Integrating Pointing Sensors for High Altitude Balloon-borne Telescope

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Introduction

The Terahertz Intensity Mapper (TIM) is an experiment to study the star formation history of the universe when the star formation rate in galaxies was at its peak. TIM will make 3D maps in far-infrared light, allowing us to peer deep into the star-forming gas in galaxies. TIM must fly on a high-altitude balloon to get above the majority of the earth's atmosphere, whose water vapor would otherwise absorb far-infrared wavelengths. This flying telescope must be able to record data and point autonomously with high accuracy. TIM flies an array of sensors to measure its orientation and motion whose signals are collated by flight computers running custom flight software to record the data and control motors determining the telescope pointing.

Methods

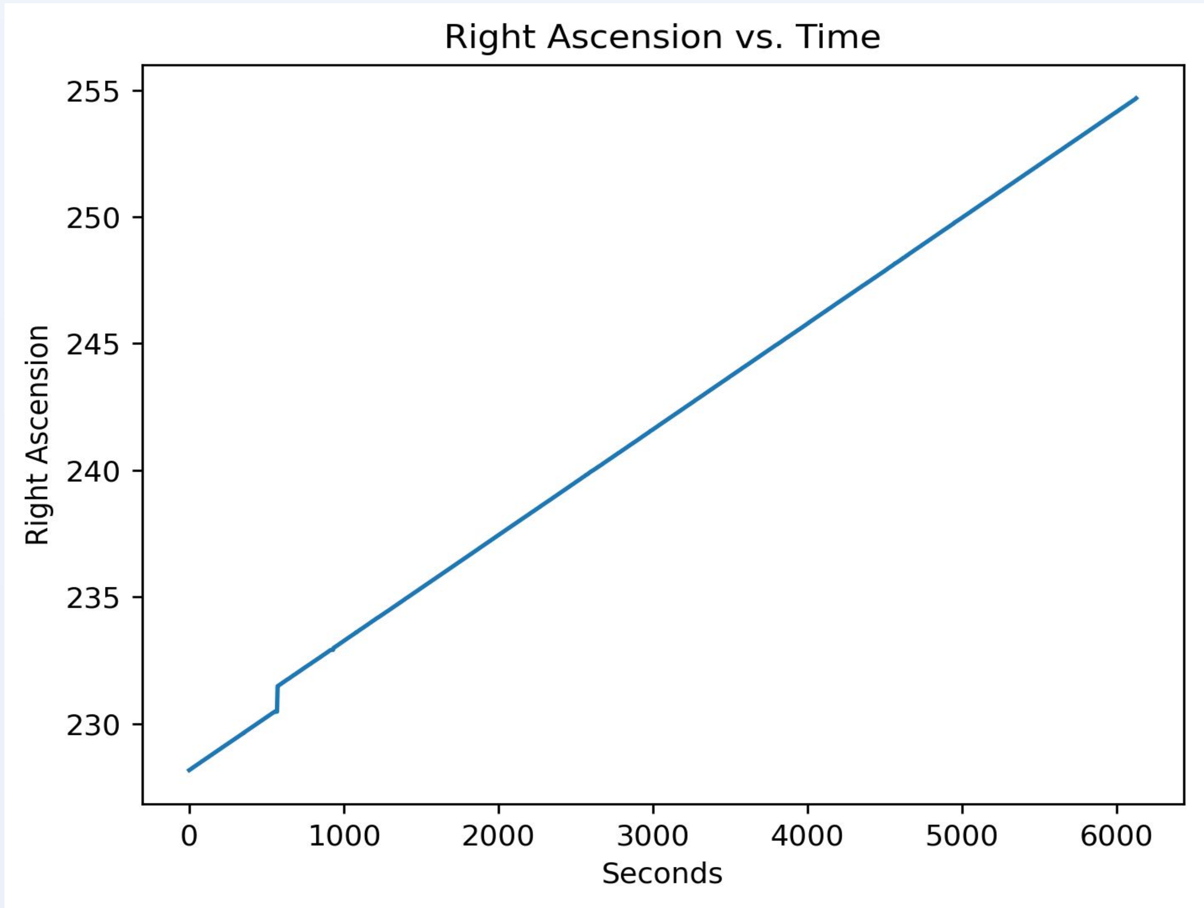
- Machined adjustments to a 4x4x6 ft steel frame to serve as a prototype gondola for TIM
- High drift sensors were mounted on dual axis rotating platform to simulate gondola movement while airborne
- Developed software in Python and C programming languages to extract sensor data and compute orientation data
- Assembled and communicated with camera and lens using C and Linux Shell
- Analyzed and plotted data using Python (Jupyter Notebook)

Absolute Sensors (Star Camera)

TIM requires an absolute sensor to verify its orientation and pointing location and adjust it accordingly. This is done through the Star Camera system, comprising of a CCD (charge-coupled device), a camera lens, and an Advantech flight computer. The Star Camera continually takes photos of the sky at its pointing location, finds the locations of stars in the photo, and runs these locations through Astrometry.net, which returns the pointing location, scale, and orientation of the image.

This system was set up and an observing session was ran on a clear night to test the Star Camera while stationary. The returned location data was plotted, and the system was verified to be working correctly. A sample plot of the location data from the observing session is shown in Figure 1 - the returned right ascension increases linearly as expected with a stationary Star Camera system.

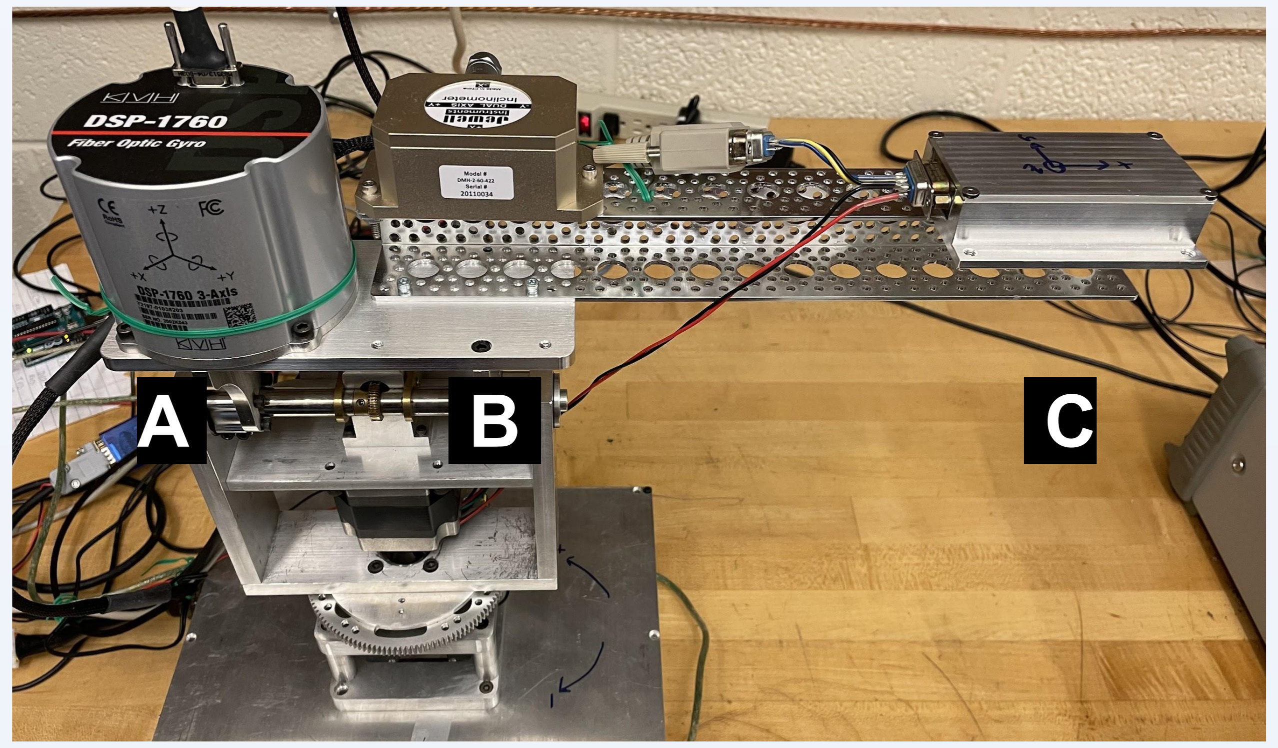
Figure 1: Observing Session Data



High Frequency Sensors

Fast sensors are continuously updated to support the slower absolute pointing sensors by providing an approximate pointing. This hierarchical scheme increases the speed of calculation and lowers risk of disorientation due to sensor failure. Figure 2 shows the sensors mounted on the experimental apparatus: fiber optic gyroscope (A), two-axis inclinometer (B), three-axis magnetometer (C).

Figure 2: Sensor mount apparatus



Software on the flight computer receives sensor data and converts it into readable format. Pointing calculations are made using data from multiple sensors (Figure 3). Data is plotted for real-time visualization while testing (Figure 3) and saved to file for post-flight analysis.

Figure 3: Heading calculation block diagram

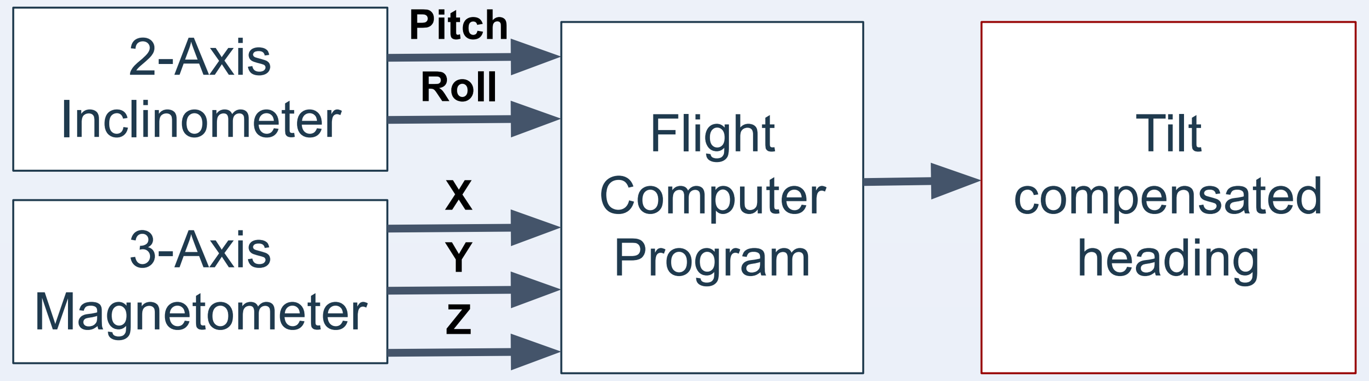
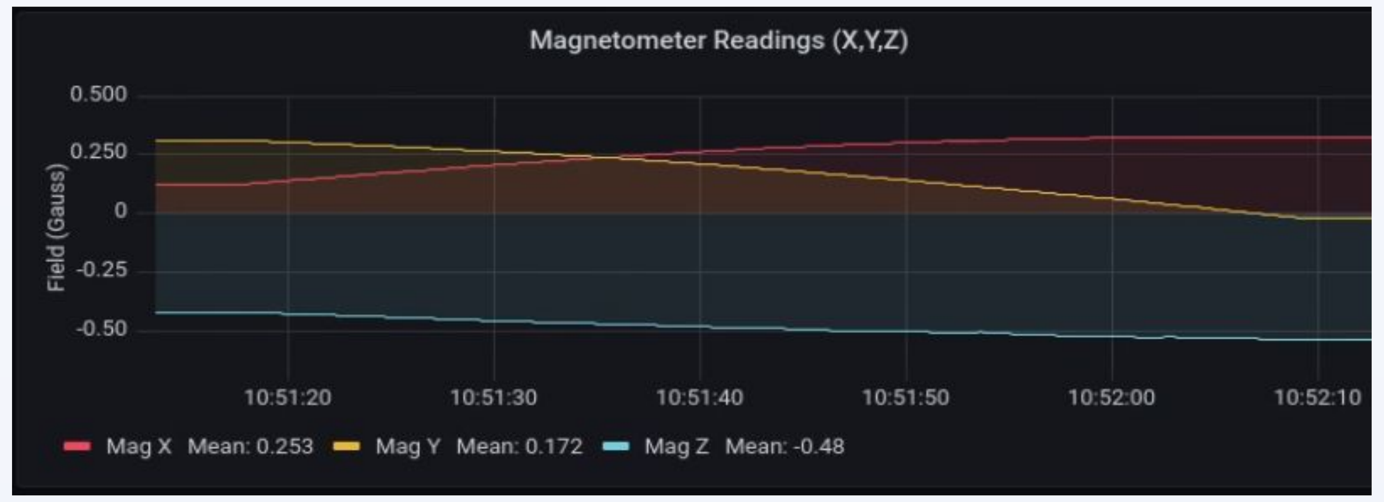


Figure 4: Magnetometer readout time-series -
Captured while rotating sensor mount in azimuth axis



Conclusion

Once these sensors systems are completed, they can be integrated with the rest of TIM. Some further improvements to be made on the Star Camera sensor system are to speed up the location solves and to increase the accuracy of the system. In addition, the high frequency sensors can be integrated with the absolute sensors to provide a faster and more accurate result.

Next Steps

For TIM, the next steps are to incorporate these sensors into the gondola frame and test them in appropriate time and weather conditions. The code for each sensor system must also be made more robust and integrated with each other. These tests and changes will be conducted in the fall and winter of 2021, and TIM itself is expected to launch around 2024.

References

1. Gandilo et al., "Probing Interstellar Grain Alignment with Balloon-borne Submillimeter Observations" (2015)
2. Caruso et al., "Applications of Magnetic Sensors for Low Cost Compass Systems"
3. DiGia, "The Design of a Star Camera for the Simons Observatory Large Aperture Telescope"