Final Milestone

5/9/2022

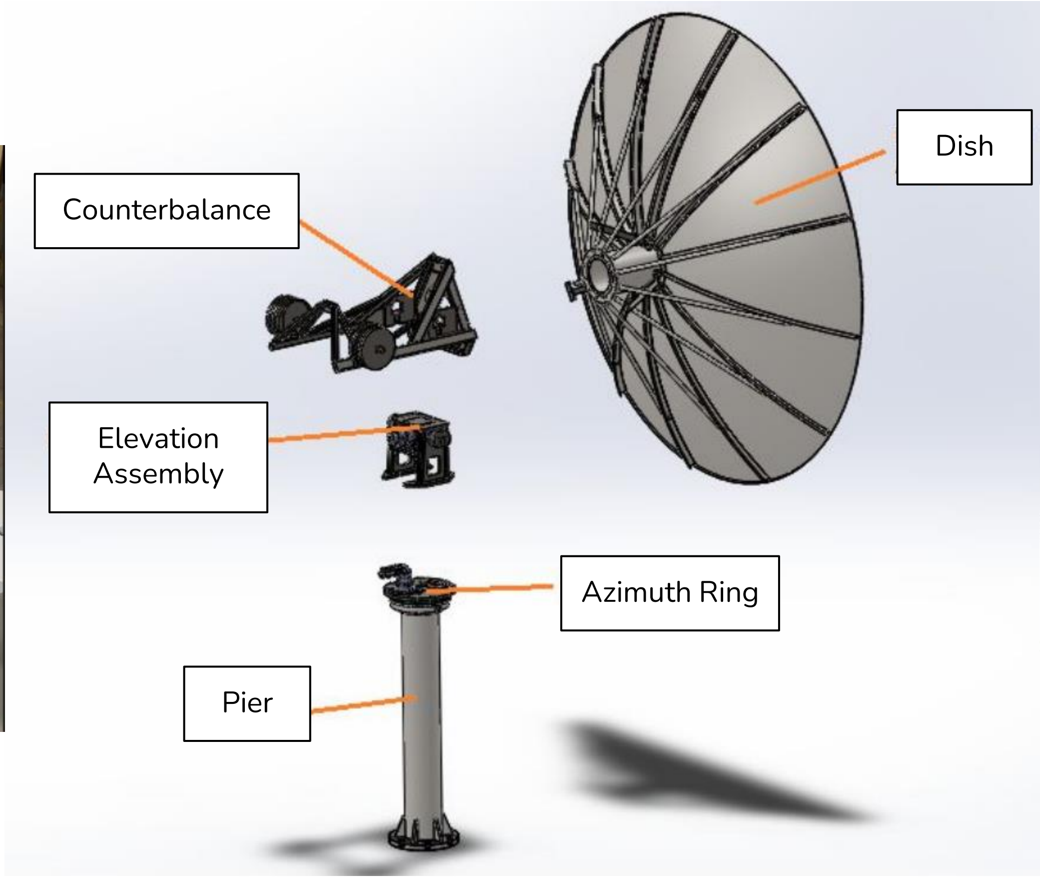
Senior Software Design - Senior Capstone

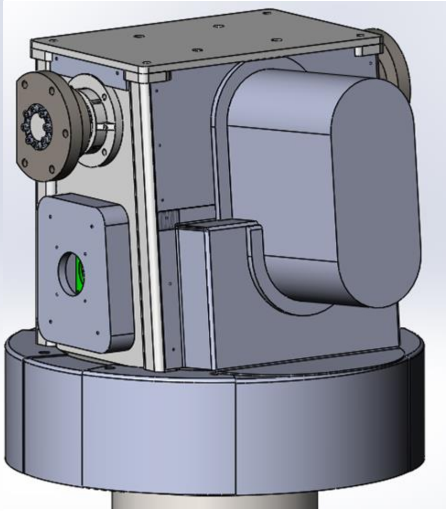
Introduction to the Radio Telescope Project

What Is The Radio Telescope?

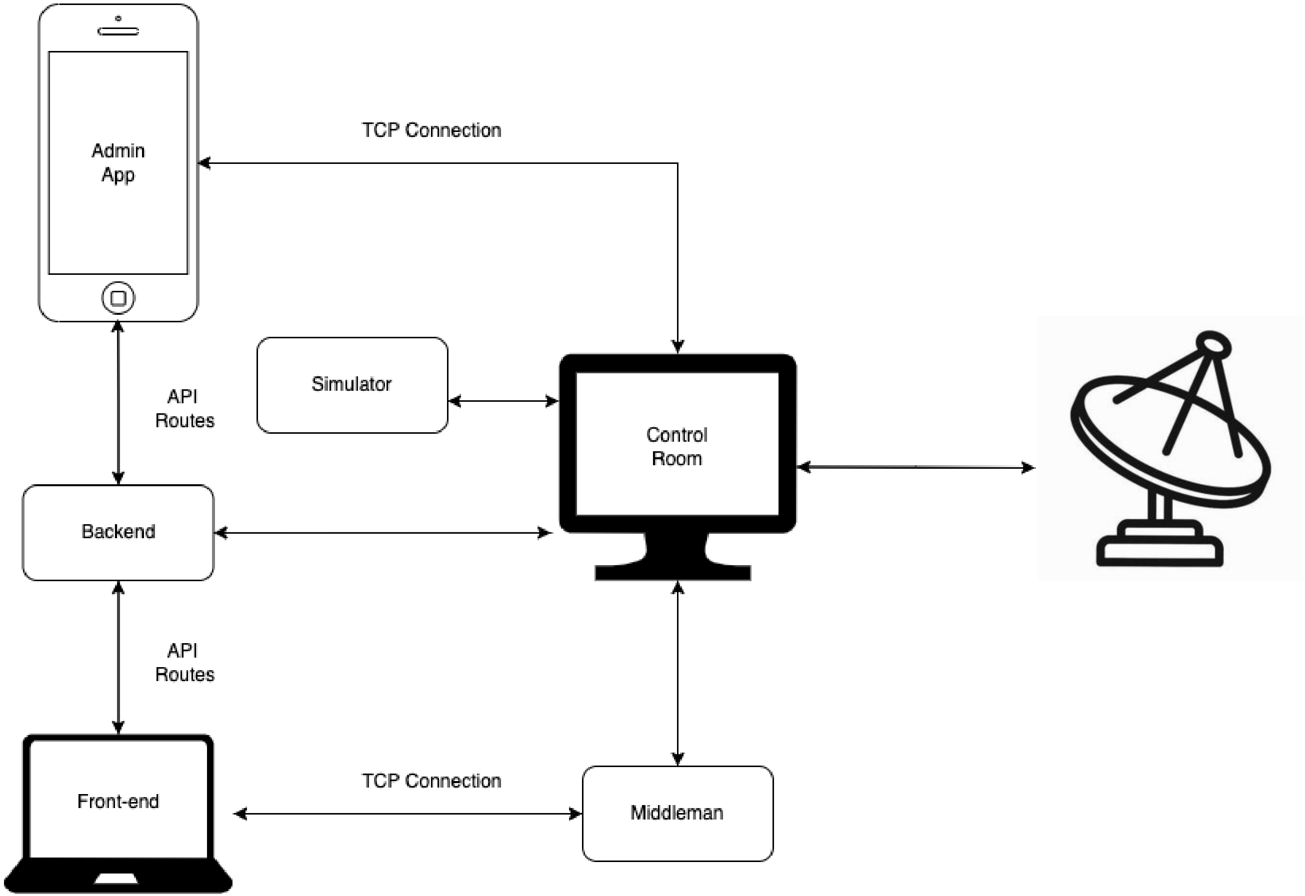
- 4.5m, remote controlled, auto-tracking, auto-locating Radio Telescope capable of scanning 1.42Ghz radio signals
- 4 years ago YCP was contracted to build a radio telescope for the York County Astronomical Society to be placed in John C. Rudy County Park, York
- The telescope is for educational and amateur astronomy research
- This has been an ongoing project, delayed by COVID-19, worked on by 77 students throughout 4 years
- The telescope is planned to be installed in the park

Major Components

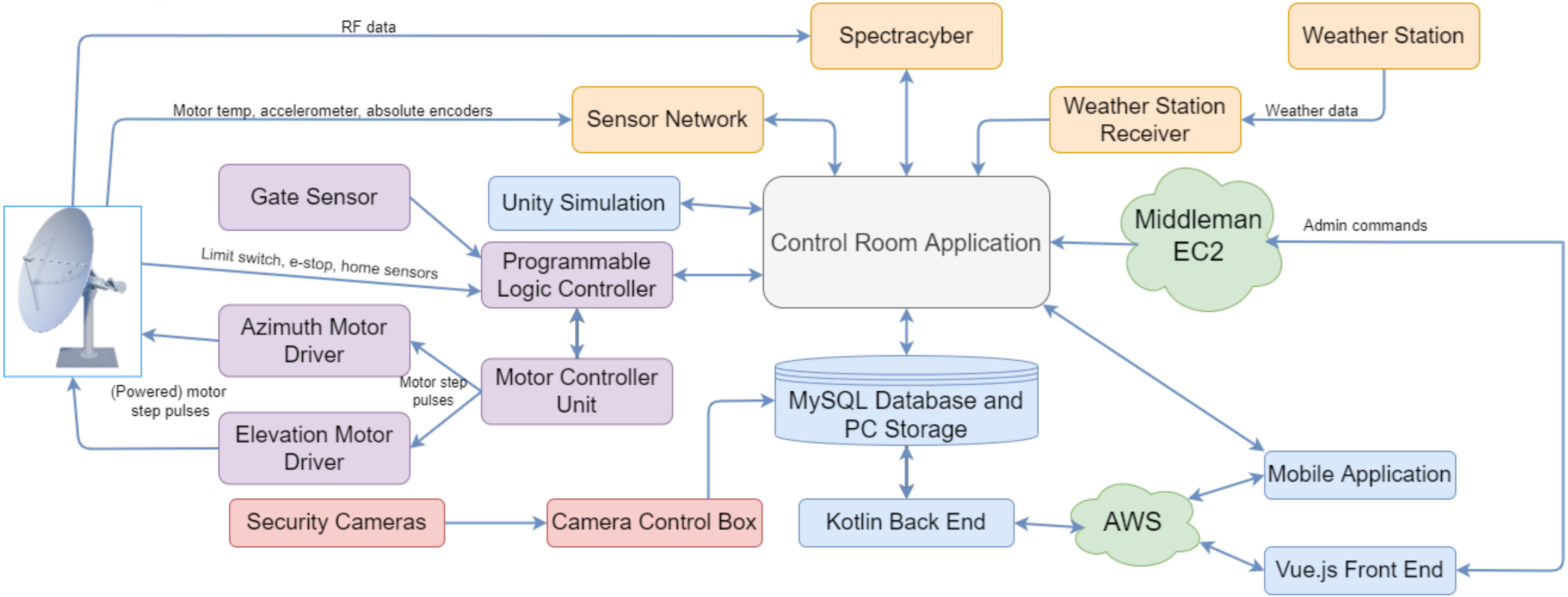




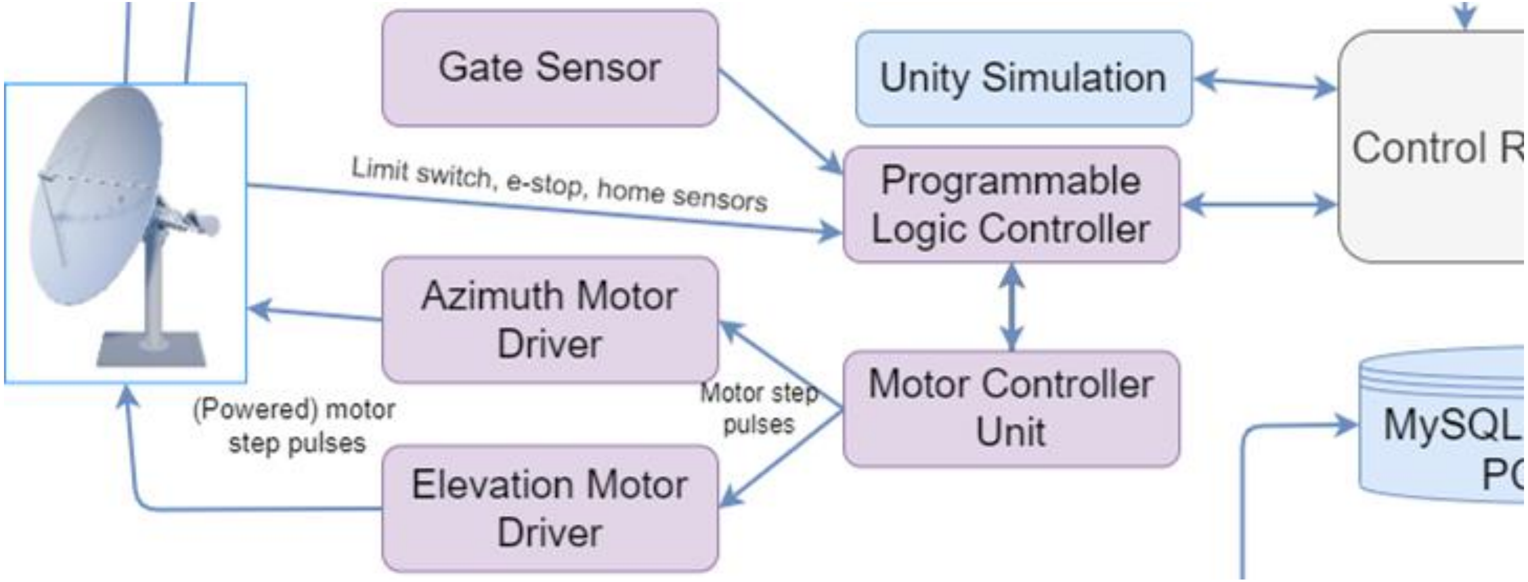
Telescope Overview



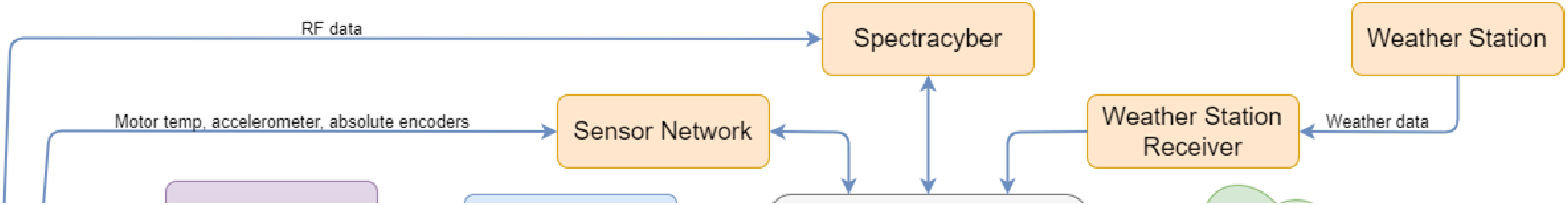
Detailed Telescope Overview



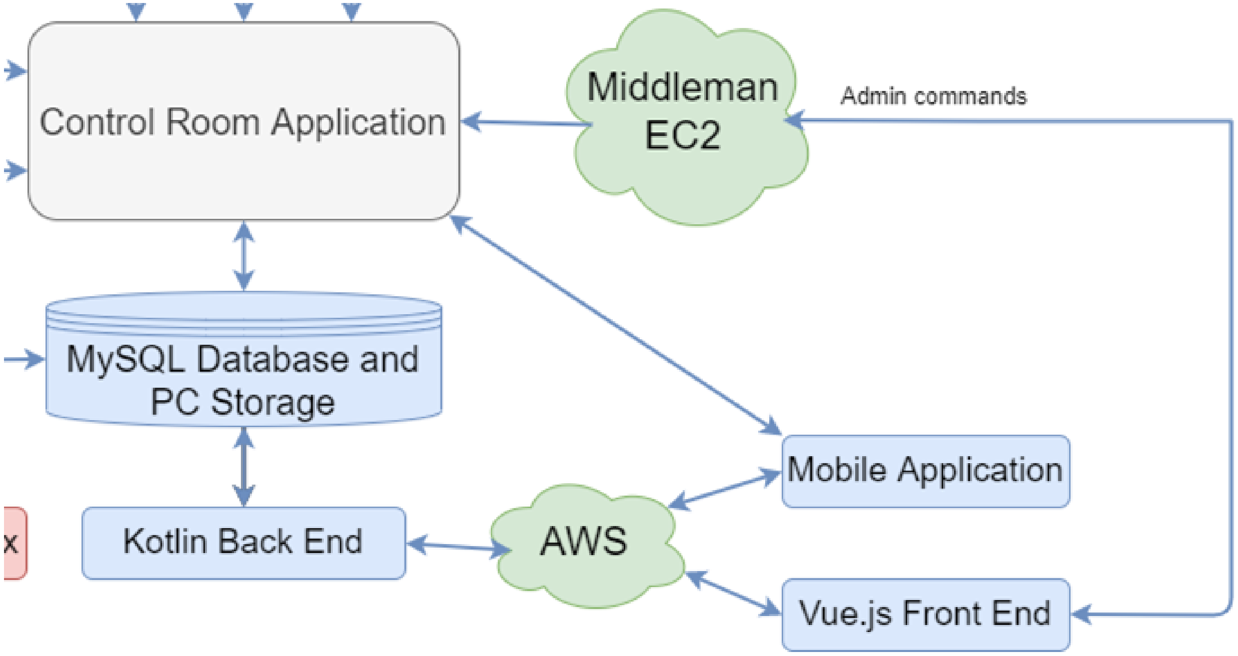
Detailed Telescope Overview - Control



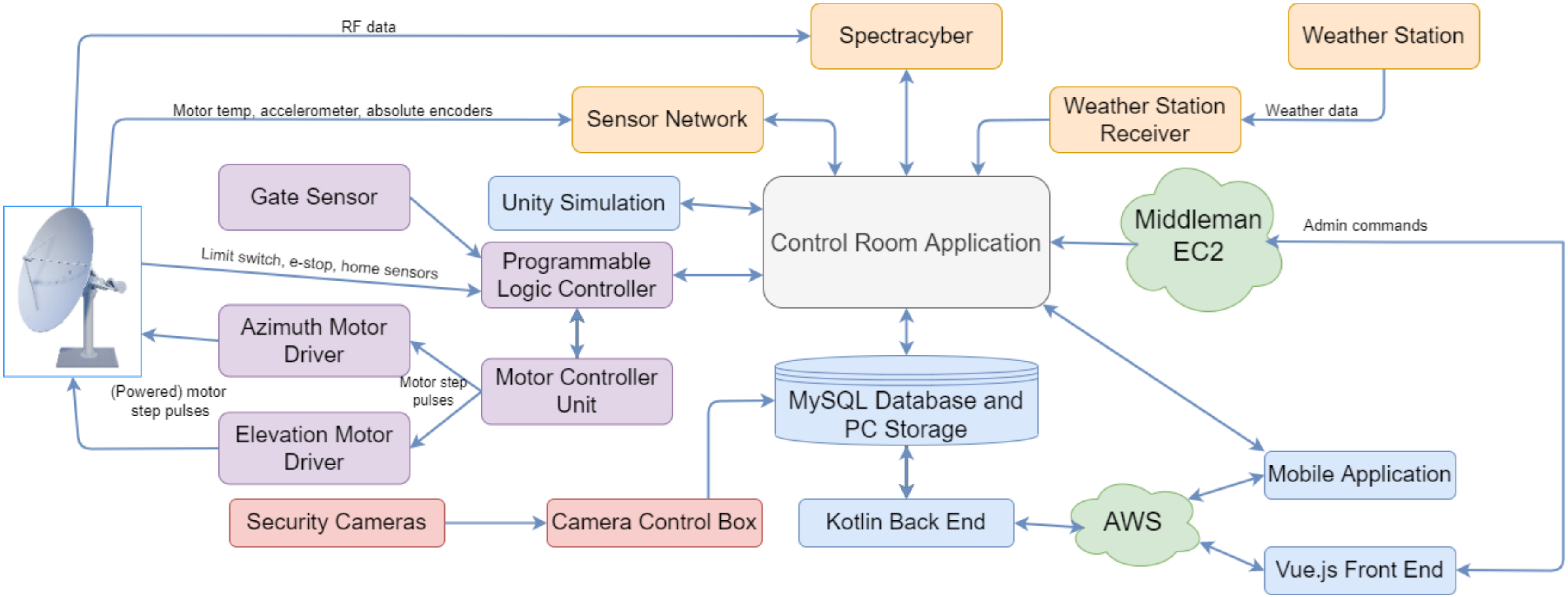
Detailed Telescope Overview - Collection



Detailed Telescope Overview - Software



Detailed Telescope Overview - Misc



How will this be used?

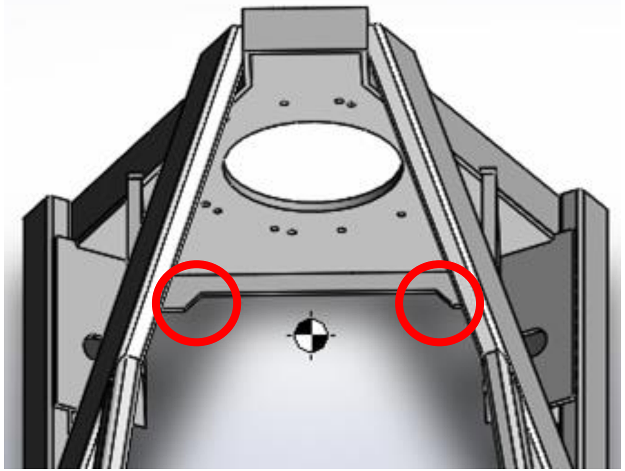
- YCAS will have a website that the general public can create accounts and set appointments
- YCAS admins can use the control room software to monitor and move the telescope
- YCAS admins will have access to the mobile app allowing them to control the telescope remotely
- YCAS will have access to a VR game version of the park and telescope that can be shown off to students

Where we started

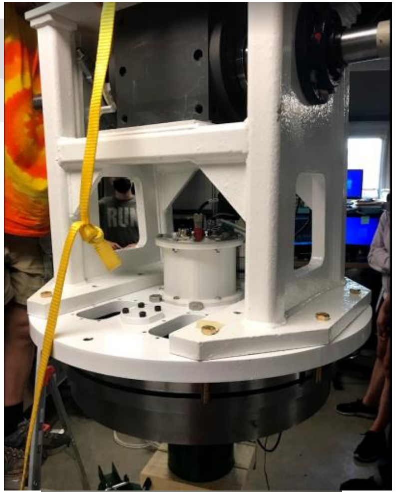
The Hub and Counterbalance

New Holes

Original Holes



The Elevation Mount



Elevation Mount Issue:

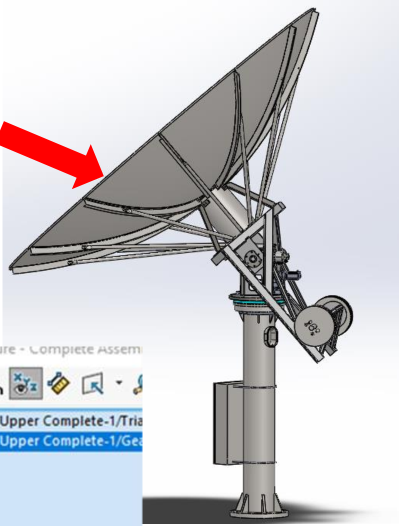
- Mating the elevation mount to azimuth ring due to misaligned bolt holes
    - Likely occurred in manufacturing

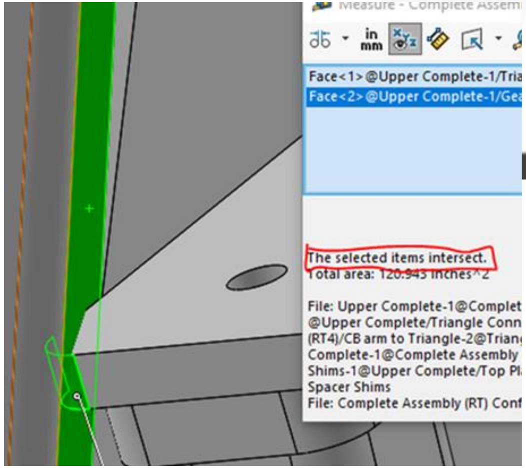
Solution:

- Bore out elevation mount bolt holes to allow enough clearance to reach azimuth ring bolt holes.
- Size up washers to account for new hole size and safety

Fixing issues (cont.)

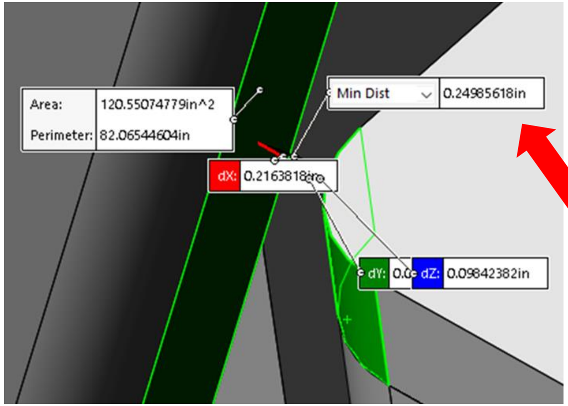
Angle of telescope with largest intersection between counterbalance and the top plate





Top Plate Issue:

- Front corners of the top plate collide with counterbalance frame
    - The two parts intersect by about ¼ inch from the corners



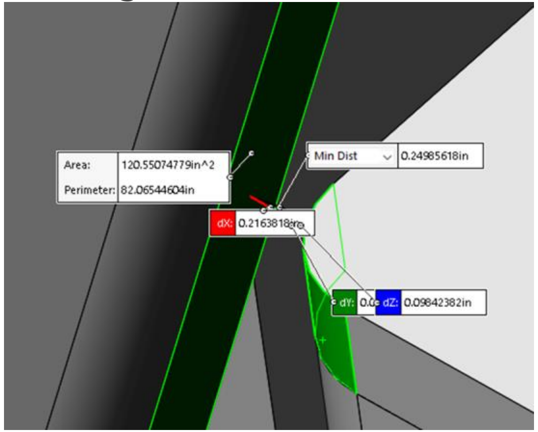
Gap Shown after making top plate flush with elevation mount

Cover

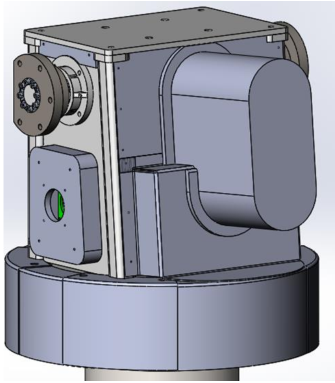
<u>Major Specifications the Needed to be Met:</u>

- Maintain seal around elevation frame and azimuth ring
- Be lightweight
- Allow access for wiring to cross cover boundaries

<u>Design Clearance issues:</u>



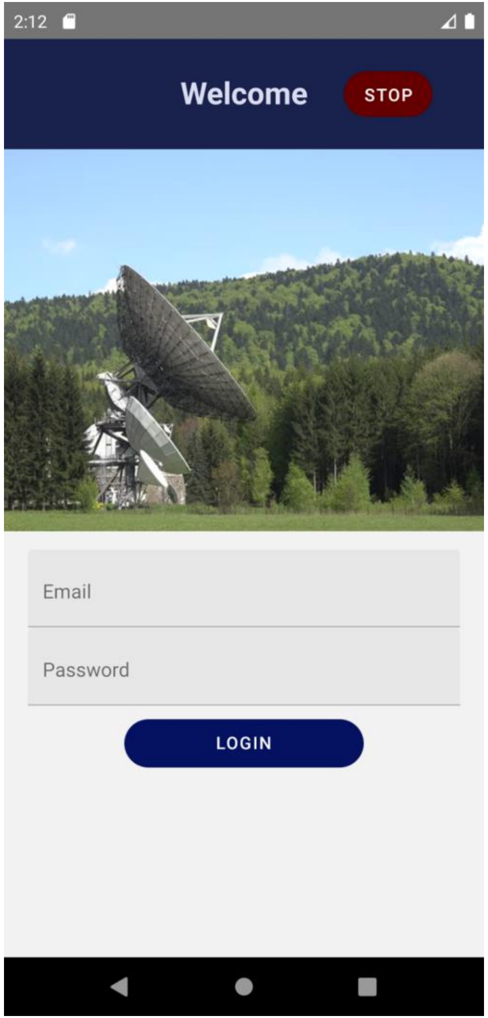
Cover Design



Life of a Command

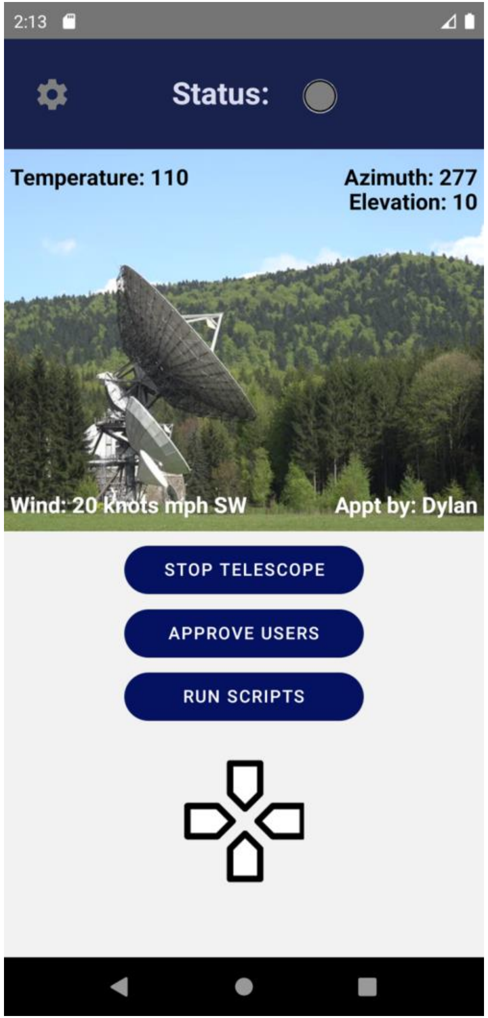
Login

- Admins will be given a login to be used when installing the app
- Their information will be saved for future use
- This login will be used to access the APIs
- A stop button is added for safety
- After login the admin will be directed to the home page



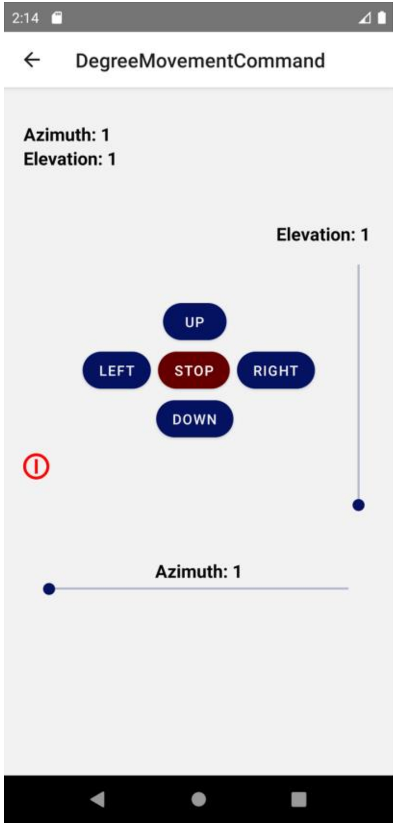
Home

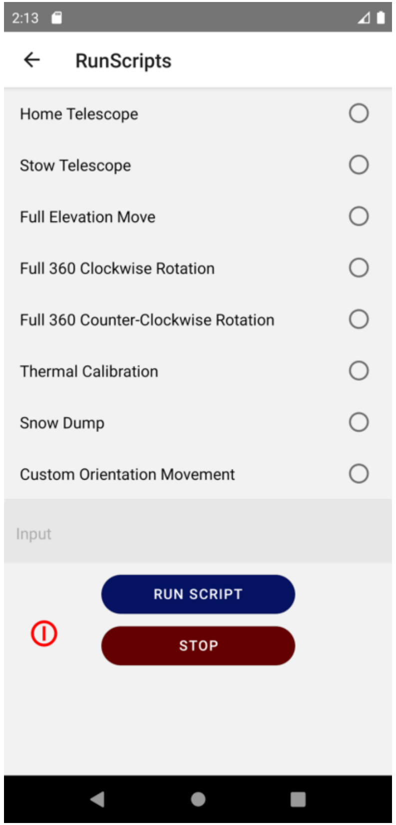
- From here the admin can navigate to:
  - Scripts
  - Degree Movement
  - Statuses
  - Weather Data



Scripts and Commands

- Degree Movement Command Page
  - Allows relative movements
- Run Scripts Page
  - All Control Room scripts
  - Custom Orientation Movement
    - Absolute position





Sending Command to Control Room

- Command is concatenated depending on the selection
- Encrypt the concatenated command
- Append the TCP version number for control room decryption
- Connect to TCP and Port specified by the constants file or edited by the admin on the settings page

Concatenated string

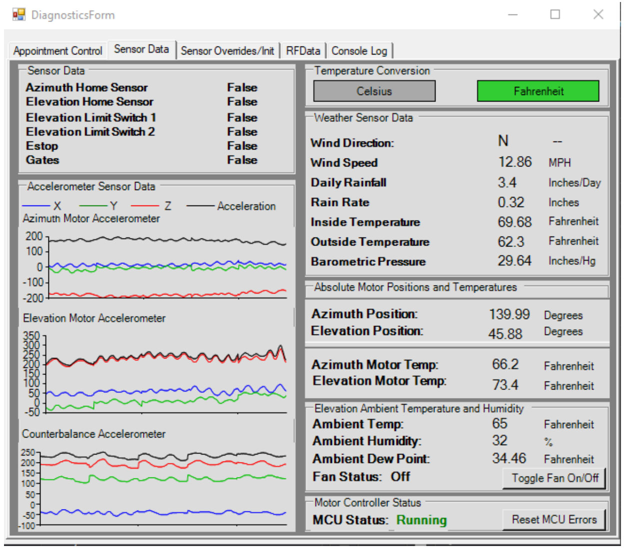
<Version NUM> | <Type> | <Name <values>> | UTC TIME

Encrypted string

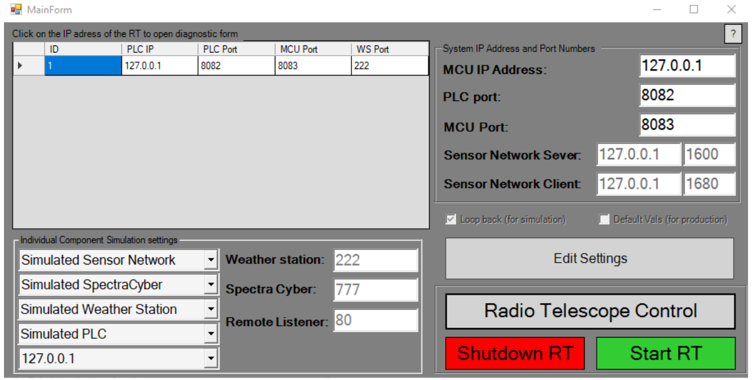
<Version NUM> | <ENCRYPTED COMMAND>

Control Room Overview

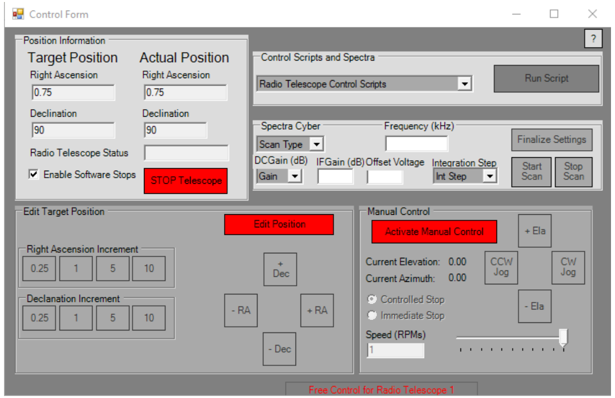
- "Brains" of the telescope
- 3 Forms
  - Main Form
  - Diagnostics Form
  - Control Form



Diagnostics Form



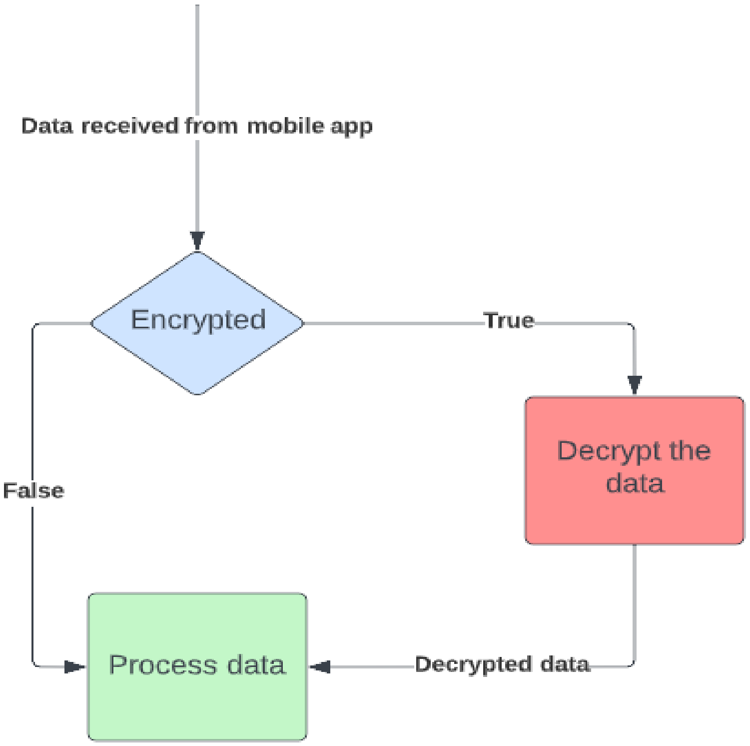
Main Form



Control Form

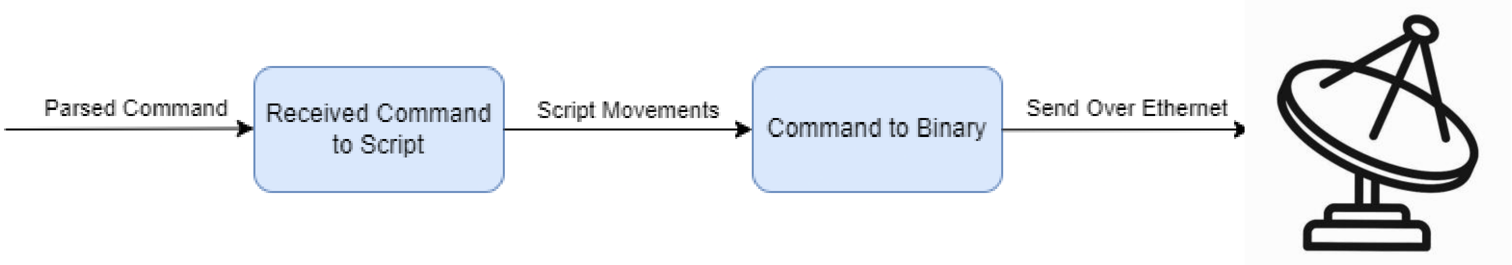
Receiving command in Control Room

- When the command is received by the control room, it's checked to see if it's encrypted before processing the command
    - Uses the **<Version NUM>** tag from command
- The control room uses the AES-256 encryption standard
- The diagram on the right visualizes the process

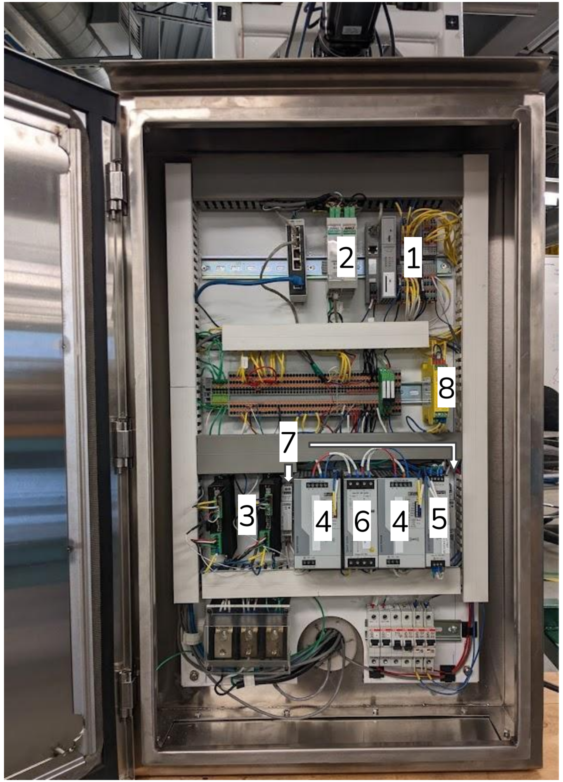


Commanding the Telescope

- Commands are interpreted as scripts
- Scripts are a series of movements
- Different movements types to send to MCU
  - Absolute movements
  - Relative movements
  - Jog movements
- Binary instructions are assembled for the move and sent via ethernet



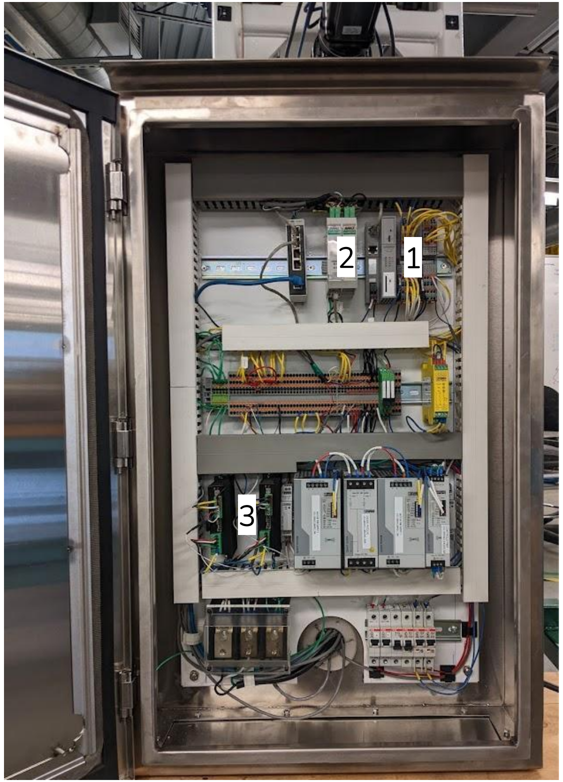
Pier Electrical Panel (PEP)



Key Components:

1. Programmable Logic Controller (PLC)
2. Motion Control Unit (MCU)
3. 2 Motor Stepper Drivers
4. 2 48VDC, 10A Power Supplies for Azimuth and Elevation Motors
5. 24VDC Control Panel Power Supply
6. Diode Redundancy Device
7. 5VDC, 12VDC power supply for the embedded sensor system
8. Safety Relay

Pier Electrical Panel (PEP)



At a glimpse:

1. Programmable Logic Controller (PLC)

   Part: Phoenix Contact Axioline 1050 Controller

   Role: Sends environment variables (inputs) to the control room software and outputs movement commands to the MCU if internal logic deems status as good.

1. Motion Control Unit (MCU)

   Part: Advanced Micro Controls ANF2 2 Axis Servo/Stepper Controller

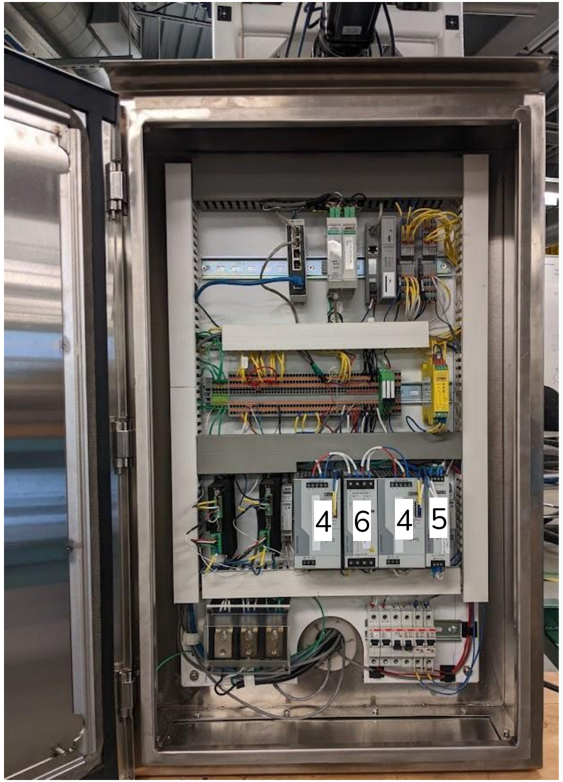
   Role: Communicates to the PLC to get movement command through Modbus serial communication. Creates a 2 axis motion profile to send to the motor stepper drivers through signal and direction signals.

1. 2 Motor Stepper Drivers

   Part: Applied Motion Products STR8

   Role: Generates the phase current switch according to the MCU signal pulses. Higher the frequency of switching = faster motor speed

Pier Electrical Panel (PEP)



At a glimpse:

4. 48VDC, 10A Power Supplies for Azimuth and Elevation Motors

Part: Phoenix Contact QUINT4-PS/1AC/48DC/10 - 2904611

Role: Converts 120VAC to 48VDC, 10A to pass through the diode redundancy devices and supply to the motor stepper drivers.

5. 24VDC Control Panel Power Supply

Part: Phoenix Contact QUINT4-PS/1AC/24DC/5 - 2904600

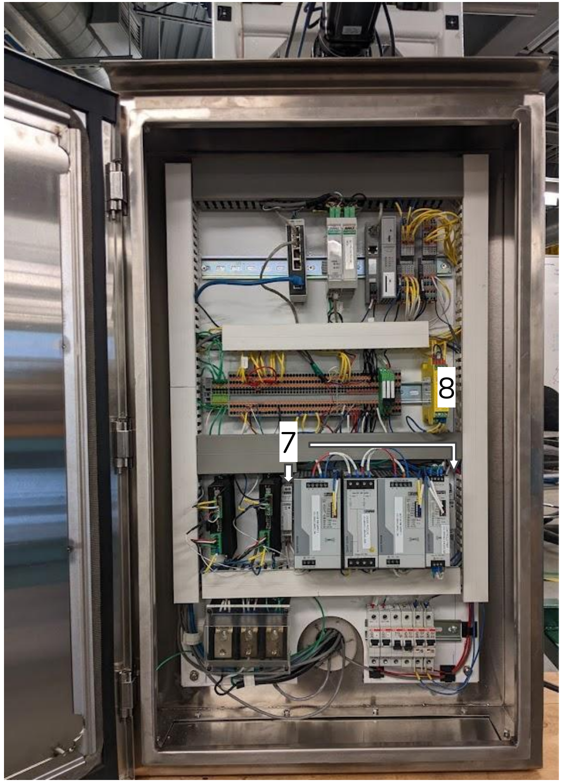
Role: Converts 120VAC to 24VDC, 5A to supply to the MCU, PLC, ethernet switch, and safety relay.

6. Diode Redundancy Device (DRD)

Part: QUINT4-DIODE/48DC/2X20/1X40 - 2907720

Role: Balances the load between the two 48VDC power supplies. In the event of a power supply failure, the DRD will allow the telescope to slowly return to the stow (upright) position.

Pier Electrical Panel (PEP)



At a glimpse:

7. 5VDC, 12VDC power supply for the embedded sensor system

   Part: Phoenix Contact STEP-PS/1AC/5DC/2 & STEP-PS/1AC/12DC/1

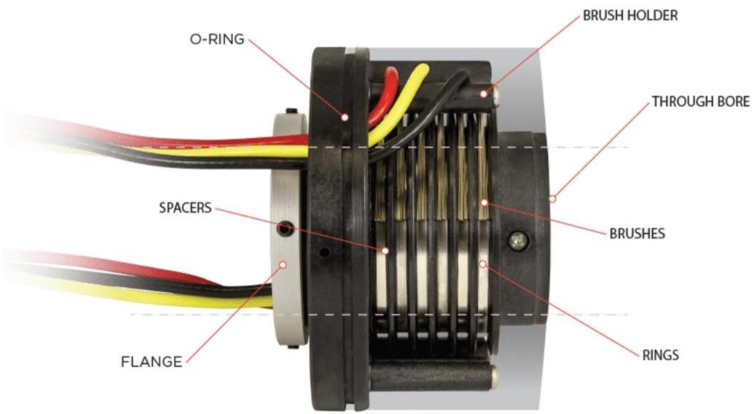
   Role: Steps 120VAC down to supply 12VDC and 5VDC to the embedded sensor teensy microcontroller and the low noise amplifier (LNA).

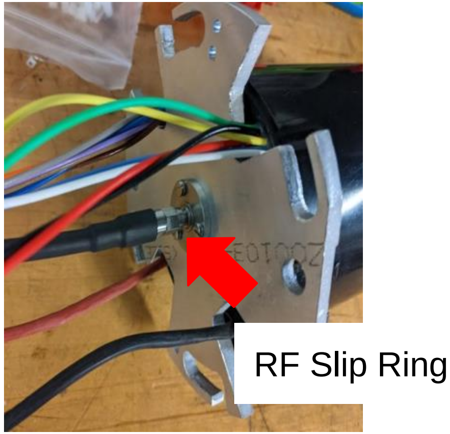
8. Safety Relay

   Part: Phoenix Contact PSR-MC72-2NO-1DO-24DC-SC

   Role: Monitors system e-stops and sends status back to the PLC.

Slip Ring Connections





- Bridges connections between the PEP and the ESS/upper telescope assembly
- Allows 360 degree motion of:
    - Motor Encoders
    - Motor Power
    - Home sensors
    - Limit Switches (signal, power)
    - ESS Power
    - Ethernet
- RF slip ring connects the 1.42 GHz signal

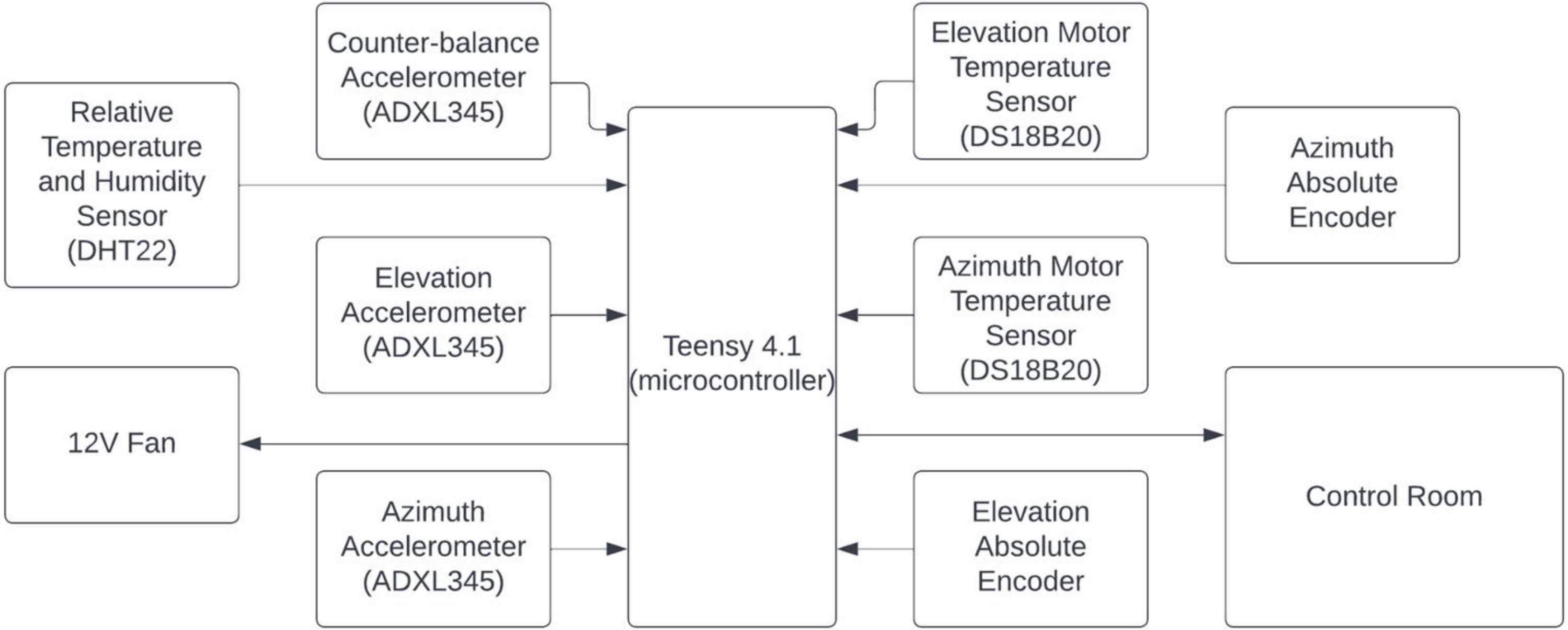
Embedded Sensor System (ESS)

- The primary purpose of the embedded sensor system is to monitor a number of sensors and send data to the control room
  - Collect vibration and temperature data of both motors
  - Collect ambient temperature and humidity data of elevation enclosure
  - Collect angular position and vibration data of counterbalance
  - Collect position data of the azimuth top plate and elevation shaft
  - Command fan to prevent condensation in elevation enclosure

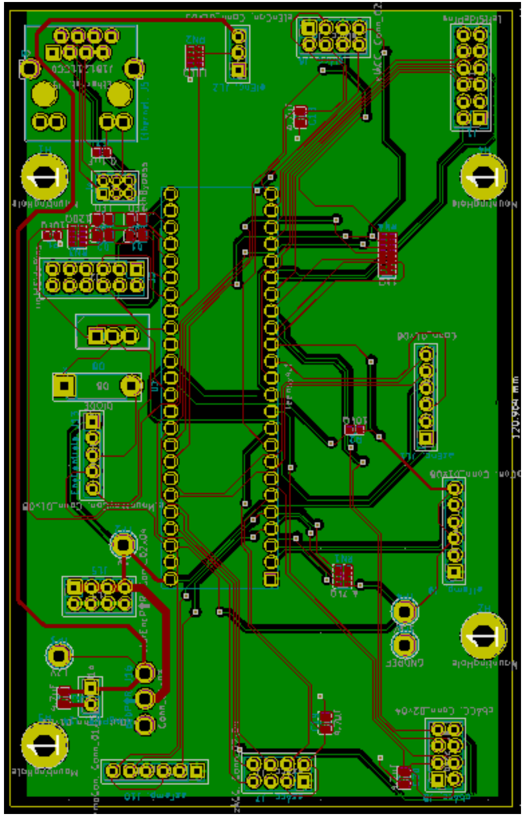
PCB Revisions 5 and 6

- Primary changes from revision 4 include
  - Removing RJ45 and implementing 2.54mm and 3.96mm connectors
  - Implementing additional connector
    - Ambient temperature/humidity sensor, 12V fan
  - Addition of Bluetooth/Wifi module for OTA updating (Rev 6)
  - Addition of shunt capacitor (Rev 6)
  - Mounting hole changes (Rev 6)
  - Reducing size of PCB (Rev 6)

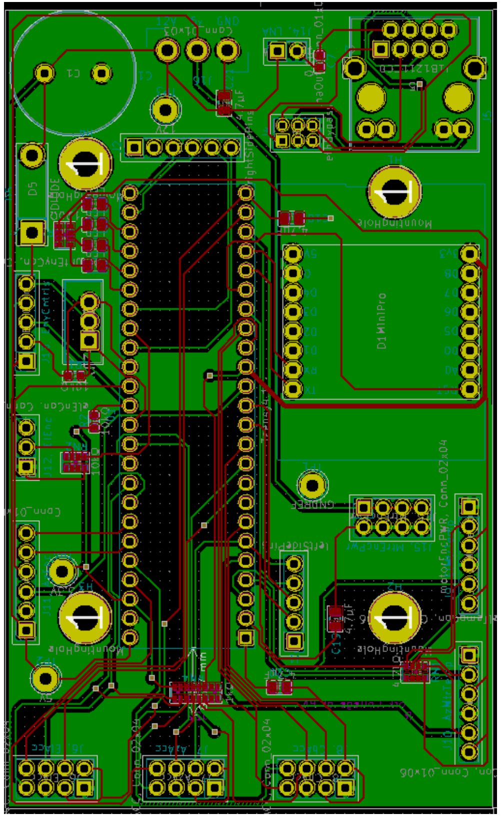
Embedded Sensor System (ESS)



Embedded Sensor System (ESS)

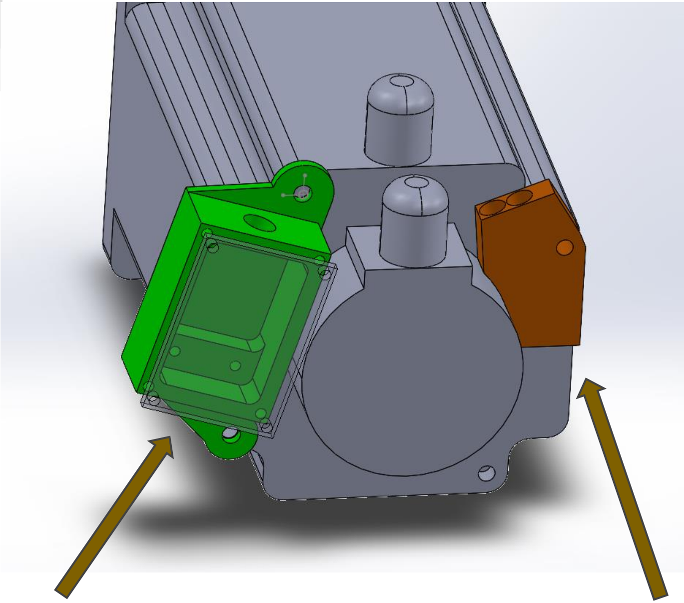


Revision 5



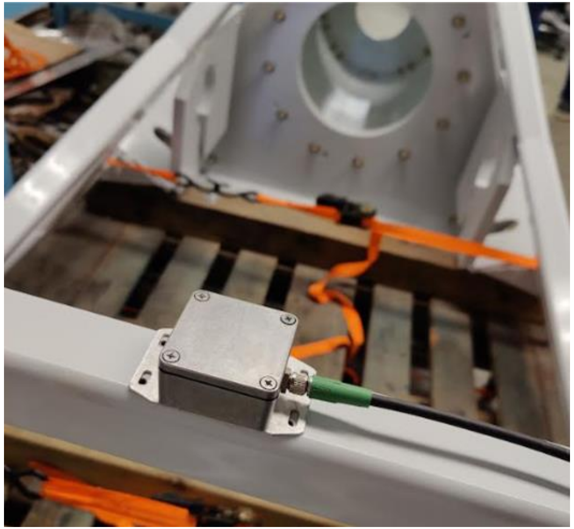
Revision 6

Data Collection of sensors



Counterbalance Accelerometer

This is mounted to the counterbalance, its purpose is to transmit position and elevation angles to the operator.



Elevation and Azimuth accelerometer

This is mounted to the Azimuth or Elevation motor, and must be tightly fastened in order for the vibrations of the system to transmit reliably to the accelerometer.

Temperature Sensor

This is mounted to the Azimuth and Elevation motor, this allows the temperature of the motor to be monitored.

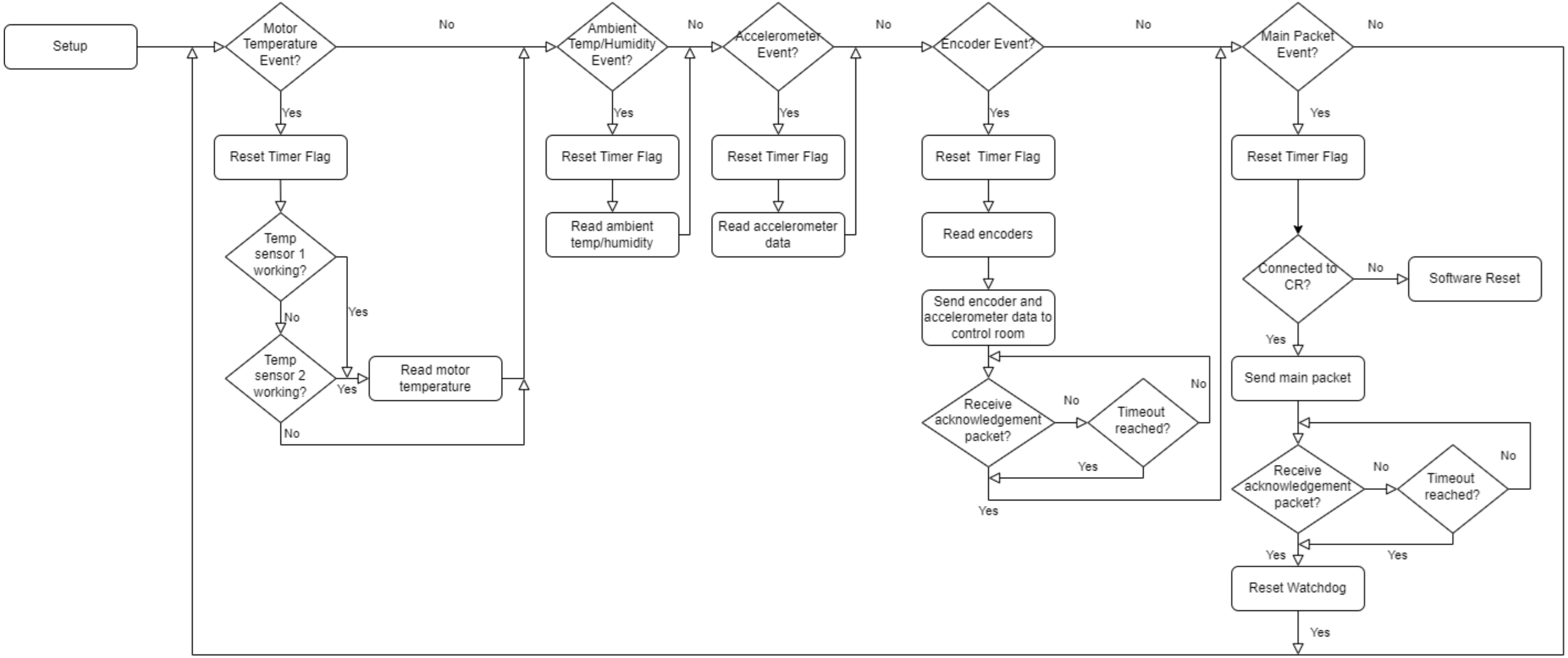
Embedded Sensor System (ESS)

- On power-on, ESS enters a “setup” state; connection to the control room established
- ESS receives 45-byte configuration packet from control room
  - Contains sensor enabling, timer values, and accelerometer parameters
- Starts watchdog timer, initializes sensors, setting up ISRs, and performing accelerometer self-tests

Embedded Sensor System (ESS)

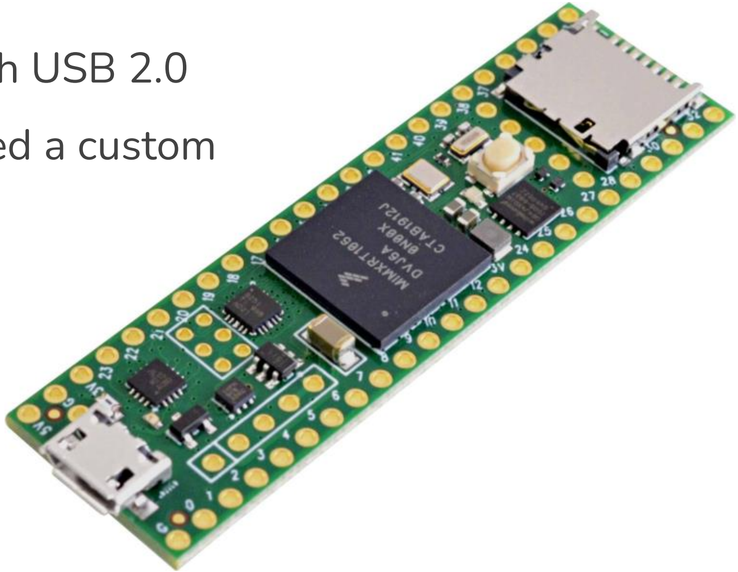
- On entering super-loop, ESS begins collecting data. On every iteration, sensor data is added to queue
- After a set amount of time, ESS sends contents of queue to control room
    - “Encoder” packet: Contains data from elevation and azimuth absolute encoders, as well as counterbalance accelerometer data
    - Main packet: Contains rest of the sensor data (accelerometers, temperature sensors
    - After every packet sent, ESS waits for a reply from the control room

Embedded Sensor System Superloop



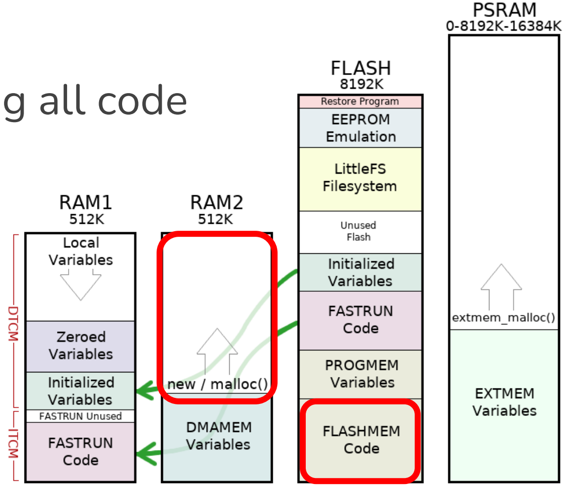
Embedded Sensor System Updating

- Updates or changes to the ESS are performed through software updates to the Teensy
- Teensy 4.1 requires USB 2.0 for standard updating via the on-board micro USB port
  - The Slip Ring is not compatible with USB 2.0
  - Designed, developed, and integrated a custom Bluetooth OTA updating protocol



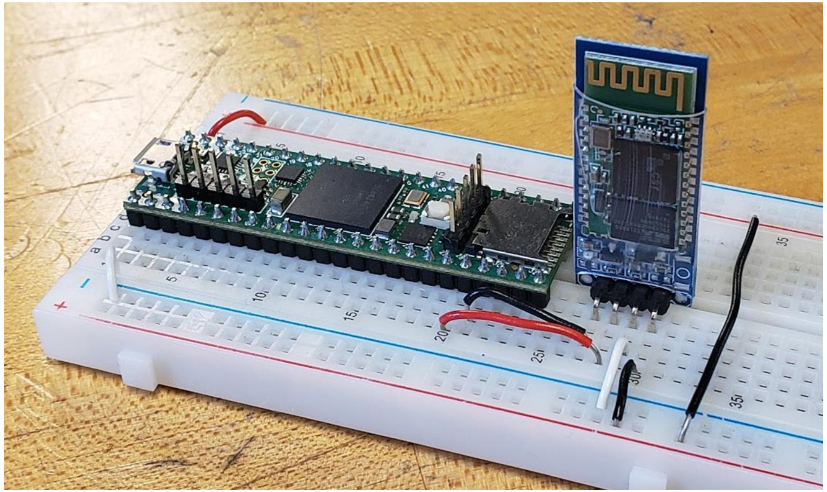
Bluetooth OTA Updating Process

- User sends serial command to ESS via BT to initiate update
- Teensy pauses Superloop
- User sends new source code in Intel HEX format via BT
- Teensy receives source code and performs validation on each line
    - Teensy stores validated source code in RAM2
- Teensy prompts user for confirmation after receiving all code
- User sends command to reboot into new code
- Teensy flashes source code from RAM2 to FLASH
- Teensy reboots into new source code

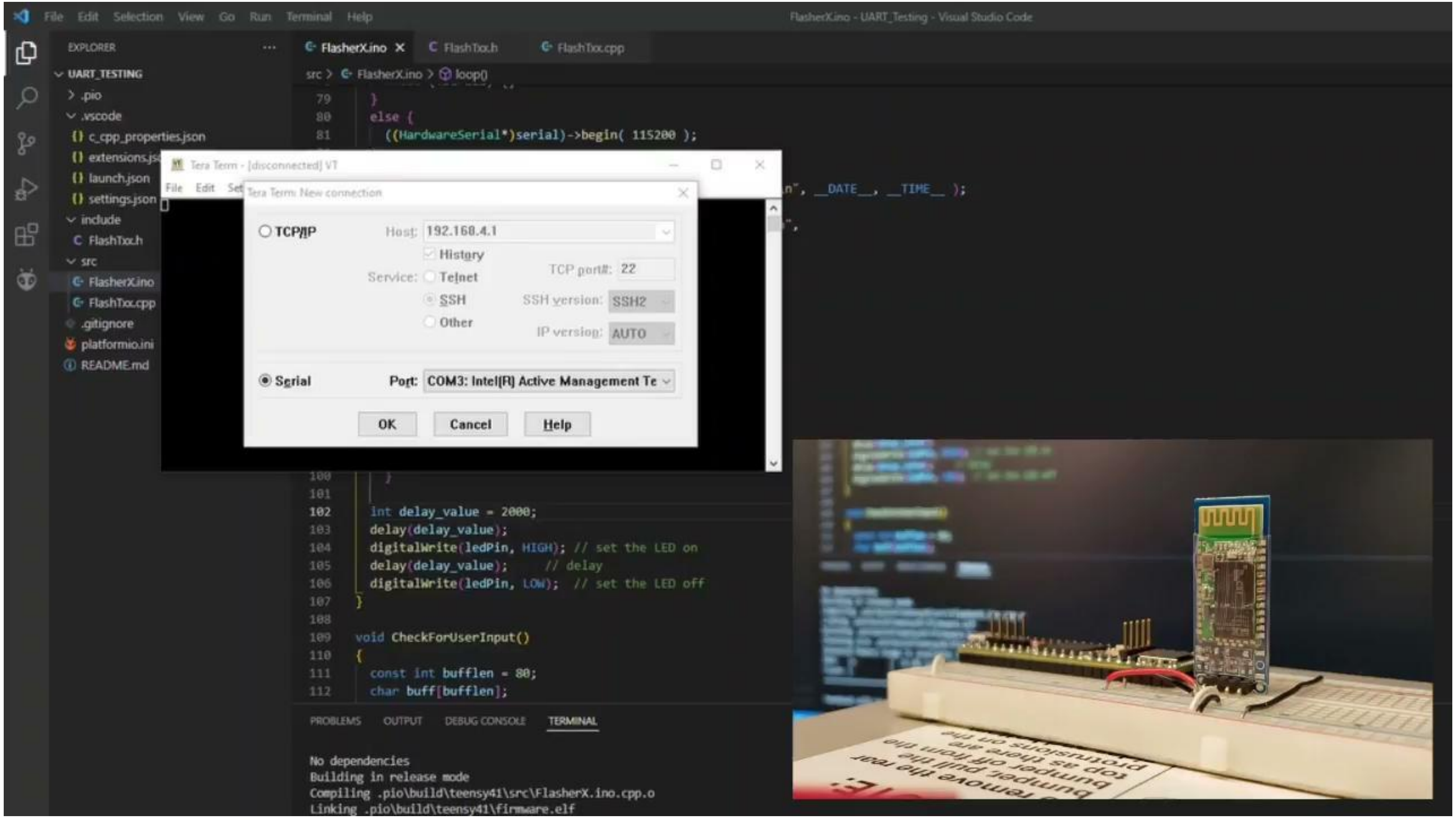


Physical Bluetooth Implementation

1. HC-06 Bluetooth module communicates with control room via BT COM port
2. Serial communication is opened with Tera Term emulation tool
3. HC-06 is powered with 5V on PCB
4. HC-06's data pair is connected to Teensy's Serial7 data pair

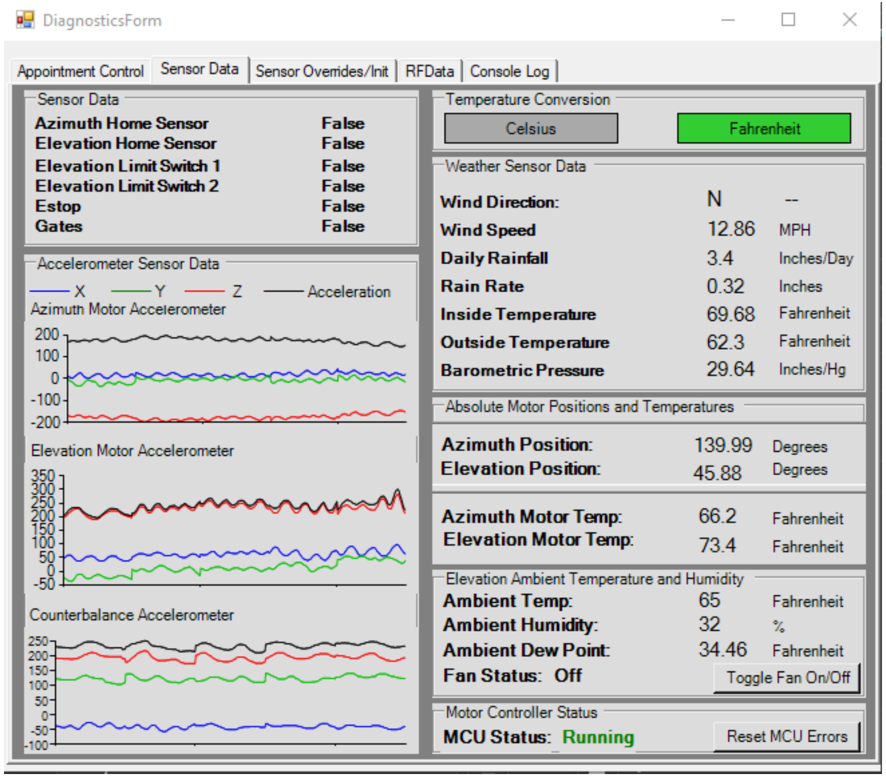


Bluetooth OTA Updating Demo



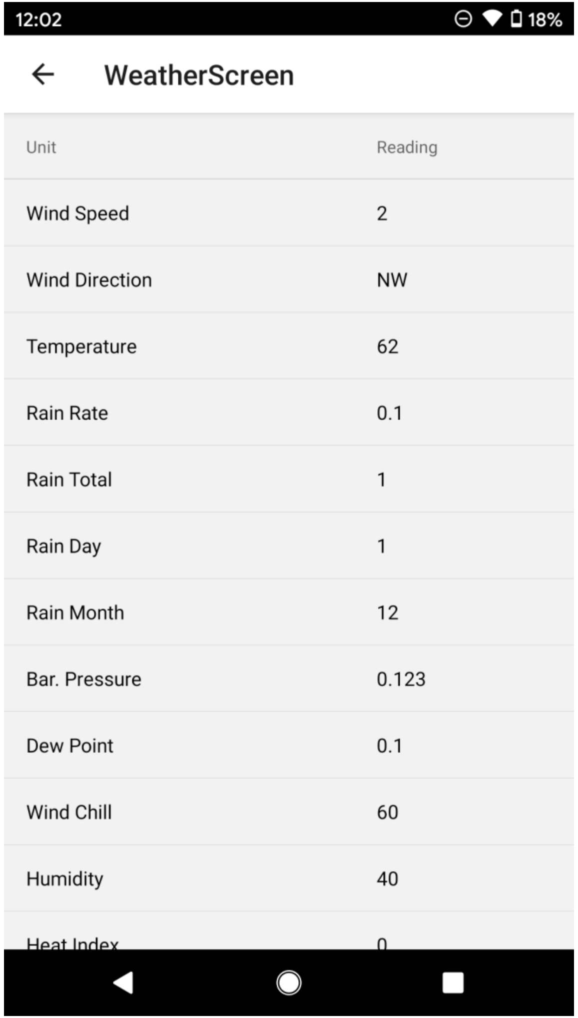
Monitoring Movements - Control Room

- As telescope moves, sensor data from ESS and weather station is collected and displayed
- Decisions are made based on the data collected and the safety of the telescope
- Toggle fan if telescope is too hot or too humid



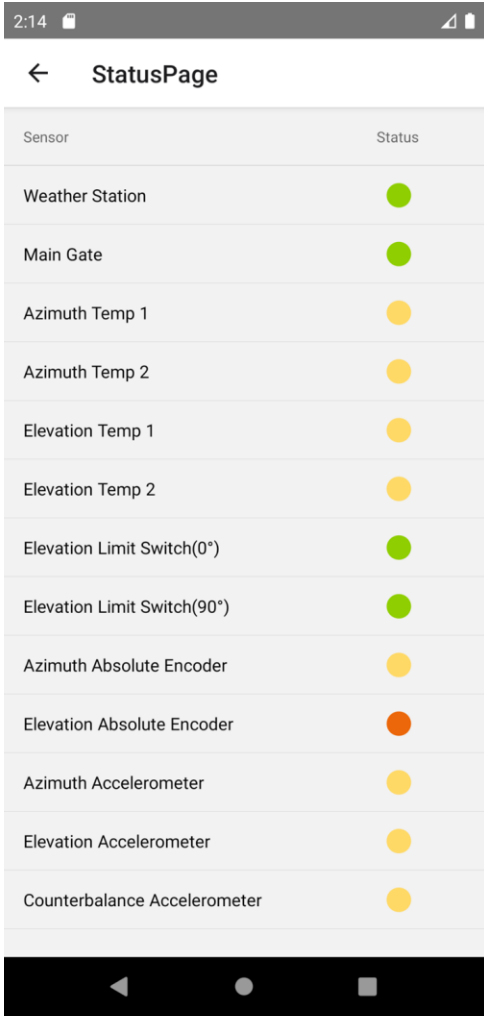
Weather Data

- Weather data will show the current weather from the Control Rooms weather station
- When moving via jog this page will update every second
- Otherwise it updates every minute



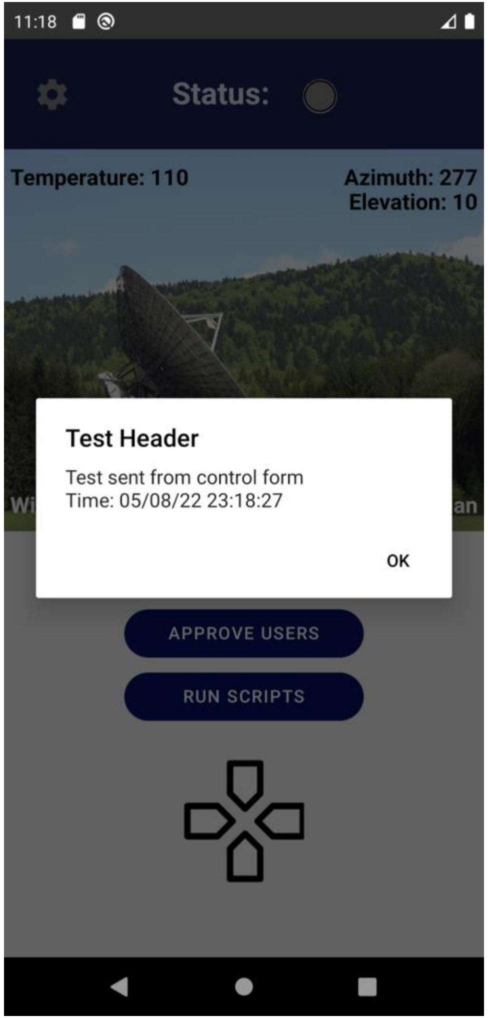
Status

- Before doing any commands admins can check the sensor status page
- The most recent status for each sensor will be shown
- Admins may override statuses from this page

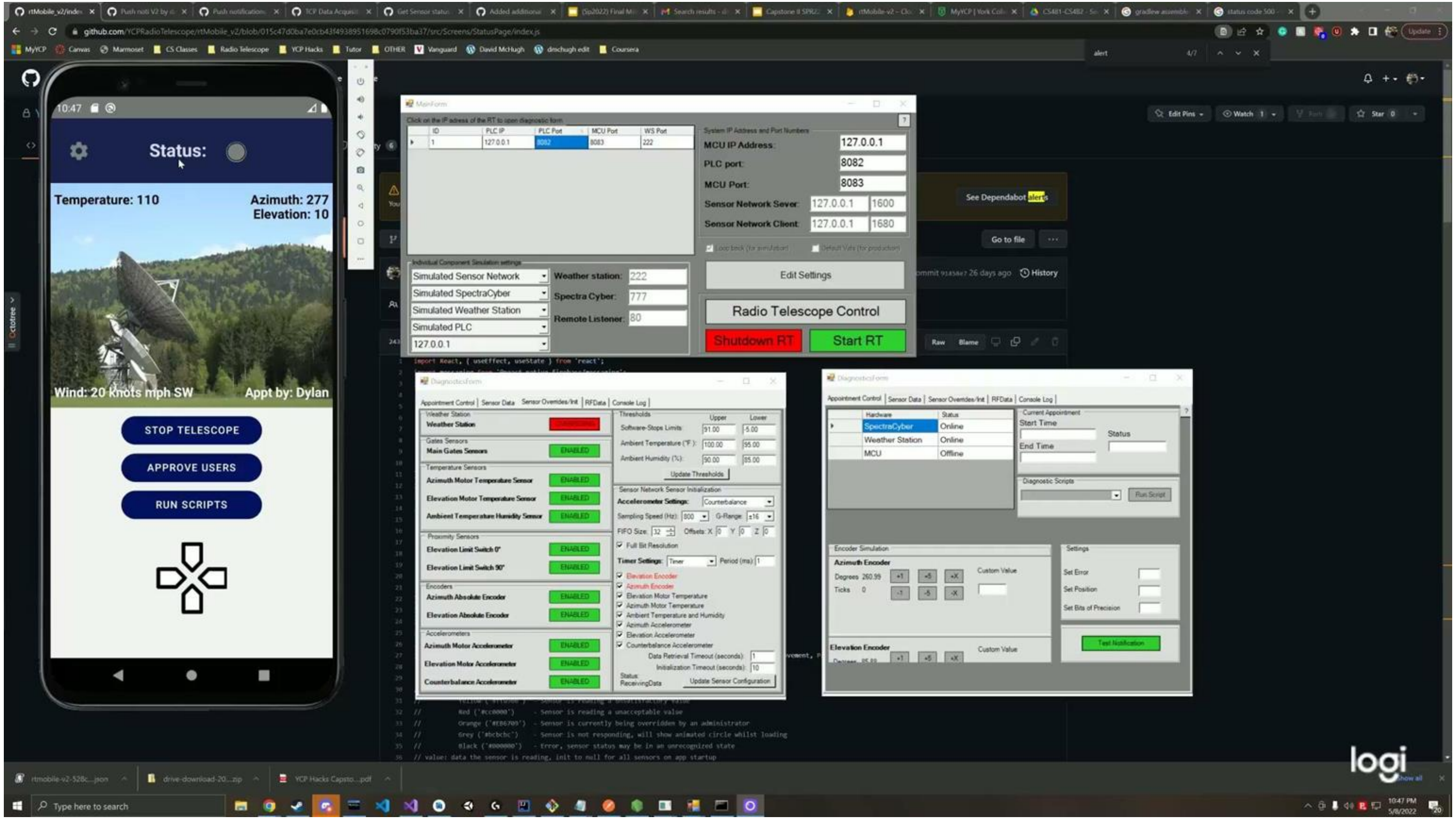


Push notifications

- Push notifications are sent from the Control Room via Google's Firebase Notification Service APIs
- Push notifications are sent when:
  - Sensors override
  - Sensors become critical
  - Disconnect from ESS



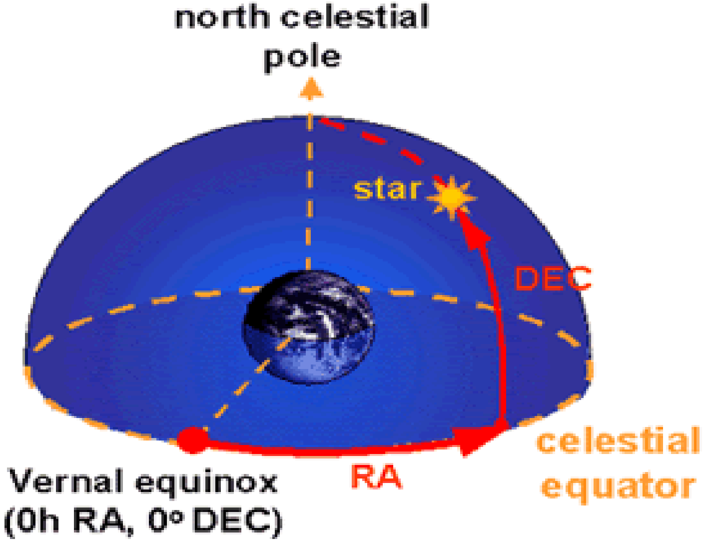
Sensor Status/ Sensor Override



Appointments

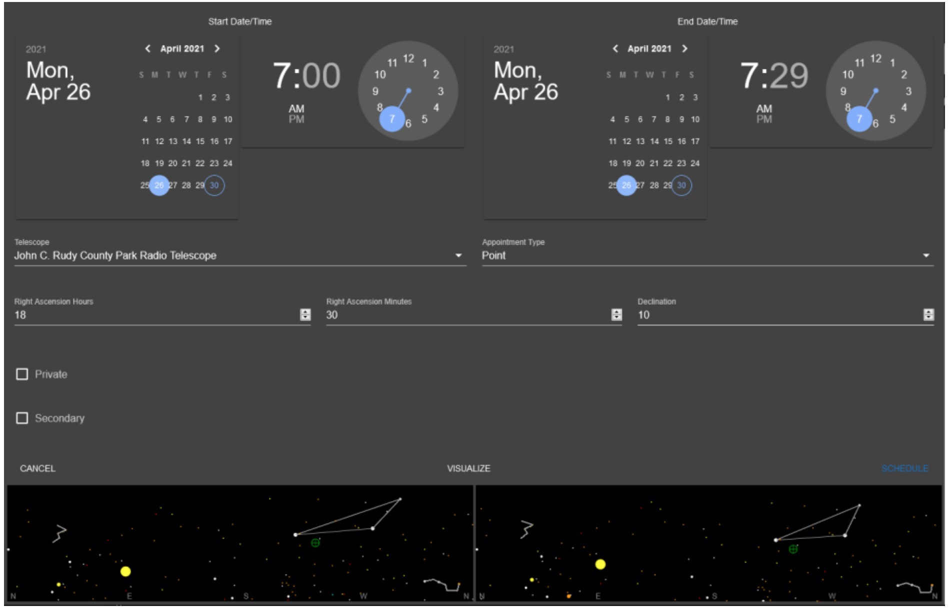
Right Ascension(RA) and Declination(DEC)

- A simple coordinate system for stars
- Right Ascension(RA) similar to X
- Declination(DEC) similar to Y



Scheduling an Appointment

- User specifies appointment type and position on website
- Submitted appointment gets reviewed by system admin
- Approved appointments get scheduled to run



Appointment Execution

- General overview, an appointment will run some movements on the telescope and save radio frequency data
  - First, the appointment data is pulled from the database
  - Spectracyber is then configured to scheduler's settings
  - Once this is done, the telescope performs calibration readings
  - After calibration, the telescope moves to the orientation specified by the appointment for the specified duration
  - Once the appointment duration ends, the telescope performs calibration readings again, and an email with the results is sent to the user who scheduled the appointment

Appointment Calibration

- Before an appointment starts, the telescope needs to be calibrated to ensure data accuracy
- The telescope is calibrated before and after every appointment
- The steps for the process are as follows (yes, we do scan a literal tree)
  - Home the telescope
  - Perform beginning calibration (Tree and Zenith)
  - Run the appointment
  - Perform end calibration (Zenith and Tree)
  - Compile the data and send it to a user

SpectraCyber & Data Collection

Figure 1. Feedhorn Assembly

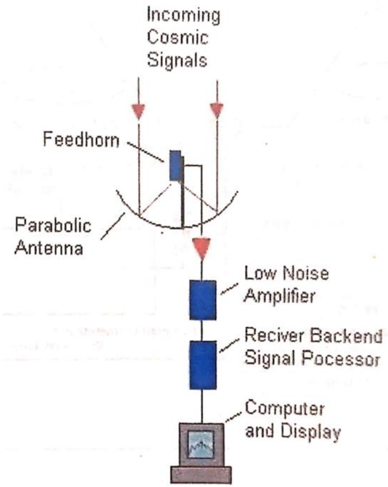


Figure 2. System diagram

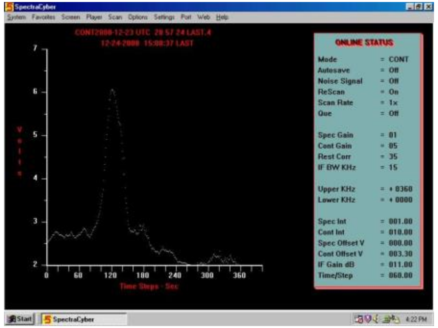


Figure 3. Sample SpectraCyber reading display

1. Parabolic antenna (the dish) reflects the RF signal to a focal point within the waveguide horn

1. 12VDC, 100mA is used to amplify the RF signal using a Low Noise Amplifier (LNA)

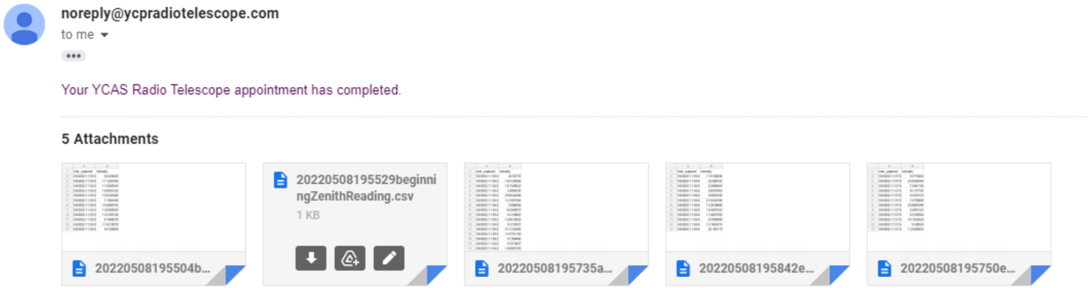
1. Signal is transferred through LMR 400 coaxial cable to the SpectraCyber

1. SpectraCyber processes the signal and displays it on the control room computer

Figures 2 & 3 Courtesy of Radio Astronomy Supplies- SpectraCyber Technical Manual

Data Collected and Sent to Users

- During the course of an appointment we collect radio frequency data
- We need to collect calibration data both before and after an appointment
  - Helps with discovering any discrepancies
- We collect data during the course of an appointment
- All data is sent to CSV files which are added to an email that gets sent to the user once appointment completion is finished



Inertial Testing

Inertial Testing Purpose

- Simulate the weight and momentum of the complete radio telescope assembly.
- Evaluate the motors ability to handle impulses and accelerations in both the azimuth and elevation directions
- Test adjustments to the motors

Inertial Testing Calculations

- Verify structural integrity of wooden support arms and steel U bolts
- Check the difference in velocity required for the inertia test frame to have the same momentum as the counterbalance and hub assembly
  - Inertia test frame has the same momentum when spun at 1.61x the rate of the counterbalance and hub assembly

D	D/2	1+D/2 (rc)	ro		
0.6291	0.31455	1.31455	1.6291	in	
Rn		Area		Moment (lb-in)	
1.295456	in	0.310835	in2	525.82	
e	co				
0.019094	0.333644	in			
σ	σy				
18144.57	36300	psi			
FS					
2.000598					

Inertial Testing Calculations:

$I = m_1r_1^2 + m_2r_2^2 \quad m_1=m_2 \quad r_1=r_2$

$=2(m_1r_1^2)$

$=2(400lbs*4ft^2)$

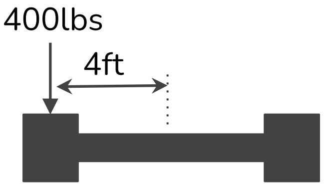
$=12{,}800 lb{\cdot}ft^2$

Momentum replication

$L = I\omega$

$I_1\omega_1 = I_2\omega_2$

$\frac{\omega_2}{\omega_1} = \frac{I_1}{I_2} = \frac{20{,}600lbft^2}{12{,}800lbft^2}$ = 1.61 times faster

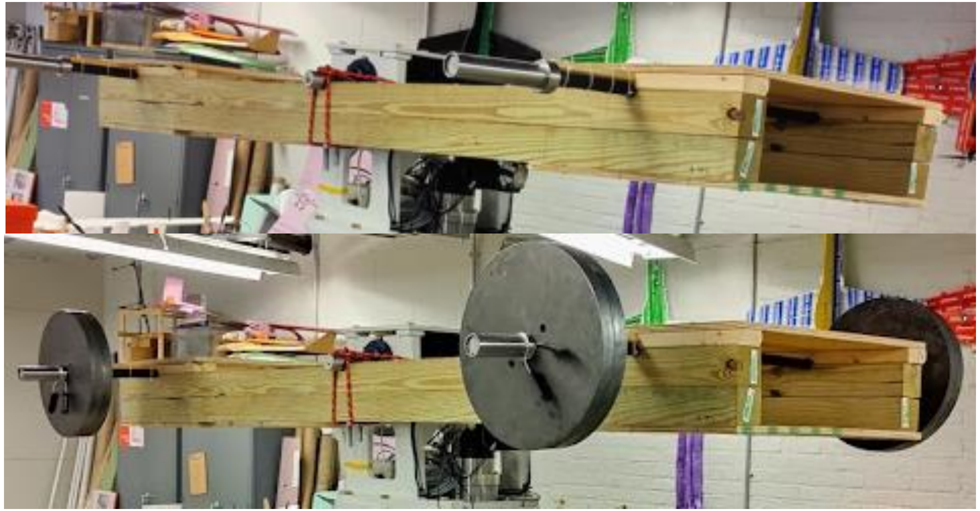


Inertial Testing Frame Construction

- Wooden support arms had circular cutouts for the elevation shaft and for barbells
- Steel U bolts were heated and bent into shape

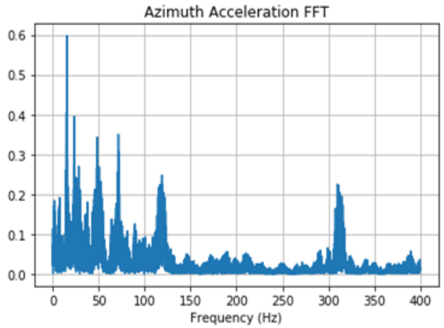
Inertial Testing Process

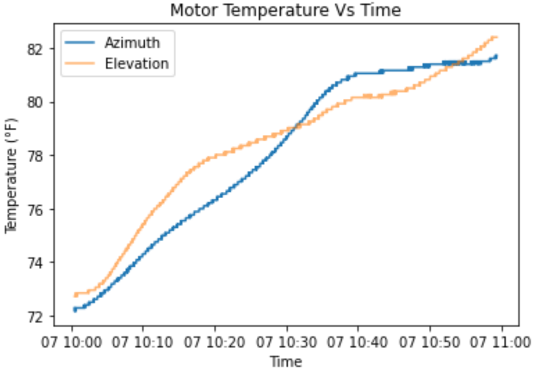
- Frame only, 400 lbs added, then 800 lbs added
- All tests run
  - Various controlled speeds
  - Stopping methods

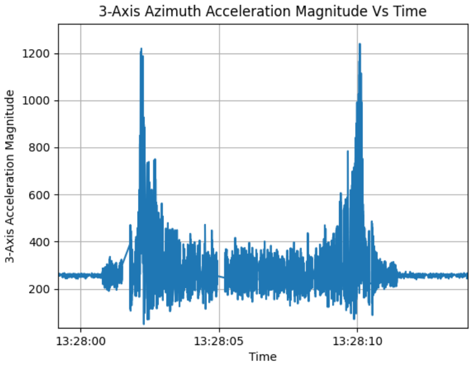


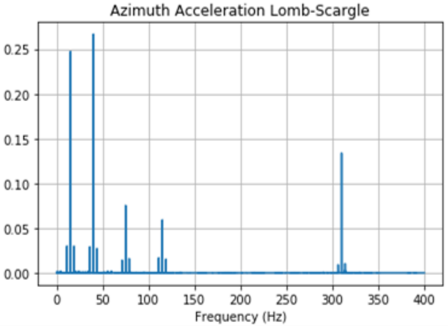
Inertial Testing Software Tools

- How data was collected
    - (Accel, temp, position, encoder positions)
- Analyzed with Python tools









Temperature

Acceleration

Vibration Frequencies

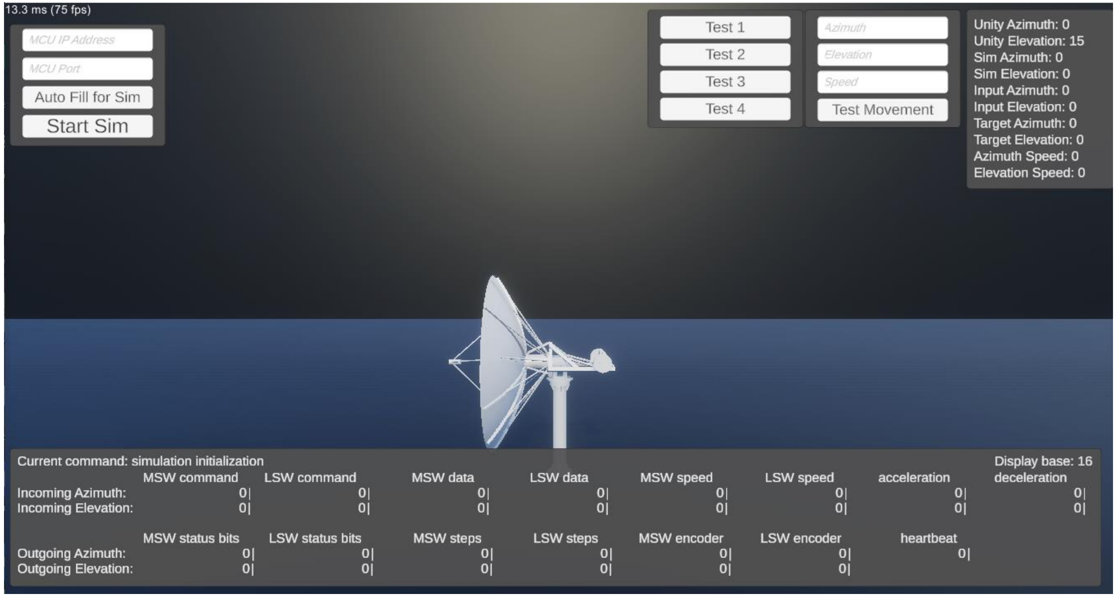
Inertial Testing Results

- Stored all data
- Immediate stop is too immediate
    - Too damaging to the gearboxes
    - Entire telescope shakes
    - Caused azimuth readings to be off
- Motors give out after Control Room disconnection
- Both motors increase in temperature even though one is moving

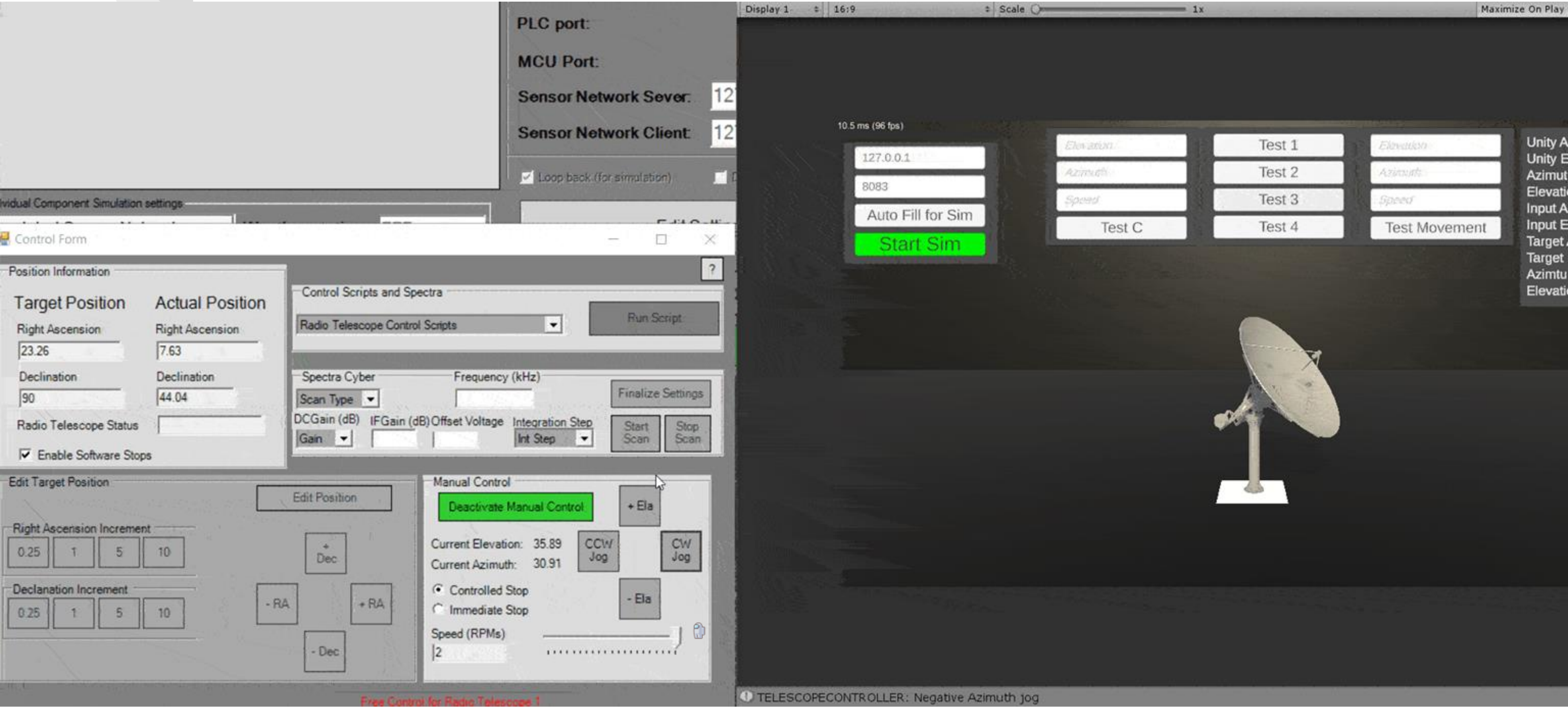
Simulation and VR Game

The Sim and Its Importance

- Useful for software testing
- Reads commands from control room
- Functionally the same as the real telescope



Example Sim Operation

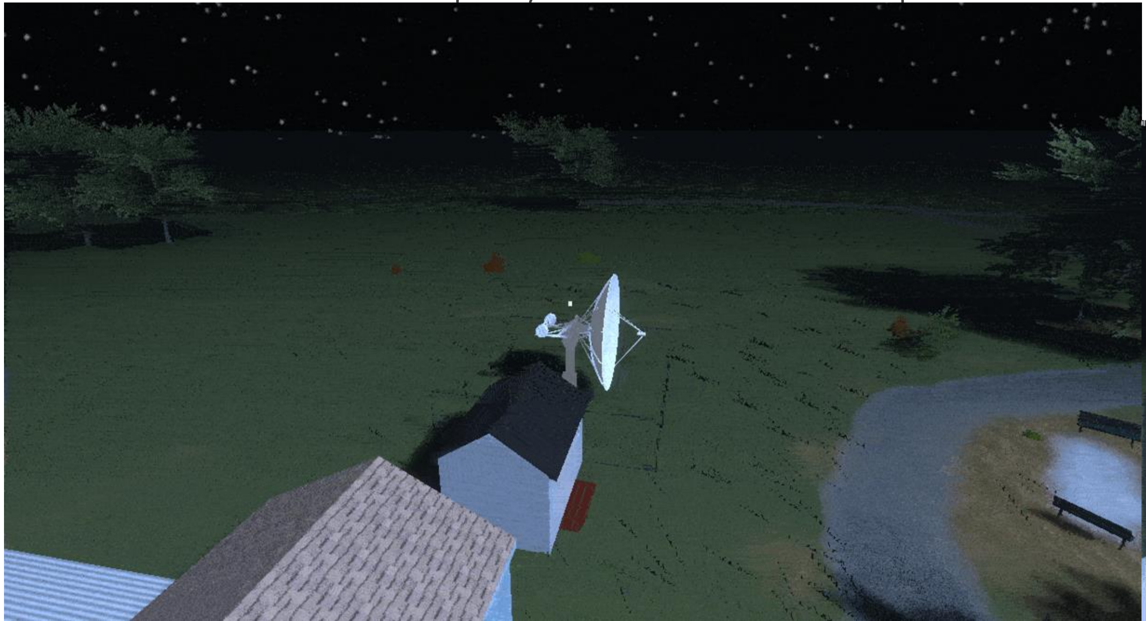


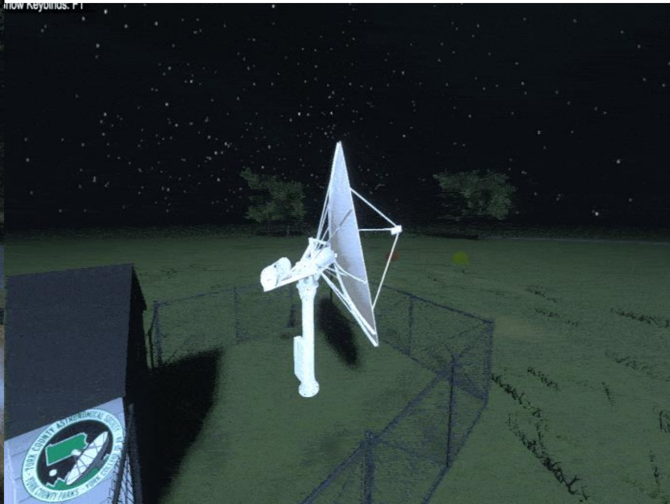
PC and VR Educational Visualizations

- Developed using Unity and C#
- Demonstrates the function and general construction of the telescope
- PC demonstration can be easily shown in classrooms
- VR demonstration effectively shows scale of telescope

PC Mouse & Keyboard Visualization

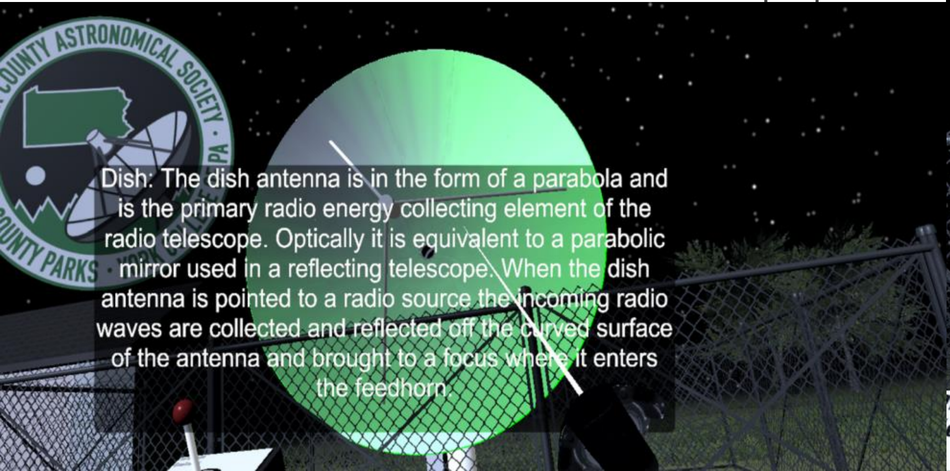
- 3D program that demonstrates telescope model and operations
- Compatible with most computers
  - High quality version for high-end computers
  - Low quality version for low-end computers
- List of User Interactions:
  - Move telescope with arrow keys
  - Interact with star system data points
  - Interact with telescope parts

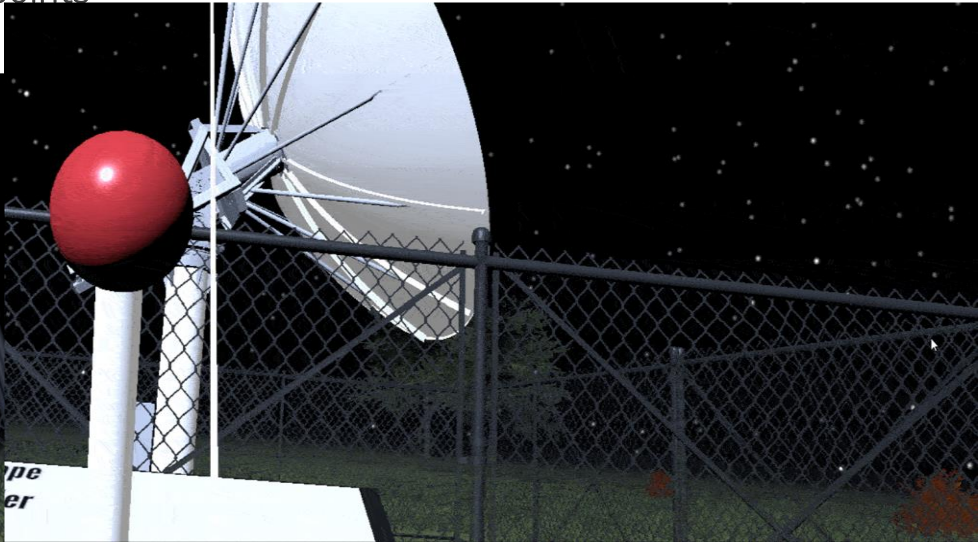




Virtual Reality Visualization

- Similar to PC version, but is compatible with all VR devices
- User can gain sense of scale of telescope
- List of User Interactions:
    - Move telescope with joystick
    - Interact with star system data points
    - Interact with telescope parts



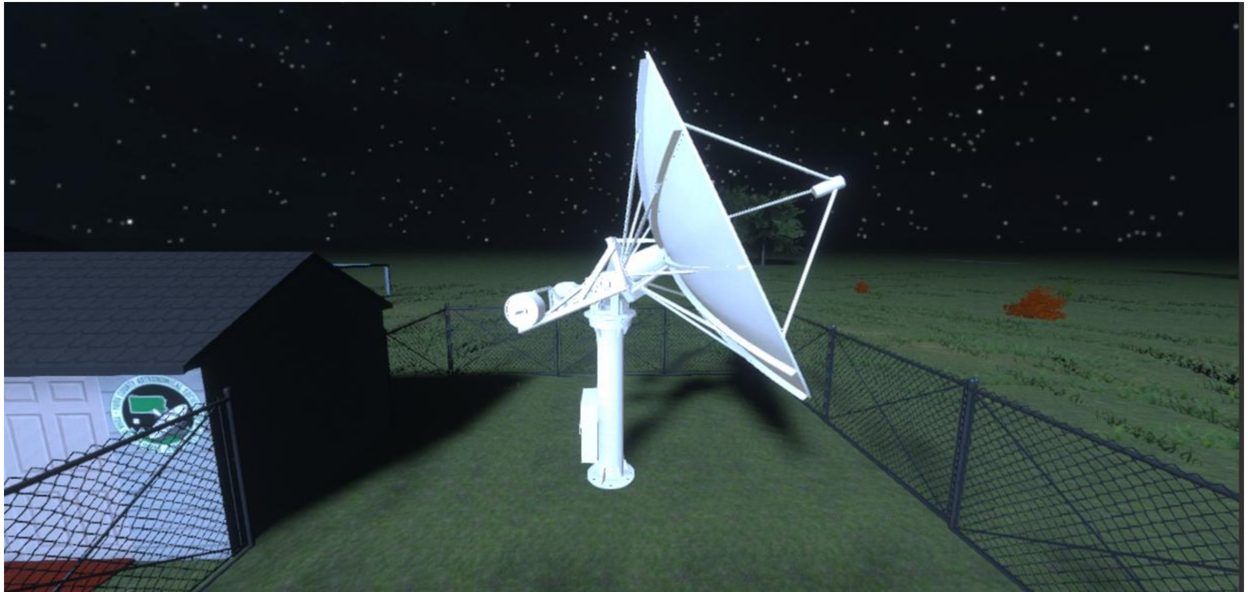


Mock Replica of John C. Rudy County Park

- Visualization scene is modeled after John C. Rudy Park
- Surrounding buildings and telescope are scaled accurately to real life
- Terrain, foliage, and benches added to simulate real life environment

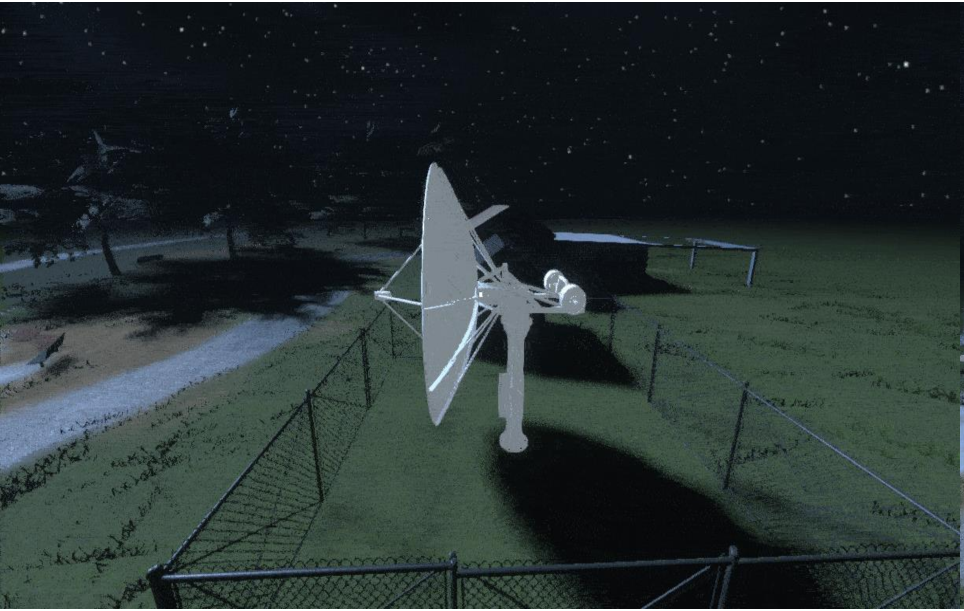
Display of Telescope Model and Parts

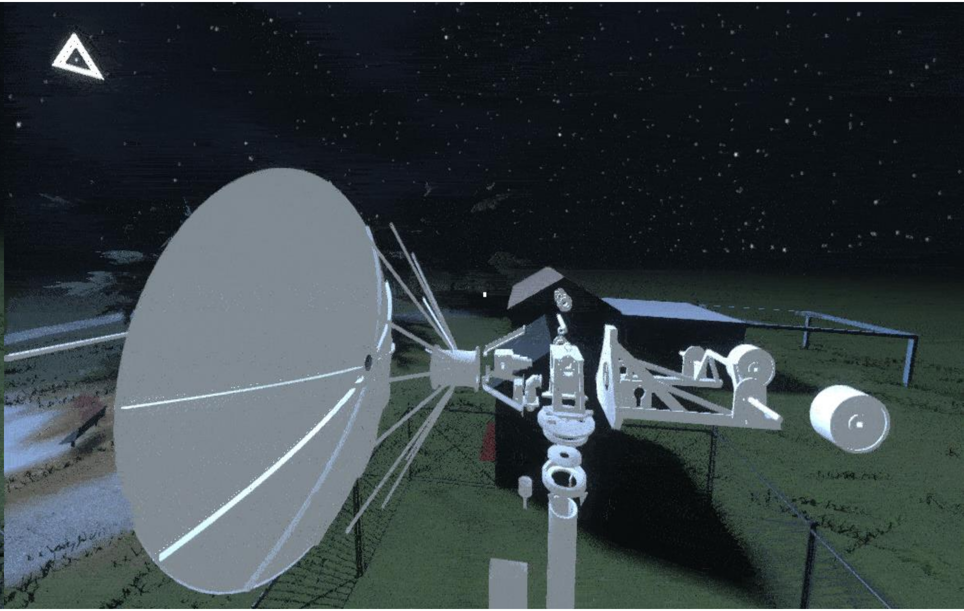
- Collaboration between CS and ME students
- Imported Solidworks models into Unity
- Telescope model fully updated to include all parts
- Descriptions added to each telescope part



Telescope Parts Expansion and Interaction

- Telescope can be expanded to show detailed composition of parts
- Interaction with a part will display its description



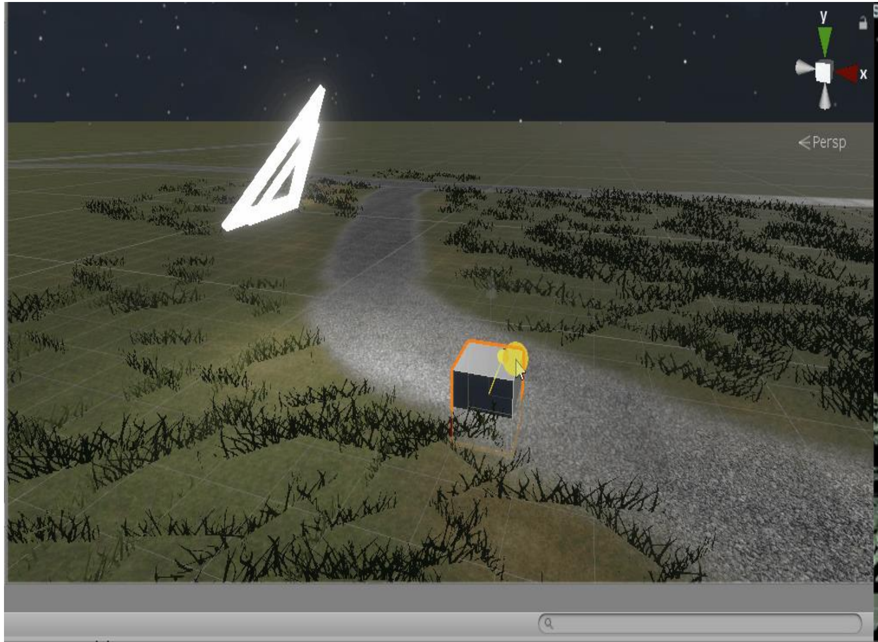


Accurate Star System

- Brightest stars are imported from public database
- Placed using (X, Y, Z) spherical coordinates
- Stars are animated

Star Interaction System

- Used to display telescope data points
- Triangle object is spawned on each data point
- Interaction shows Label, Description, and Image of data point

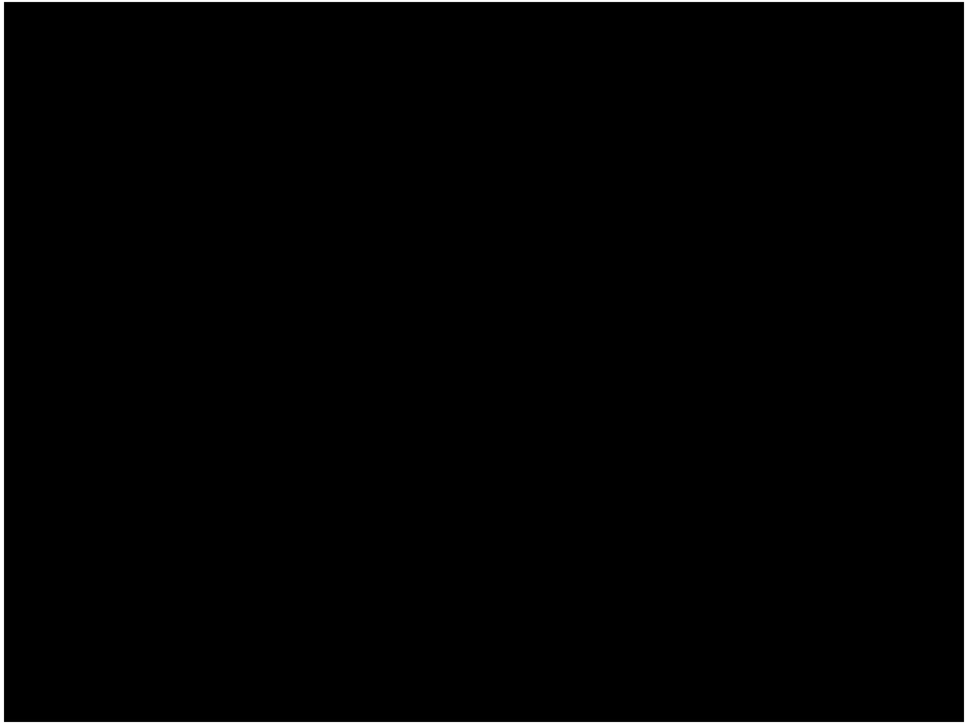


Visualization Accessibility and Compatibility

- Using SteamVR API for VR compatibility
- Currently supporting Oculus Quest 2 and HTC Vive
- Separate Oculus Quest 2 APK demonstration

Demo

Appointment Calibration Demo



Questions?