Affordable, Portable, Orbital Desktop Satellite Tracker

Design

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Problem to Solve

In my previous research [4], I learned that using potentiometers to measure position requires a lot of calibration and they run out of room to rotate when they reach their limits.

In this project, I designed and tested a Desktop Satellite Tracker. I wanted to know if an accelerometer and a magnetometer could replace the potentiometers, automatically calibrate, and rotate without reaching a limit. In addition, I wanted to develop a hands-on tracking tool for teachers in the classroom.

Hypothesis

My hypothesis is that I can use an accelerometer and a magnetometer in a Desktop Satellite Tracker to measure the position of an antenna to track satellites, planets and stars.

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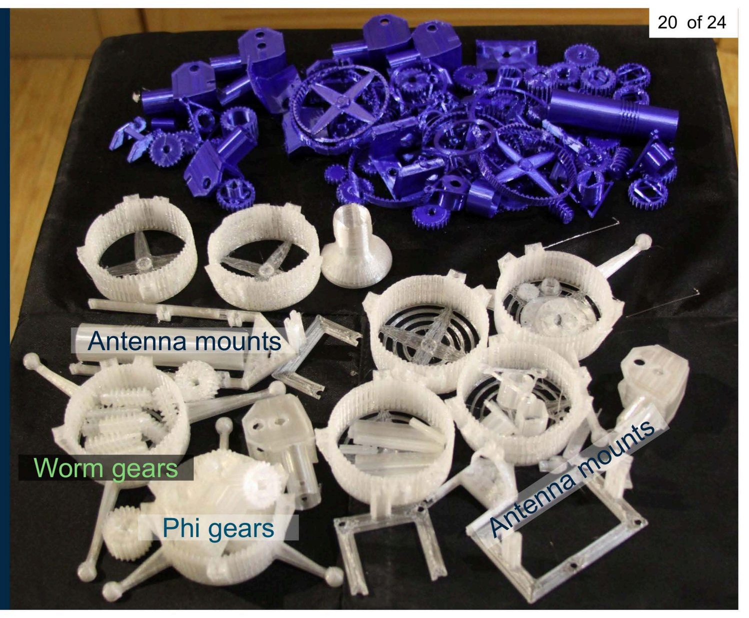
3D Print Attempts

3D prints were designed and tested but needed revision:

- 20 worm gears
- 15 phi gears
- 3 motor triangles
- 12 rings
- 10 phi assemblies
- 3 antenna mounts

Three things surprised me:

- How hard it was to accurately 3D print to make the gears mesh correctly
- Difficulty in fitting the circuit board over the ring
- Needing to increase the footprint of the tracker so it would not fall over.



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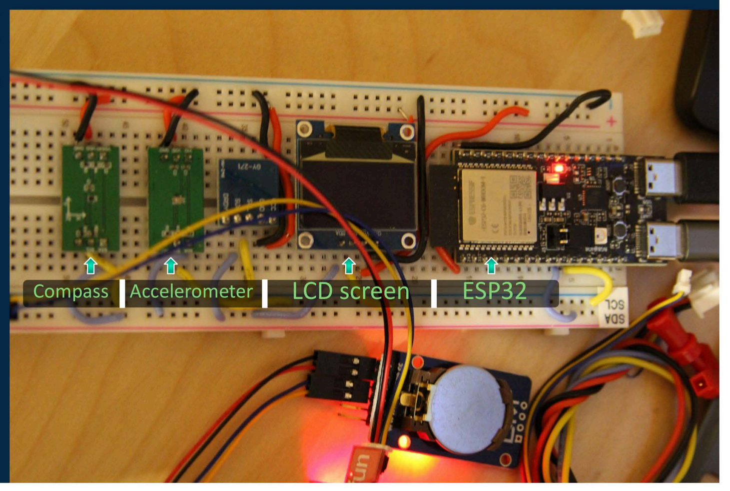
Experimental Design: Development Board

To test my hypothesis, I started with a development board which allowed me to test my circuit and software before putting it on the real tracker.

- ESP32 [11]
  - Micro controller chip that controls the tracker
- LCD screen
  - Displays satellite telemetry
- Accelerometer [8]
  - Measures the angle (up/down) to point at the satellite
- Compass [7]
  - Measures the angle (left/right) to point at the satellite



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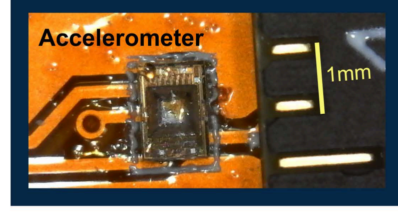
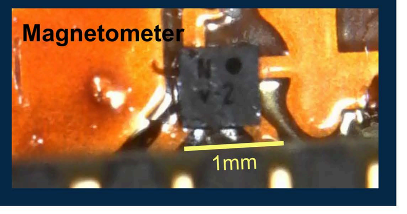
Expected Results

- According to the datasheet[7], the magnetometer is accurate to about 1 degree once calibrated.
- According to the datasheet[8], the accelerometer is accurate to about 2 degrees. It allows the base to be moved around and keeps the antenna pointed in the same direction.
- According to [3], 42.5 degrees is within an acceptable margin for getting pictures from space with my 13cm helical antenna.



(Notice the component scale)



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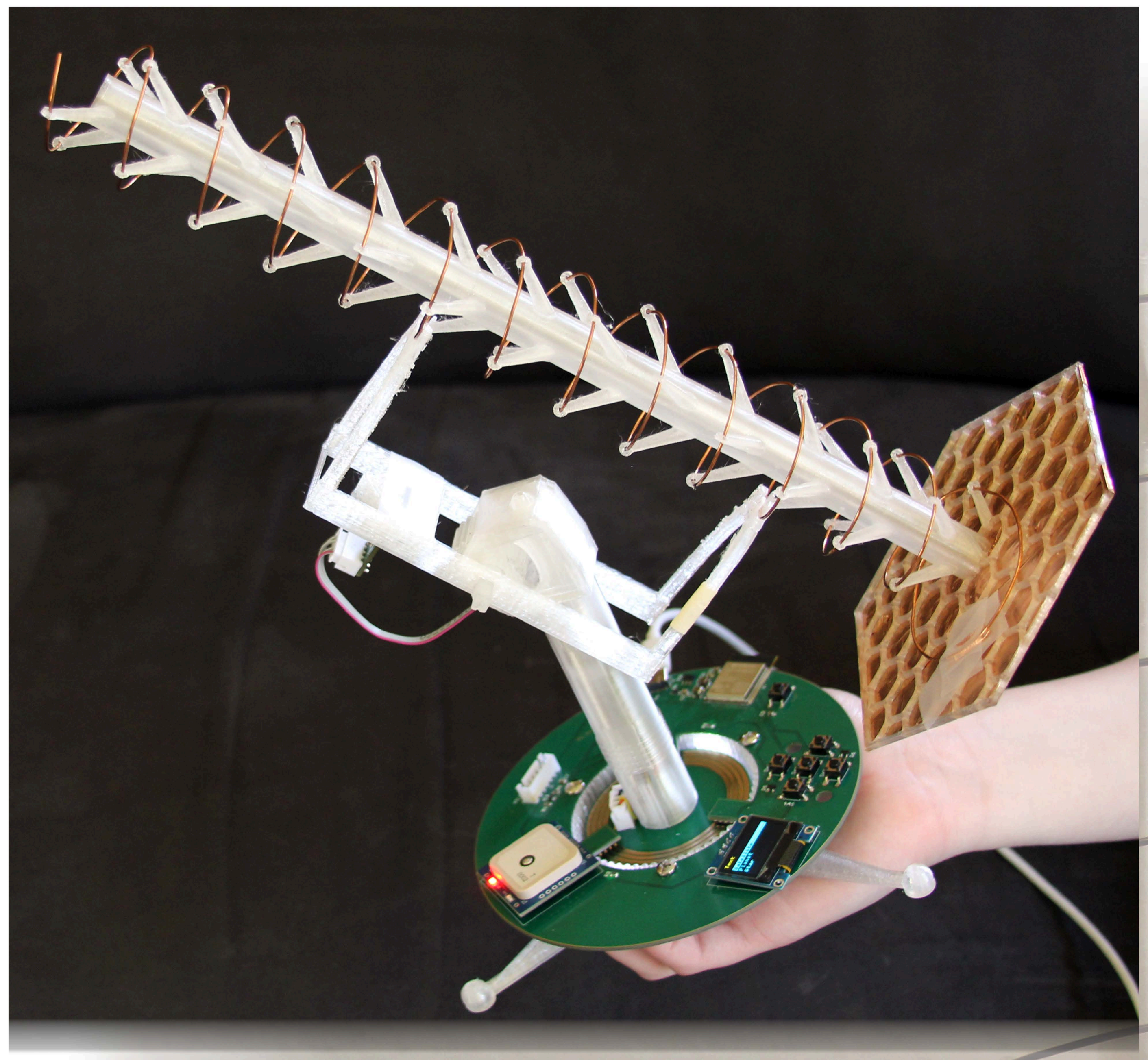
Affordable Portable Orbital Satellite Tracker for Educators

Ezekiel Wheeler	Exhibit Number: MS-EG-0003

In this project, I designed a Desktop Satellite Tracker and used a magnetometer and an accelerometer for measuring position. I modeled my Desktop Satellite Tracker in 3D CAD and designed the circuit boards to control it and to allow it to track satellites. The Desktop Satellite Tracker tracks satellites, planets and stars.

I wanted to create the Desktop Satellite Tracker to help science teachers teach STEM because I could not find any small affordable satellite tracker that was commercially available. I got the idea to do this project from my previous research, which used potentiometers to measure position.



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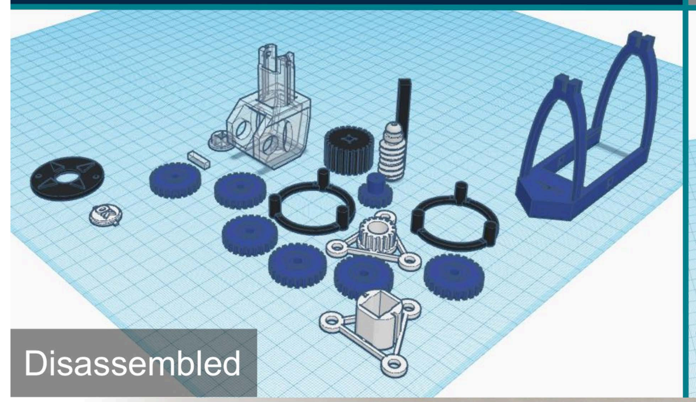
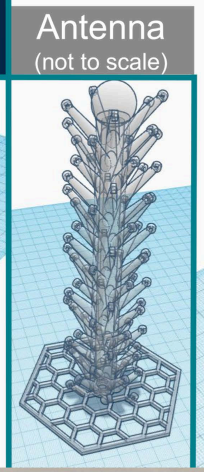
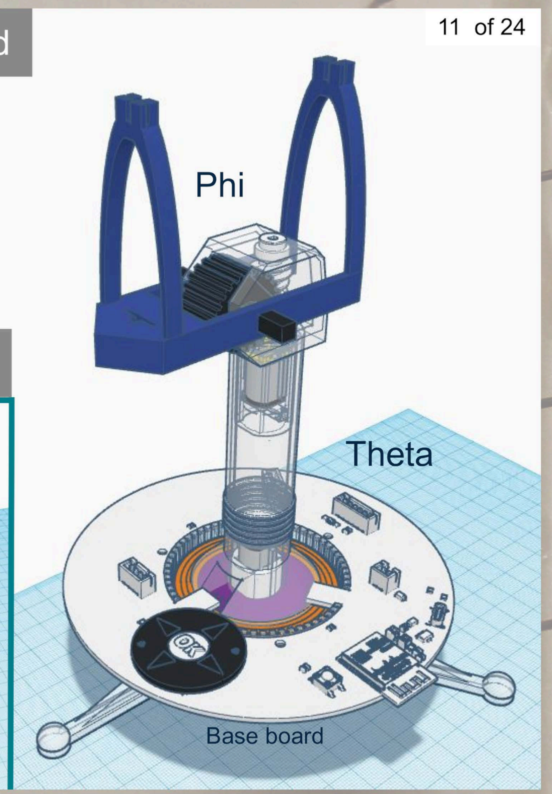
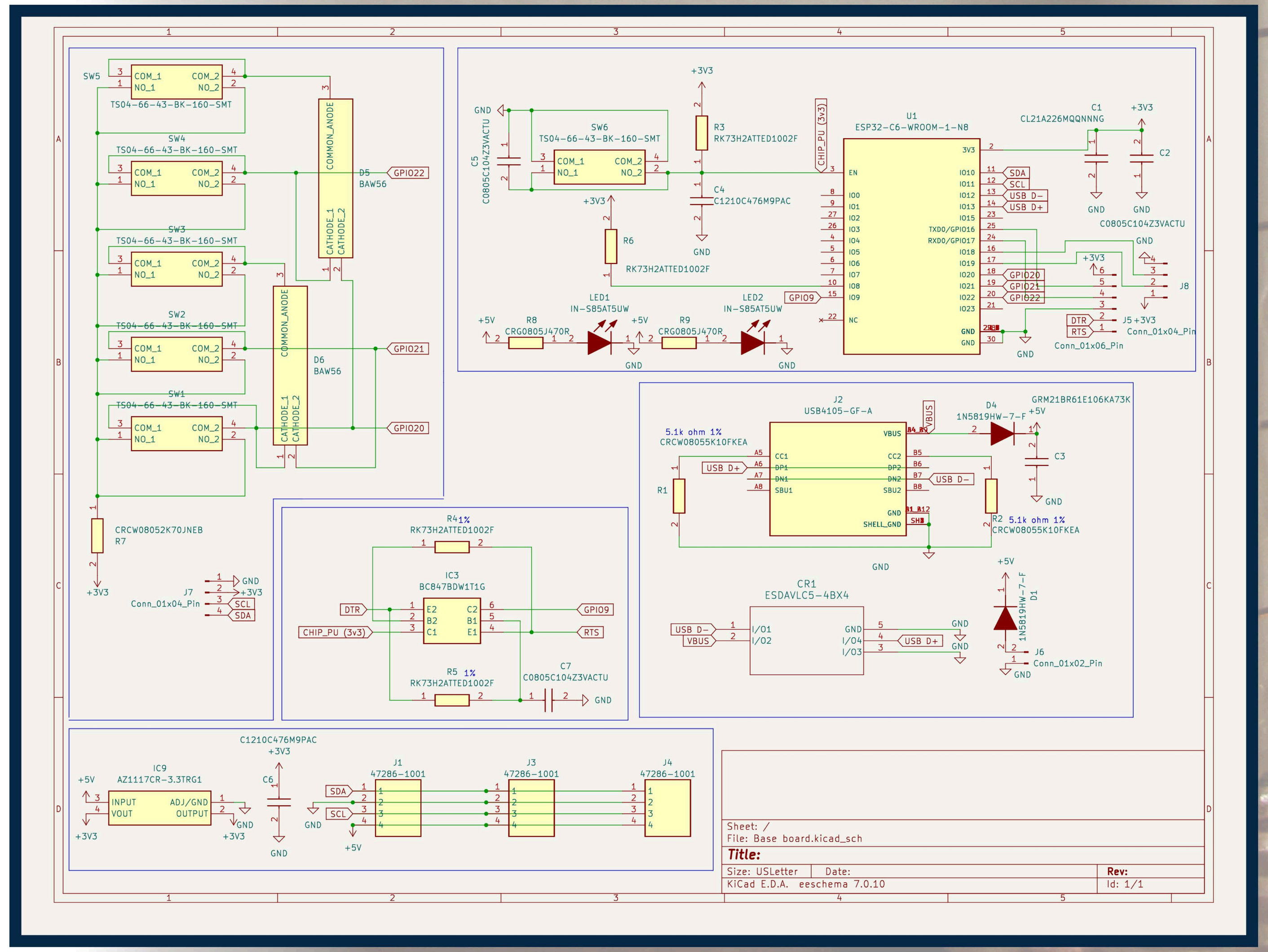
Tinkercad Model

I designed and built this Desktop Satellite Tracker model in Tinkercad [1], an online 3D design tool.









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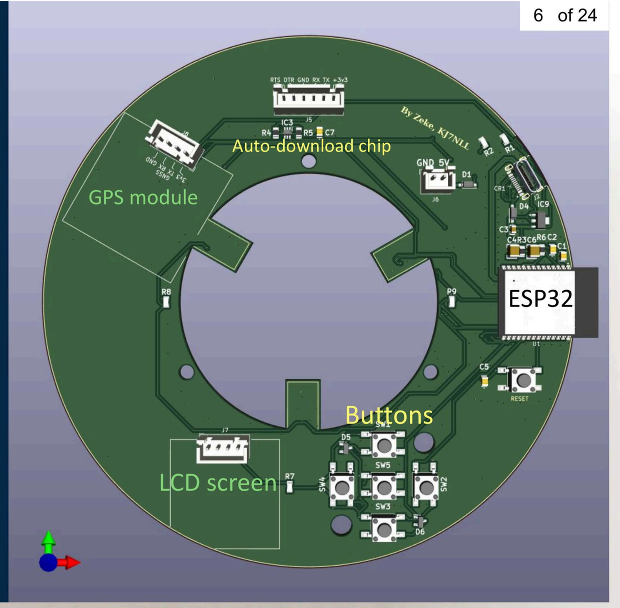
Base Board

This circuit board is based on the development board and attaches to the actual tracker.

- GPS module [12]
  - Obtains accurate positioning for satellite tracking.
- Auto download chip
  - Builds software onto the ESP32.
- Buttons
  - Controls the tracker along with the menu on the LCD screen.



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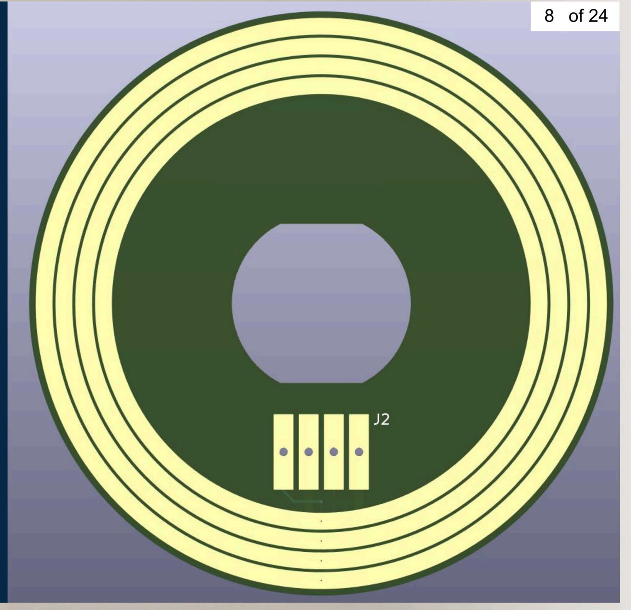
Circle Board

This circular circuit board is a connector between theta, which moves antenna left/right, and phi, which moves antenna up/down.

- I could not use a wire to connect theta and phi because it would twist up when the antenna rotates. Instead, contacts on the base board press onto the rings thus eliminating the need for a wire.



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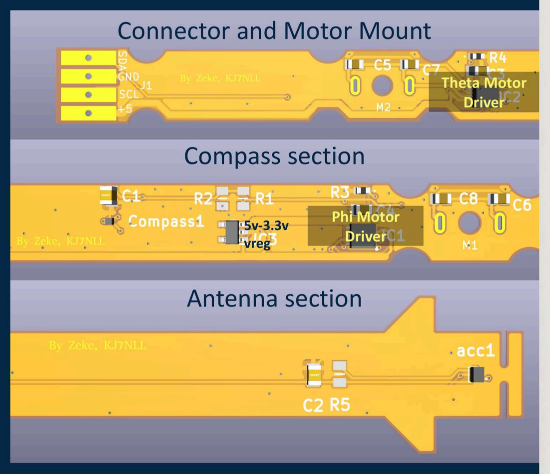
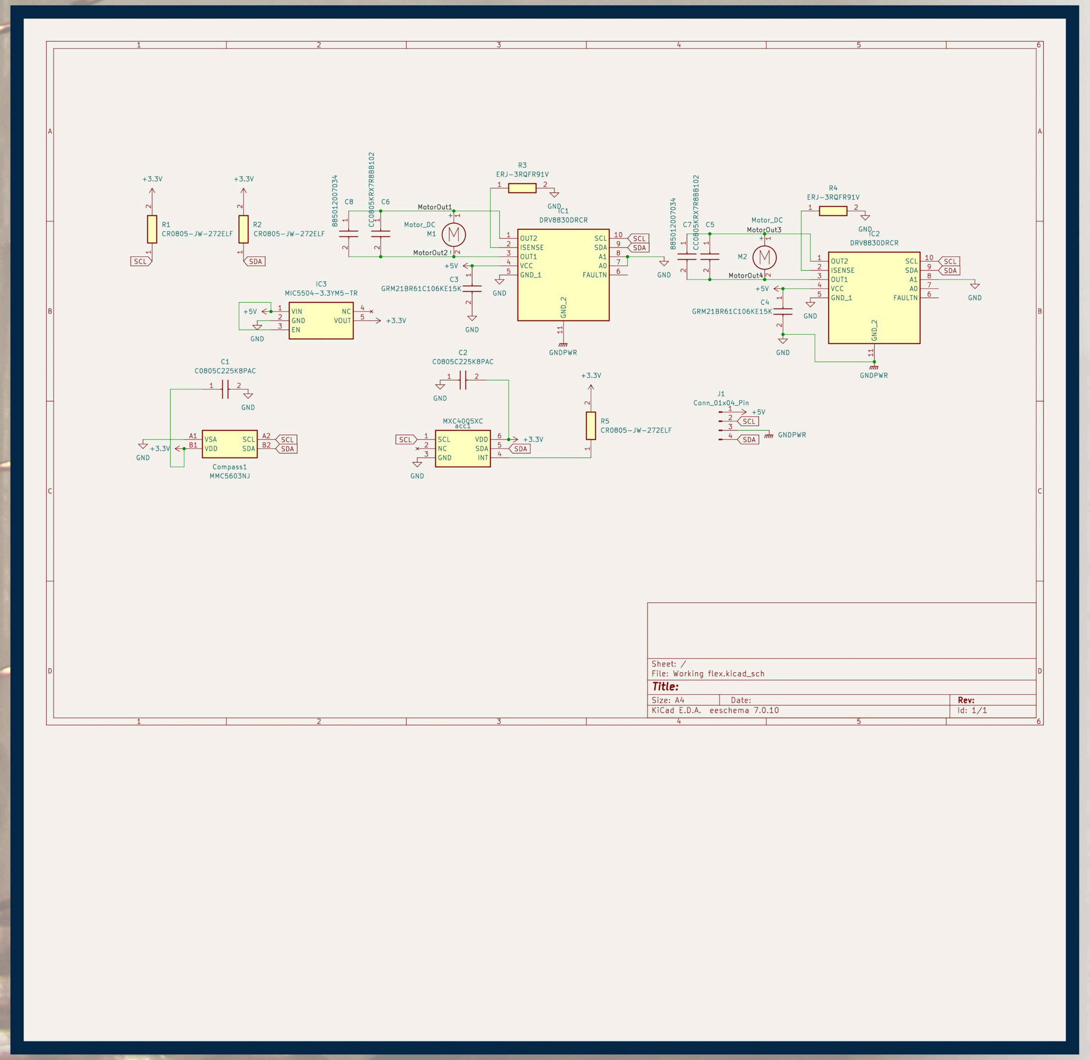
Flex Board

This is a flexible circuit board that folds into the tracker to connect the motors to the sensors.

- Connector
  - Connects to the circle connector to get power to the flex board.
- Theta motor driver [13]
  - Controls the Pulse Width Modulation (PWM) for the theta motor.
- Phi motor driver [13]
  - Controls the PWM for the phi motor.
- 5v-3.3v vreg
  - Lowers the 5-volt supply for the motors to 3.3-volts for the compass and accelerometer.
- Acc1
  - The accelerometer (I2C bus)
- Compass1
  - The compass (I2C bus)



Note: The flex board was fragile, so I switched to a solid board.



Results

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Results: Magnetometer Accuracy

I used a compass [10] to measure the accuracy of the magnetometer:

These measurements show that -7 degrees is within the half power beam width of 42.5 degrees. Clearly, this is accurate enough to get a signal from OreSat0.

North, +2 degrees off
002 degrees measured

East, -7 degrees off
083 degrees measured

South, -2 degrees off
178 degrees measured

West, +1 degree off
271 degrees measured

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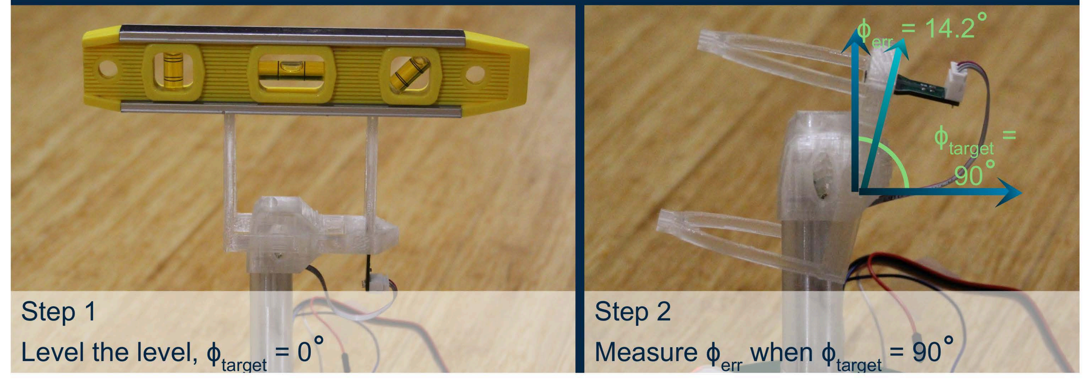
Results: Accelerometer Accuracy

I used a level to measure the accuracy of the accelerometer:

Phi has an error of 14.2 degrees, which is acceptable because it is within the 42.5 degree half-power beam-width.



Step 1
Level the level, $\phi_{target} = 0°$

Step 2
Measure ϕ_{err} when $\phi_{target} = 90°$

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Accelerometer and Magnetometer - How it Works

$tan(\theta) = \frac{\bar{z}}{y}$

$atan(tan(\theta)) = atan(\frac{\bar{z}}{y})$

$\theta = atan(\frac{\bar{z}}{y})$

$a^2 + b^2 = c^2$

$b = a$ when $\theta = 45°$, therefore:

$2a^2 = 1g$

$\frac{2a^2}{2} = \frac{1}{2}$

$a^2 = \frac{1}{2}$

$\sqrt{a^2} = \sqrt{\frac{1}{2}}$

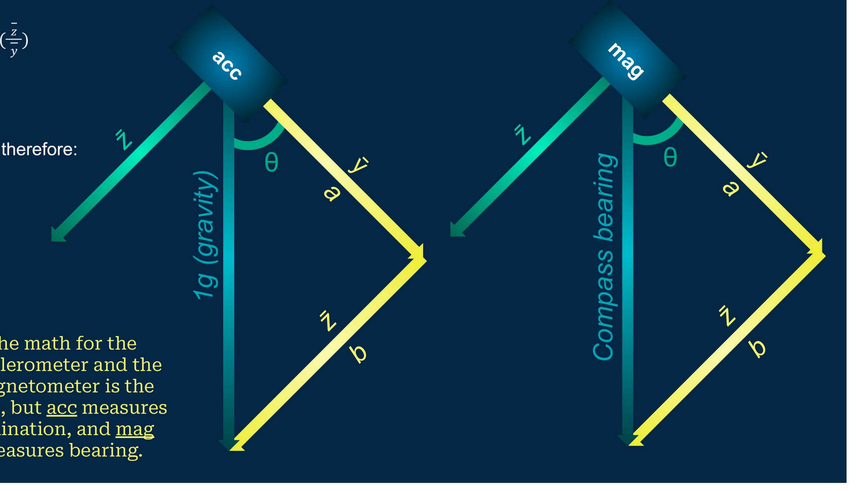
$a = \sqrt{\frac{1}{2}}$

$a = \frac{\sqrt{1}}{\sqrt{2}}$

$a = \frac{\sqrt{1} \cdot \sqrt{2}}{\sqrt{2} \cdot \sqrt{2}}$

$a = \frac{1 \cdot \sqrt{2}}{2}$

The math for the accelerometer and the magnetometer is the same, but acc measures inclination, and mag measures bearing.



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Favorite Moment

My favorite moment in the project was when the circuit boards arrived, because it was the first time that I could actually start working on making the Desktop Satellite Tracker track a satellite.

Later, I felt a real sense of accomplishment when I realized that I had been programming in C all evening without receiving help.

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Conclusion: Takeaways and Future Work

In this project I designed, built, programmed, and tested a Desktop Satellite Tracker to move a 13cm antenna to point at satellites, planets, and stars.

Problems:

The magnetometer did not always calibrate fully. This happened because either there was metal nearby which affected the measured position, or there was a bad I2C signal.

The accelerometer has a 14.2 degree error. This may be due to the fact that the chip is not level on the circuit board, or that it needs to be calibrated.

Solutions and Future Work to Expand the Project

To fix the calibration problem for the magnetometer, I can discard any bad samples and I can ignore spikes in the magnetic field.

Regarding the accelerometer, I can add a limit switch to the tube to allow for automatic calibration.

I also want to make a curriculum for teachers to use with the Desktop Satellite Tracker, to teach their students about astronomy and satellite communication.

Image Credits: Ezekiel Wheeler