Ground Station and Satellite Tracking System

A Western CubeSat Project

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Introduction

Western University's CubeSat Project is designing two parallel CubeSat satellite systems, with different communication frequency bands, that will undergo a trade-off, launching only one of them in 2021.

They lack an accessible system on the ground that can provide real-time communication, monitor and predict movement of the satellite, and correct antenna direction based on its trajectory. This ground system must be robust to either communication schemes.

Problem Statement

The problem is to design and build a functional satellite tracking ground station with high alignment accuracy between the CubeSat in orbit and the ground station, to achieve better communication and data transfer.

Problem Scope

This project will cover the electrical and mechanical subsystems for motor actuation and sensory data acquisition, control system for mitigating tracking error, and the orbital prediction algorithm that the ground station will employ to track the satellite's orbit.

Background Research

- A CubeSat is a miniature satellite intended for low earth orbit (LEO) weighing less than 1.33 kg [1]
- UHF frequency requires a Yagi antenna, which needs a 30˚ field operating around 300 MHz [2]
- S band requires a parabolic dish, which needs to rotate between 15˚ to 165˚ operating around 2 GHz [2]
- Simplified General Perturbations (SGP) models are used to model the orbit of LEO objects using a two-line element set, a data format that encodes orbital elements of a satellite at a given point of time [3]

Project Objectives

- Compact size in comparison to existing ground stations
- Requires little maintenance
- Manufactured mainly from COTS components

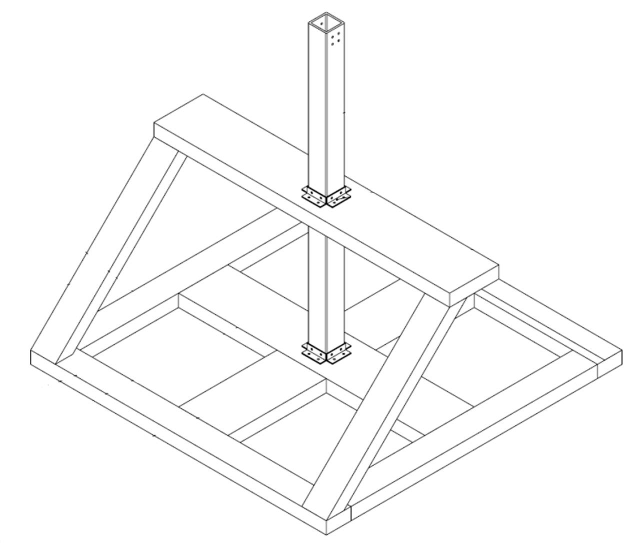
Project Constraints

- Maintain high alignment accuracy with the satellite
- Predict orbital trajectory and correct antenna direction
- Withstand external environment conditions
- Design must be within the $1300 total budget

Mechanical Design

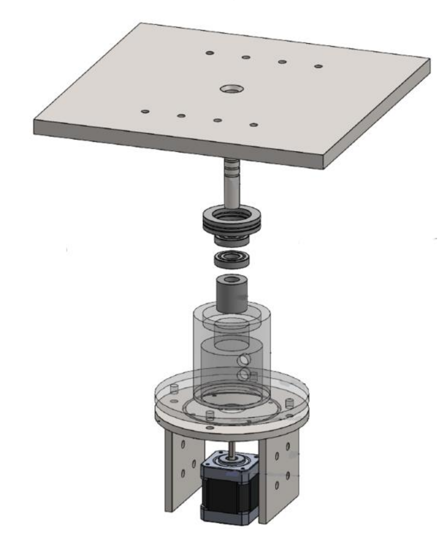
Base

- Truss structure for stability, made out of lightweight pine planks
- Medium carbon steel for main shaft
- Machined angle brackets



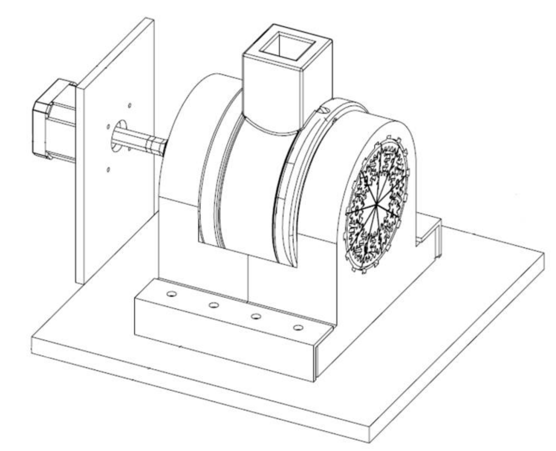
Azimuth Subassembly

- Radial bearings to absorb any wind load on elevation subassembly
- Thrust bearing to remove load on motor shaft
- Custom designed bearing holder machined on a lathe to allow correct placement of bearings



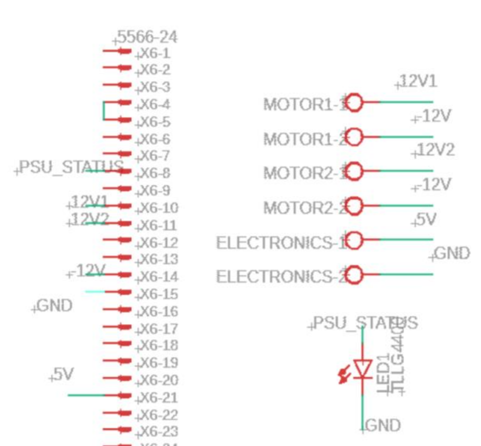
Elevation Subassembly

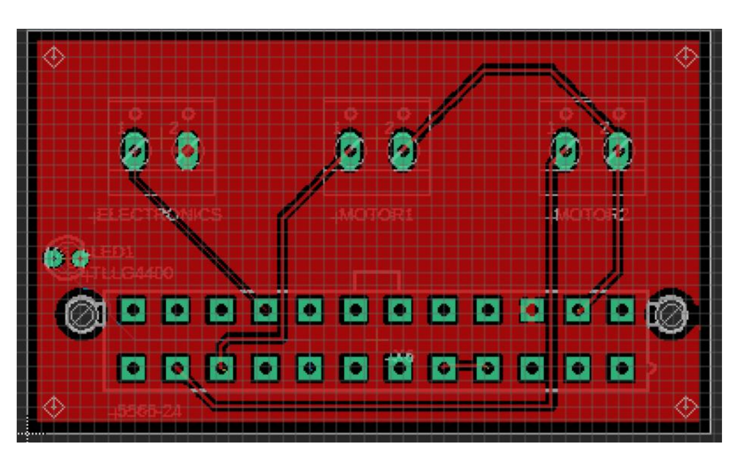
- CNCed base plate to ensure concentricity with motor shaft
- 3D printed 160:1 gear ratio compound planetary gearbox [4]



Electrical and Control Design

- Motor terminal blocks take a 12V input and pass it to the motor drive through copper wires with the return line being -12V, giving an effective potential of 24V
- Terminals for the electronics are a simple 5V output, connected to a power rail through copper wires
- Custom PCB designed to route power from input pins of the power supply to accessible screw terminals that will connect to the power rails and motor drivers

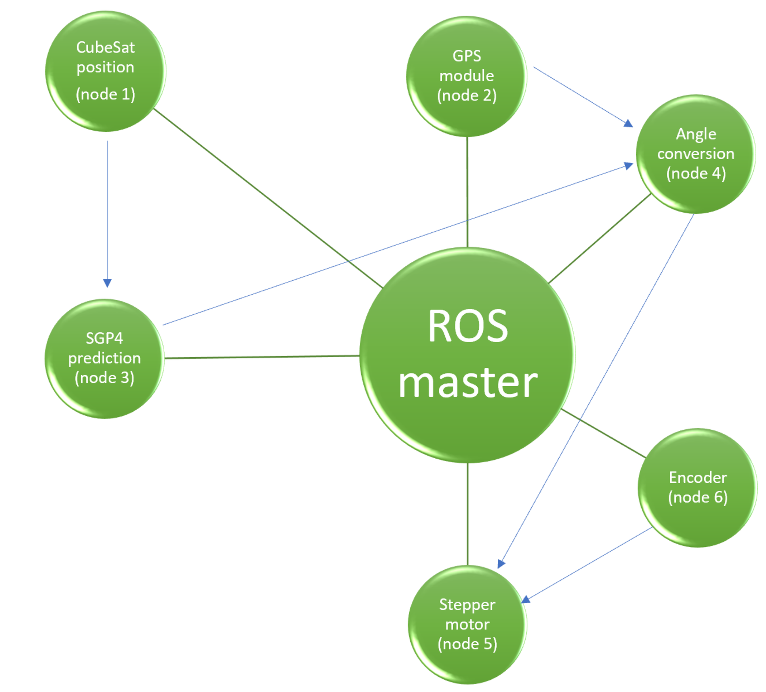




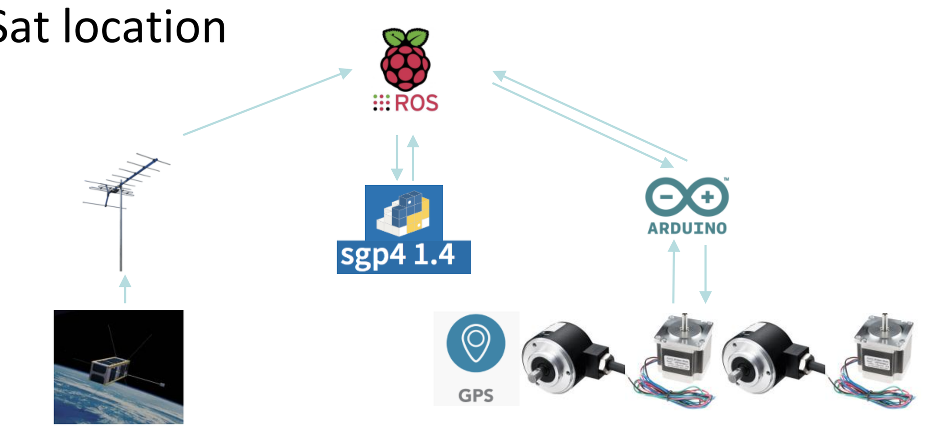
- Closed loop control with the use of absolute encoders
- Using an interface between Raspberry Pi and Arduino, real time control of the motors was established

Software Design

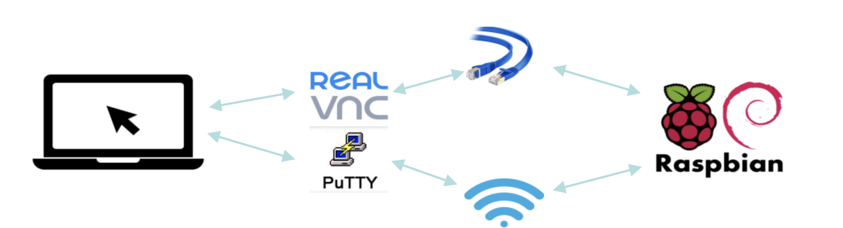
- The core architecture is based on the Robotic Operating System (ROS), a language-neutral middleware that provides services including low-level device control, implementation of commonly-used functionality, and package management



- There are three main parts of the system architecture: the control of devices through the Arduino board, CubeSat orbit prediction using SGP models, and the CubeSat location



- Remote access to the RPI is obtained through Secure Shell (SSH) connection through Ethernet or mobile Wi-Fi and use of telnet clients PuTTY or REALVNC



Engineering Validation

Inertia of Arm

$$\Sigma M = Fr = 15kg \times 9.81\frac{m}{s^2} \times 0.20\ m \times \cos(\alpha) = 29.43\cos(\alpha)\ N\cdot m$$

Torque from Wind Considerations

$$F_{wind} = \frac{1}{2}\rho_{air} v_{wind}^2 A_{dish} \qquad \rho_{air} = 1.2\ \frac{kg}{m^3} \qquad v_{wind} = 80\ \frac{km}{h} = 22.2\ \frac{m}{s}$$

$$A_{dish} = 0.622\ m^2 \cdot cos45° = 0.439.82\ m^2$$

$$F_{wind} = \frac{1}{2} \times 1.2\ \frac{kg}{m^3} \times \left(22.2\ \frac{m}{s}\right)^2 \times 0.439m^2 = 130.0\ N$$

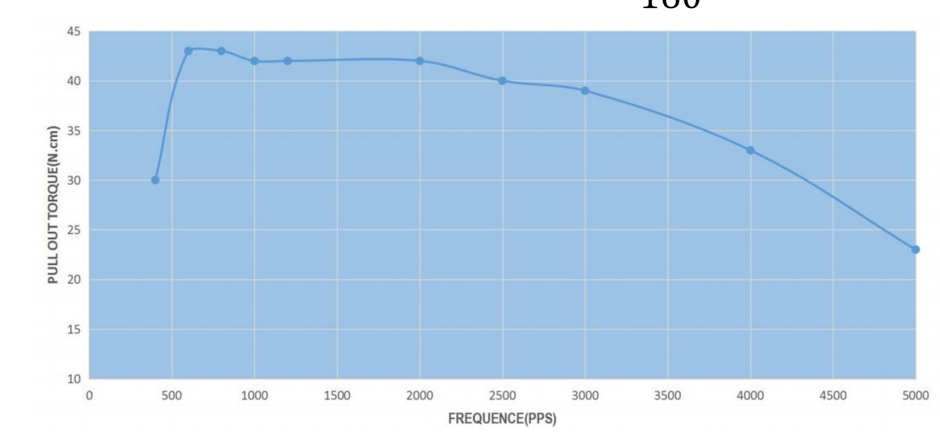
$$\tau = Fr = 130.0\ N\ \cdot 0.4\ m\ \cdot \cos 45° = \ 36.8\ N\cdot m$$

Torque of Elevation Motor

$$\alpha = 0.0043\frac{rads}{s^2} \qquad \tau = I_z\alpha = 0.5449kg\cdot m^2 \times 0.043\frac{rads}{s^2} = 0.023\ N\cdot m$$

Total Torque

$$29.43\cos(0.0043) + 36.8 + 0.023 = \frac{66.25\ N\cdot m}{160} = 0.414\ N\cdot m$$



Tipping Point

$$A_{dish} = 0.622\ m^2 * \cos(0) = 0.622\ m^2$$

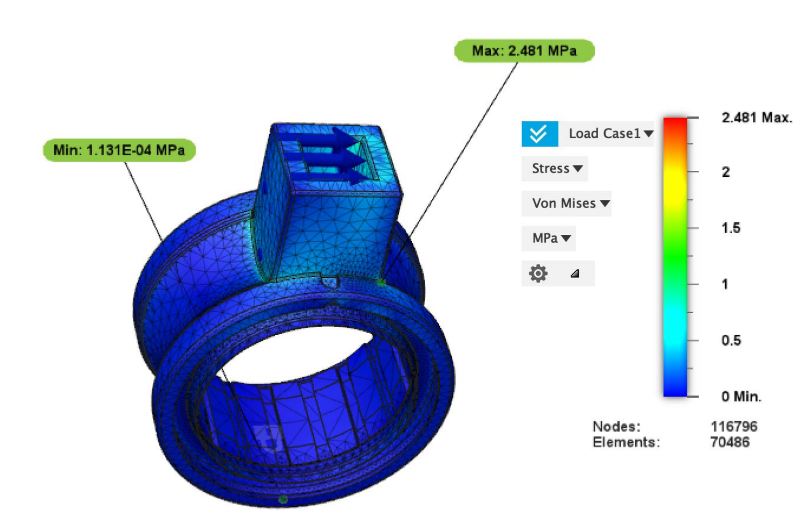
$$F_{wind} = \frac{1}{2} \times 1.2\ \frac{kg}{m^3} \times \left(22.2\frac{m}{s}\right)^2 \times 0.622m^2 = 183\ N$$

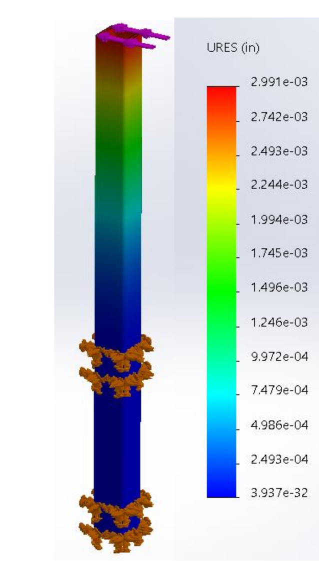
$$M_{wind} = \frac{L_{base}}{2} \cdot m_{total} \cdot g$$

$$1.4m\ \cdot 183N = \frac{L_{base}}{2} * 55\ kg * 9.81\ \frac{m}{s^2}$$

$$L_{base} = 0.9497\ m$$

Stress and Failure Point Analysis





Future Directions

- Depending on chosen antenna, finalize connection between gearbox housing and antenna main shaft
- Have the ground station be self maintaining by monitoring with housekeeping sensors and creating maintenance routines when not tracking
- Create outer protective box out of the obtained weatherproofed wood sheets
- Continue to test tracking with the moon, as it is the most visible orbiting element with available data

References

[1] What is a CubeSat. (2018, November 27). Retrieved from http://www.asc-csa.gc.ca/eng/satellites/cubesat/what-is-a-cubesat.asp

[2] Cakaj, S., Kamo, B., Lala, A., & Rakipi, A. (2014). The Coverage Analysis for Low Earth Orbiting Satellites at Low Elevation. (IJACSA) International Journal of Advanced Computer Science and Applications, 5(6).

[3] E., V. W. (1994). Mitigation of EMI generated by a variable frequency drive controller for an AC induction motor (Unpublished master's thesis). Naval Postgraduate School, September.

[4] High Torque 160:1 Compound Planetary Gearbox. (n.d.). Retrieved from https://www.thingiverse.com/thing:2375916