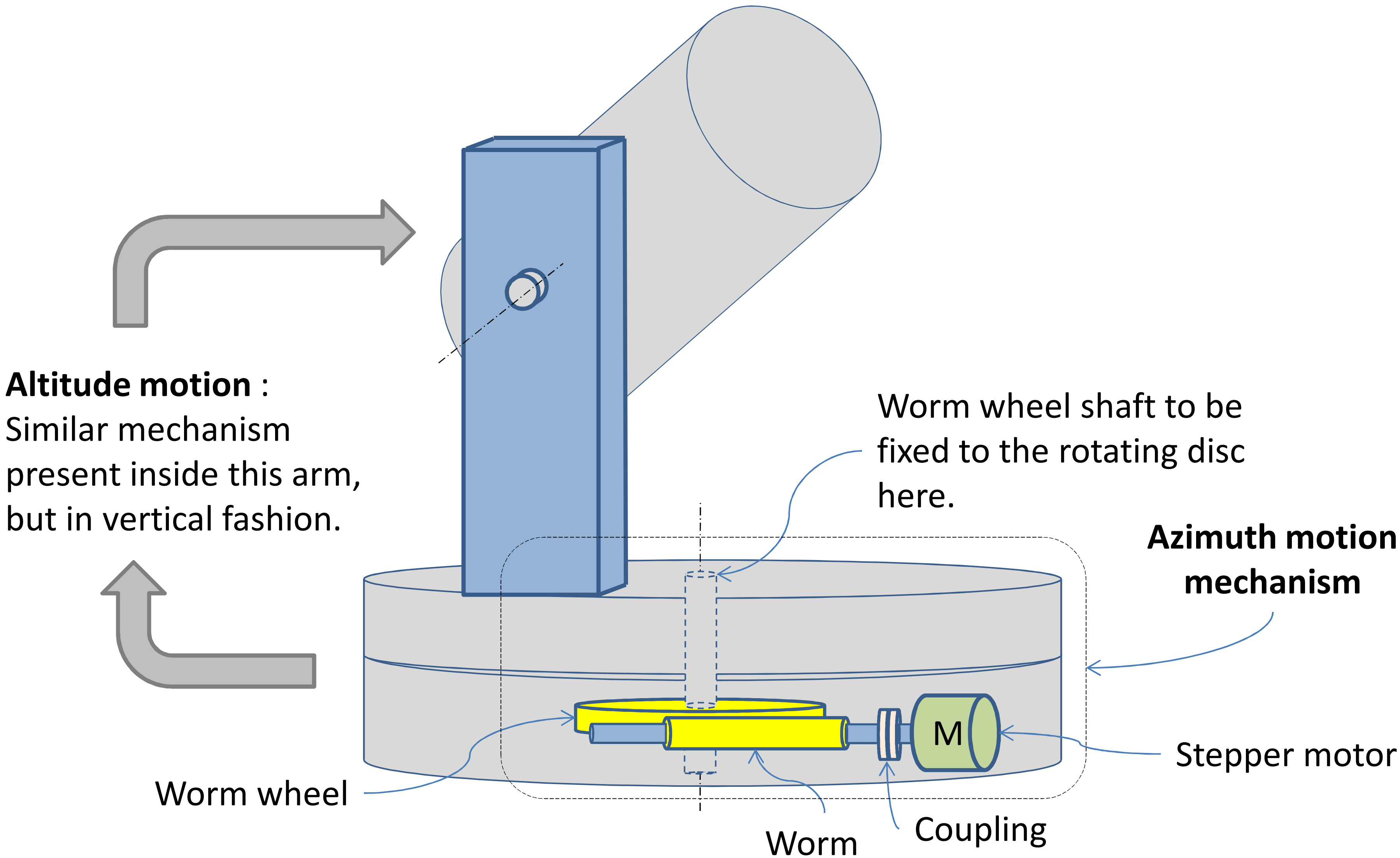
Modes of operation



Mechanical Design : Alt-azimuth mount



Alt-azimuth mount : Internal components



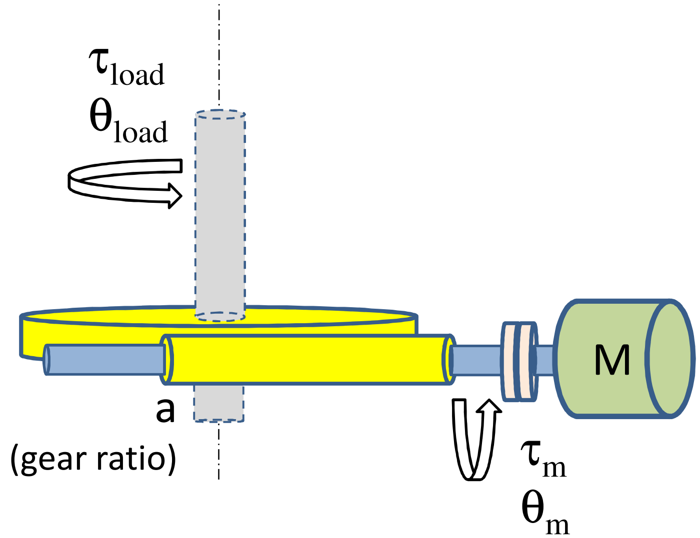
Mount Load calculations – Altitude motion

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 -

(green)	Input values in green cells
(yellow)	Output values in yellow cells



Mount Load calculations – Azimuth motion

Load calculations for "Azimuth motion"

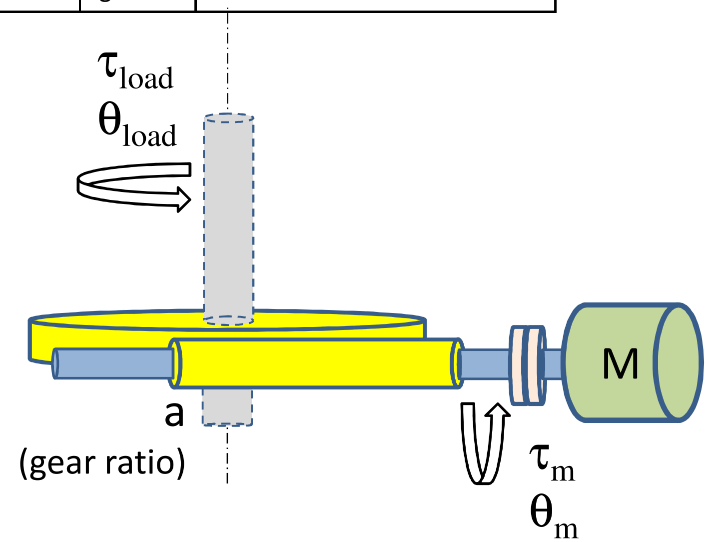
Item	Value	Unit	Description
θ_{load}	0.1	degree	Req angular displacement resolution
τ_{load}	22.50	kg-cm	Required load
a	40		Gear ratio
θ_m	**1.8**	**degree**	Req motor step angle
τ_m	**0.56**	**kg-cm**	Req motor torque

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

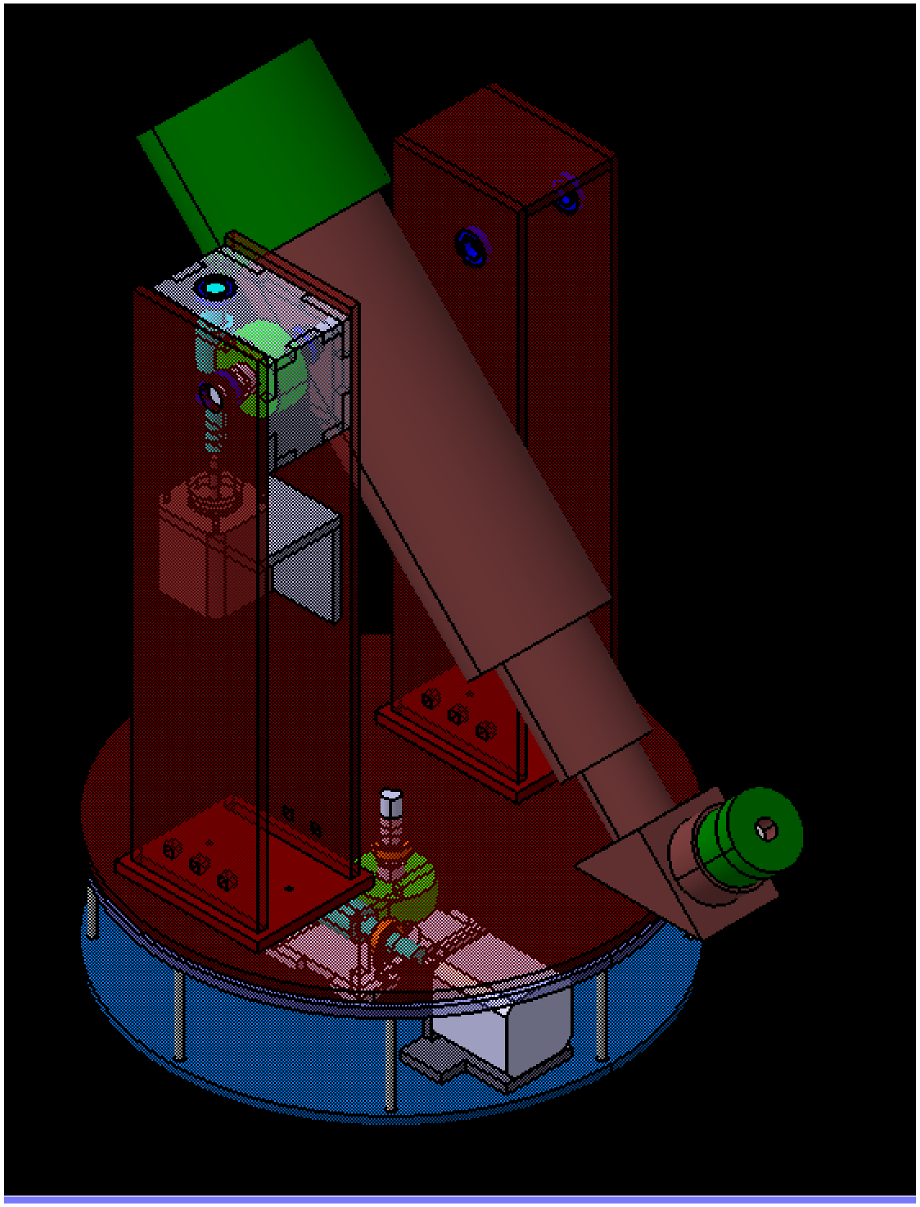


Mount model

- The mount model is designed using CATIA V5 software.

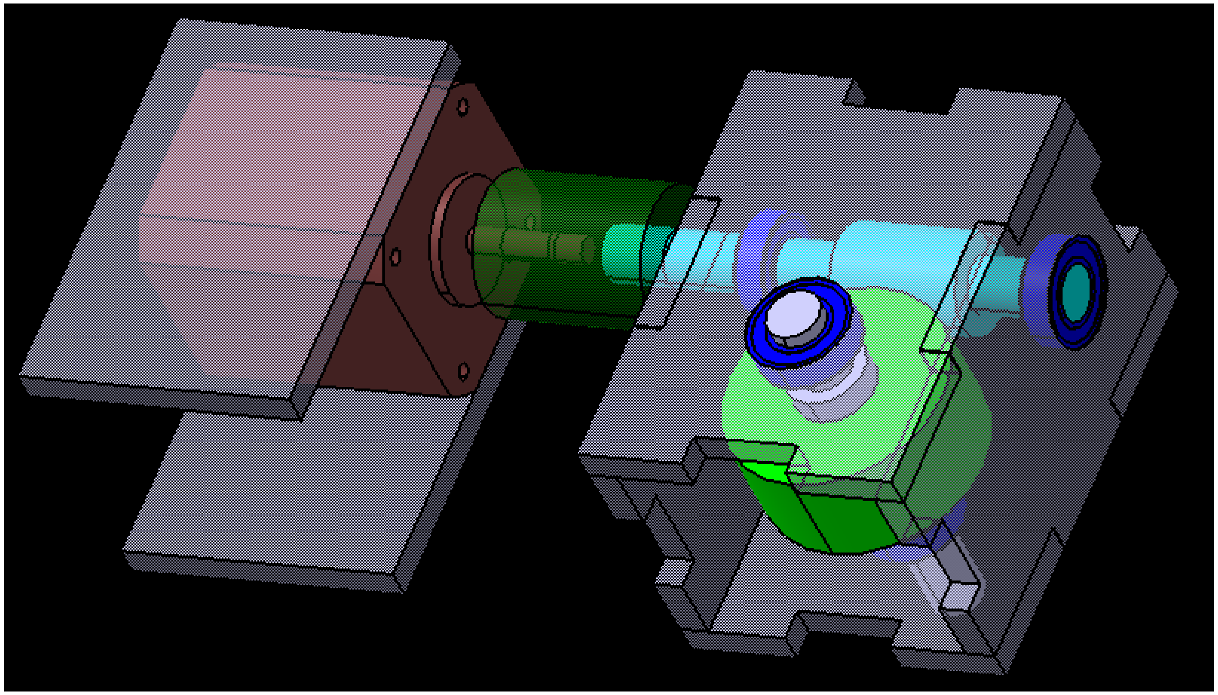
- Part design is divided into following –
  - Worm and wheel gears
  - Motor, Couplings, Bearings
  - Motor clamps and gear housings
  - Telescope
  - Bottom frame and vertical frames
  - Supporting plates

- Assembly is done in following stages –
  - Gear and housing assembly
  - Motor and coupling with gears
  - Horizontal drive
  - Vertical drive
  - Telescope attachment

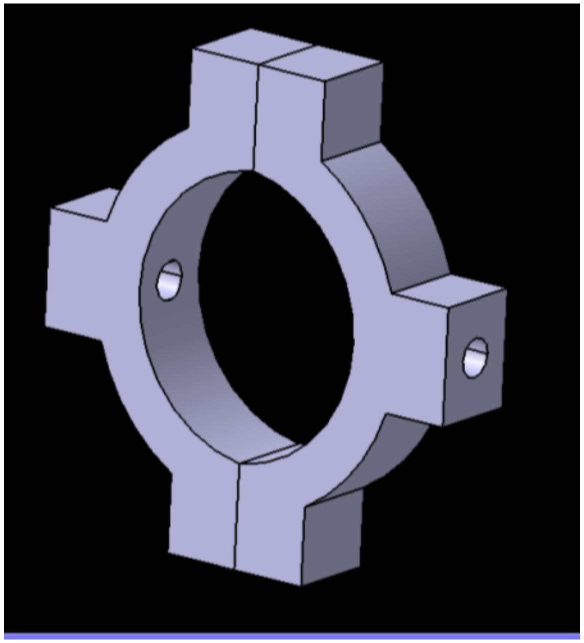


3D model of telescope mount

Mount model

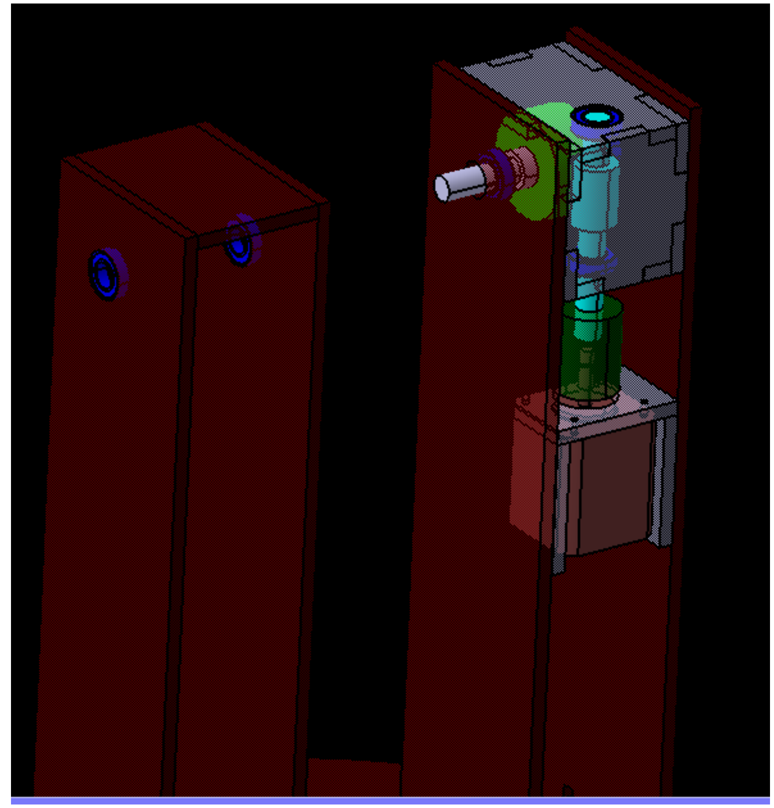


Motor and gear assembly

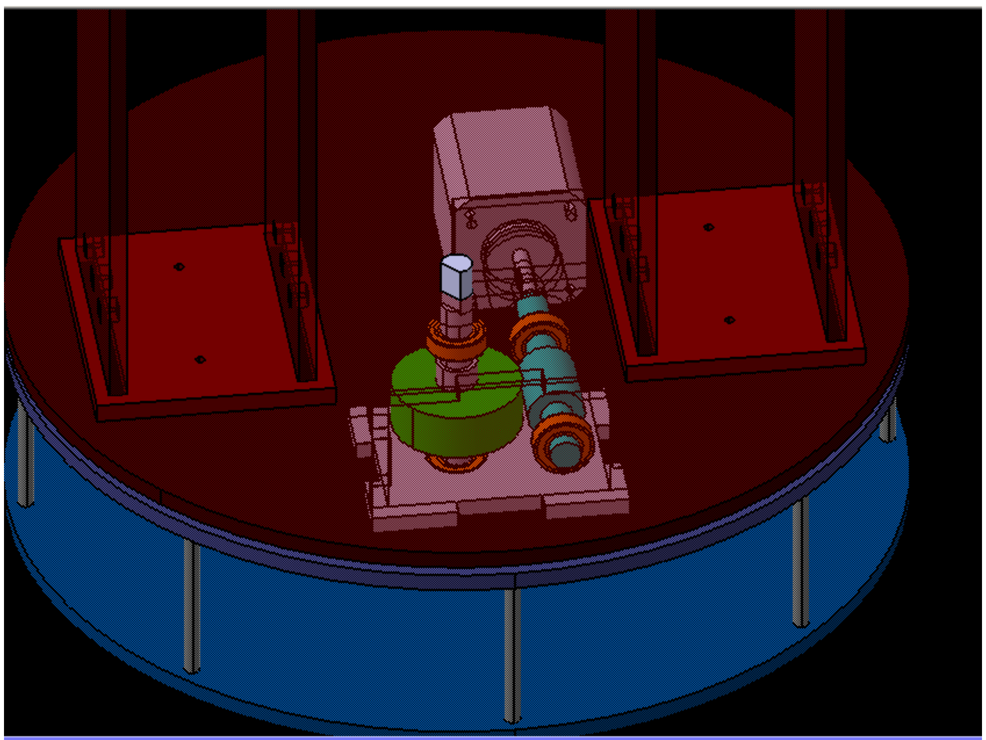


Telescope attachment

Mount model



Horizontal drive assembly



Vertical drive assembly

Mount photos

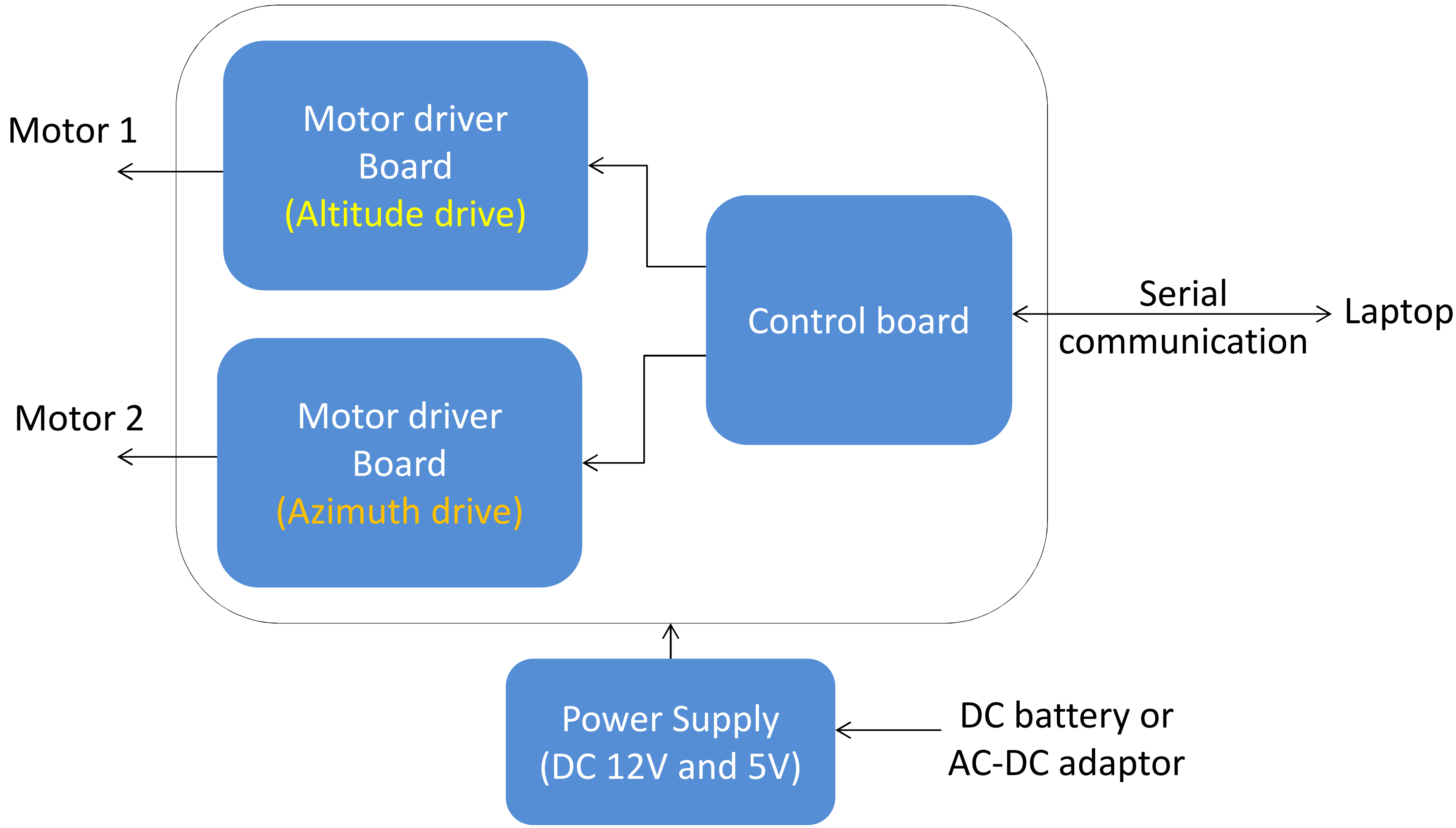
Vertical drive assembly

Horizontal drive assembly

Entire mount

Electronic Design

- The control and drive part of the mount together make the electronic module of the mount.
- Below is a block diagram of the mount electronics.



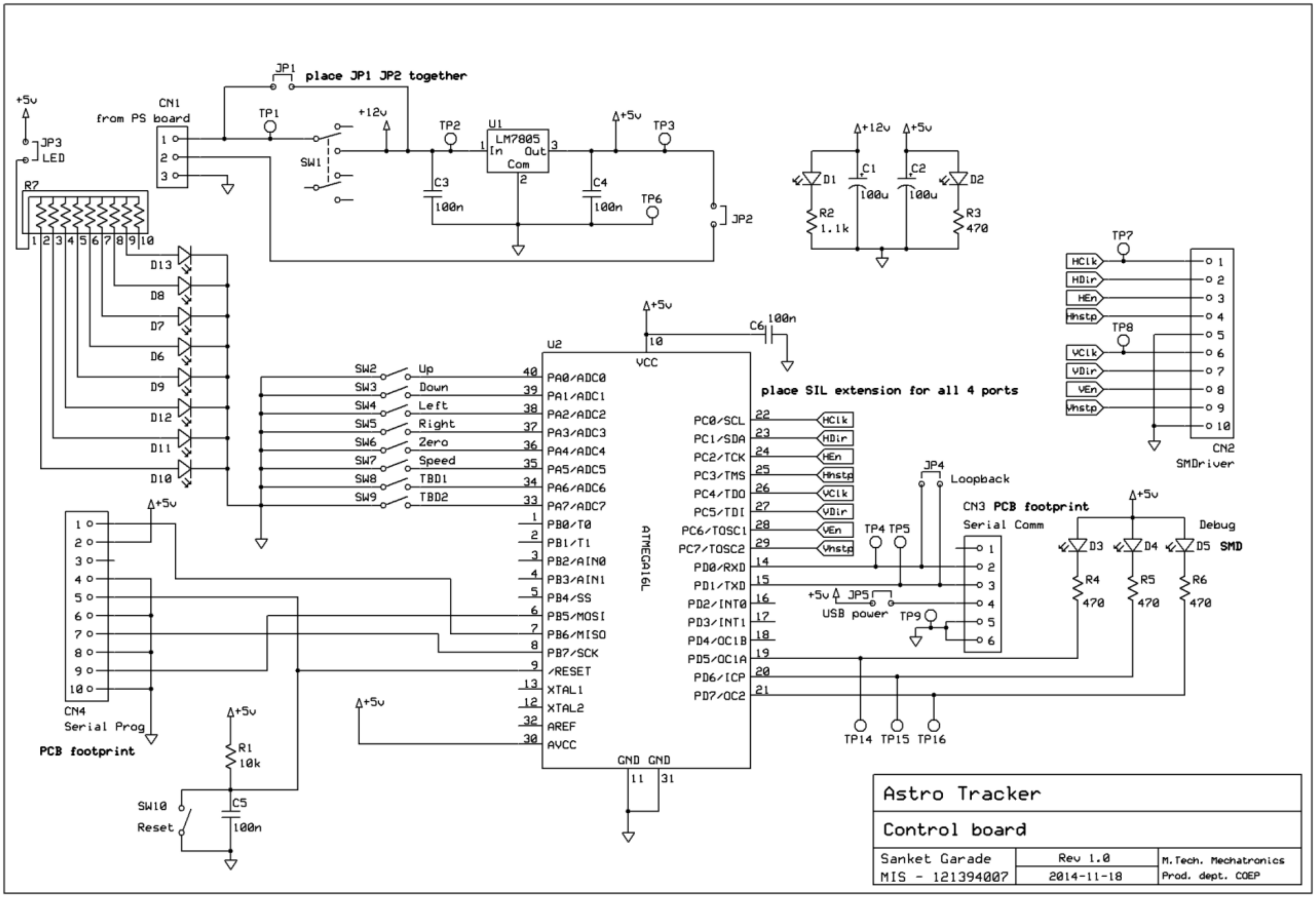
Electronic Design – Motor driver

- The motor driver mainly consists of the following components:-
  - Stepper motor controller (IC L297) - For stepper motor sequencing
  - H bridge driver (IC L298) - For motor driver
- The stepper motor selected is 4209L-03 motor as shown below:
  - Step size = 0.9°
  - NEMA Standard 17 size
  - Torque = 0.44 Nm

Model #	Rated Current (Amps/Phase)	Holding Torque (oz-in)	Holding Torque (N-m)	Resistance (Ohms/Phase)	Inductance (mH/Phase)	Inertia (oz-in^2)	Weight (Lbs.)	Number of Leads
4209L-03S	0.29	62.0	0.44	57.3	163.7	0.37	0.80	4

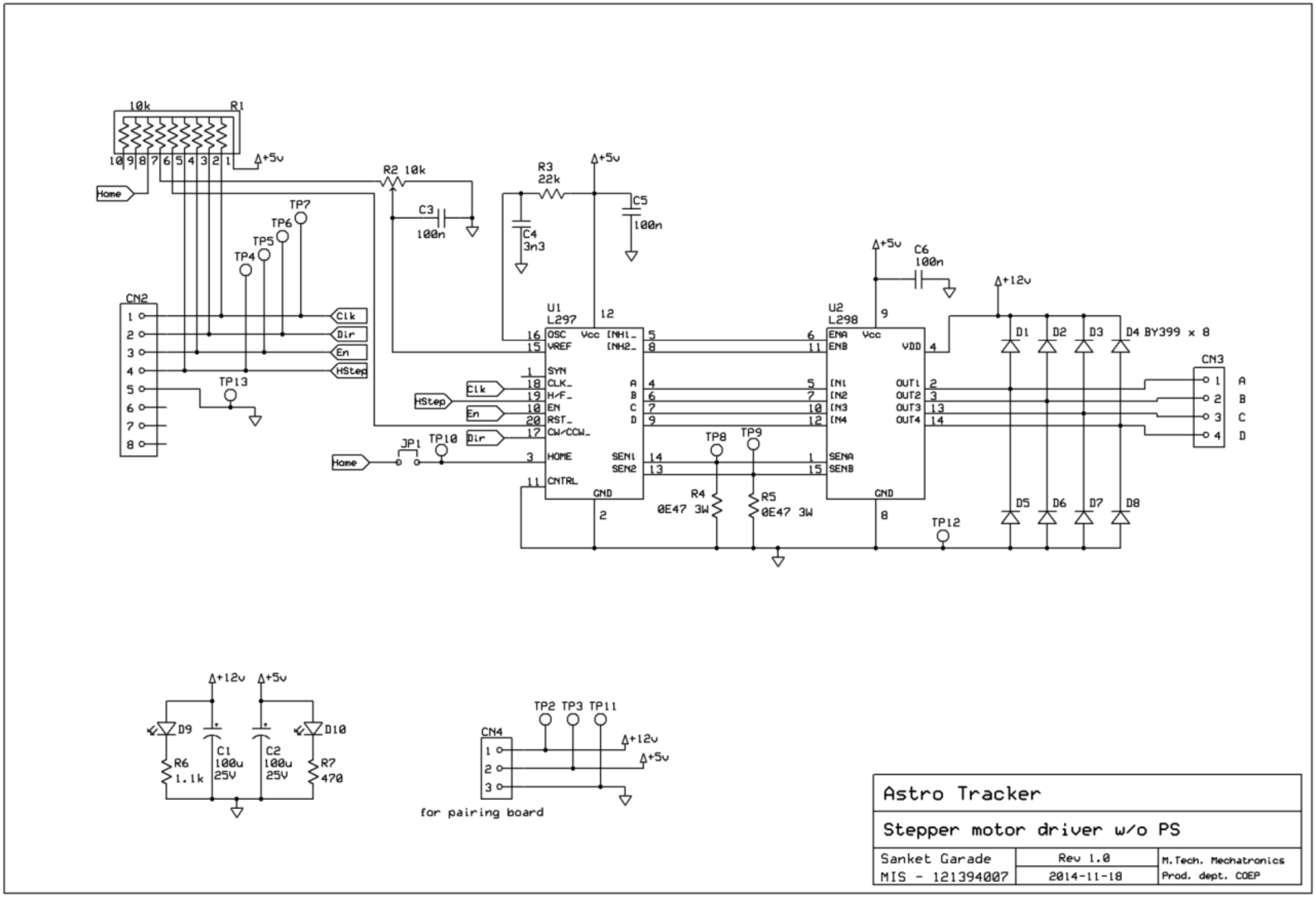
Electronic Design – Schematic

- SCH – Control board



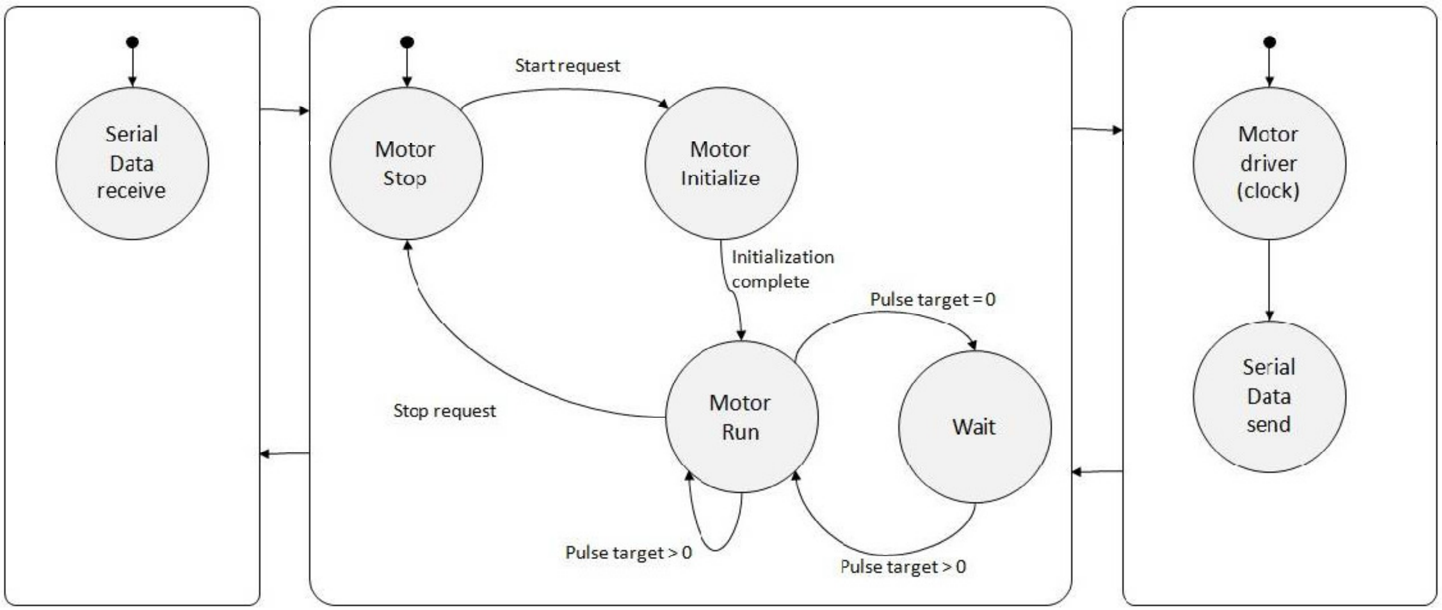
Electronic Design – Schematic

- SCH – Stepper Motor driver



Electronics Design – Firmware

- The firmware architecture is shown below.
- It incorporates 3 separate tasks –
  - Background job (lowest priority)
  - Serial reception interrupt (intermediate priority)
  - Timer interrupt (highest priority)



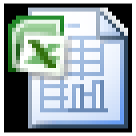
Interrupt 2
(Serial Rx interrupt)

Main loop
(background job)

Interrupt 1
(Timer interrupt)

Communication Design

- The communication between the computer software and the control board will be done using serial communication (UART)
- A communication protocol is designed which will be used to carry the information.

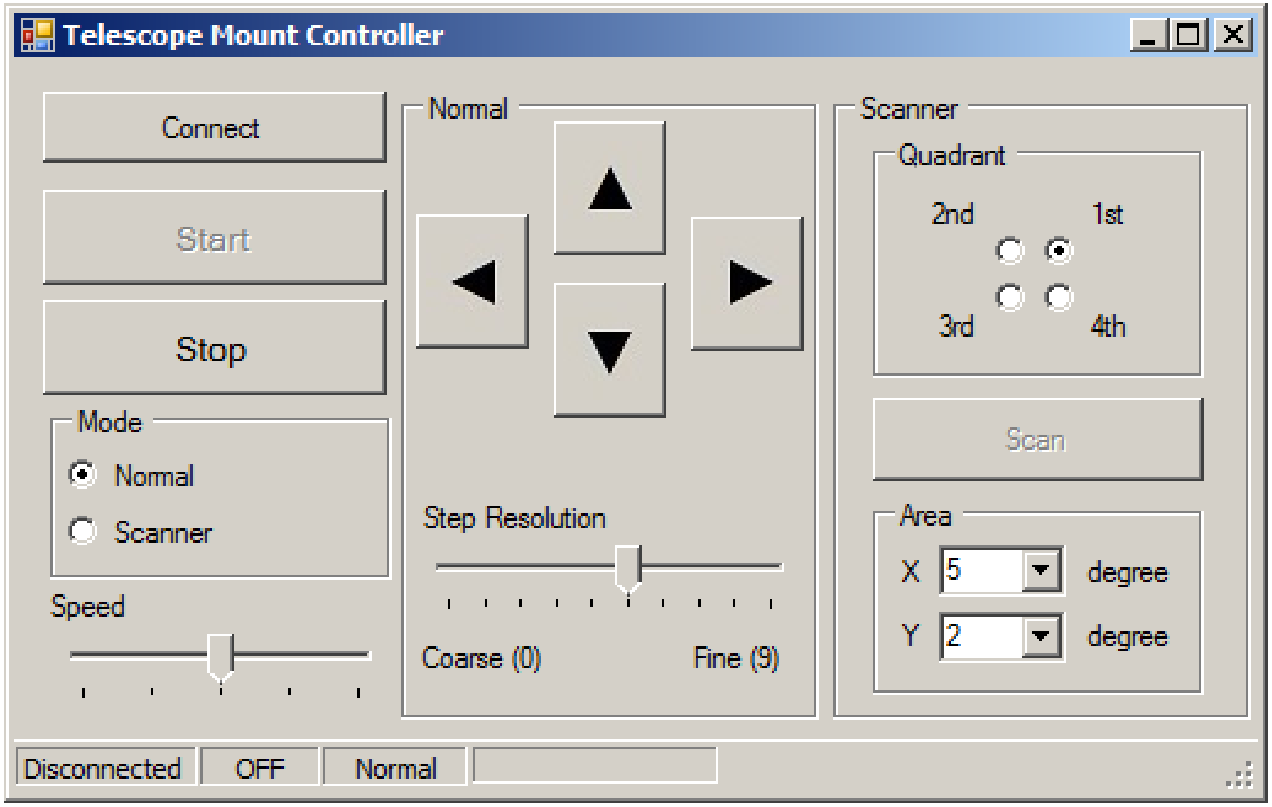


Communication Interface

- The communication interface is designed in such a way that it ensures that the received data is valid and error free. This is done by implementing checksum logic.
- Also if either entity does not receive communication from other entity, it indicates communication error.

Software Design

- Windows application developed in Visual Studio 2010
- Issues commands to the mount control board via serial communication
- Displays various statuses of the mount controller in the status bar



Control software – Application Window

Conclusion

- An alt-az telescopic mount was designed, developed and tested successfully.
- It was able to achieve the targeted system requirements such as 1Kg load and 0.1° angular resolution.
- It is working correctly as per the designed operating modes and their controls.
- The failsafe feature is also working as expected and stops the mount in case of communication failure.

Thank you