Development of Real-Time Image Stabilization and Control Systems for an Airborne Infrared Spectrometer

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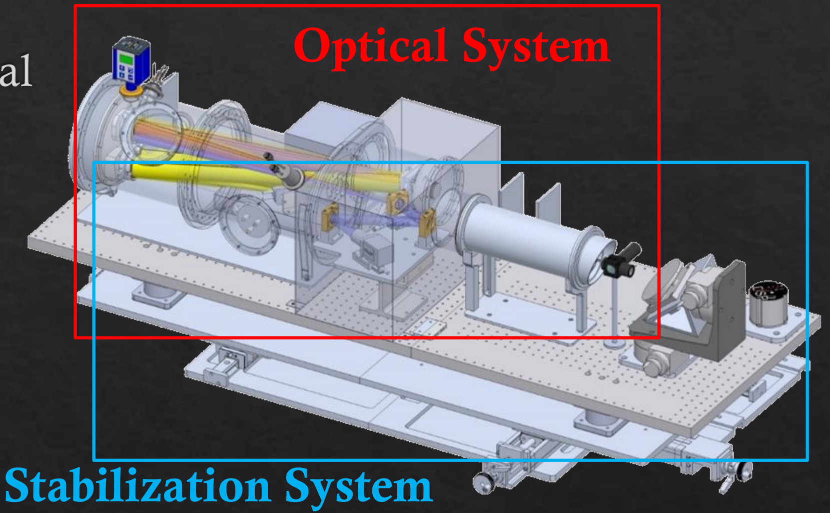
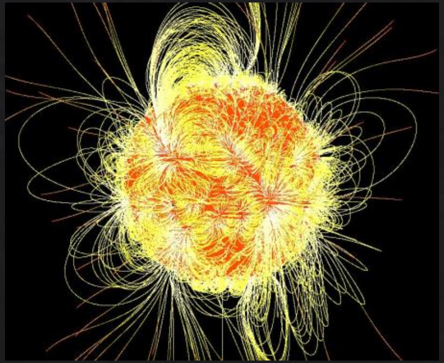
The AIR-Spec Project

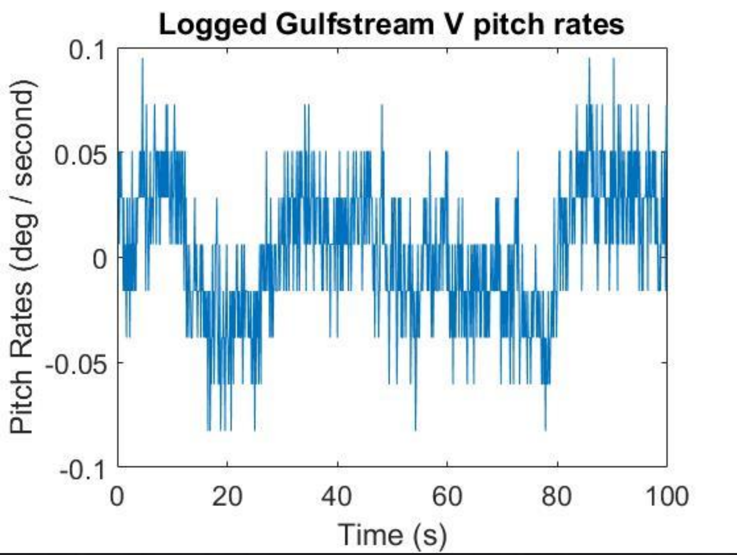
- **Experimental Overview:**
  - Study of multiple emission lines in the infrared spectrum.
  - Instrument mounted on a NCAR jet during a solar eclipse.
  - Presence of emission lines indicates viability of measuring the coronal magnetic field.
- **Scientific Impact:**
  - Magnetic field strength measurement would increase coronal model accuracy.
  - Useful parameter for studying many solar events.

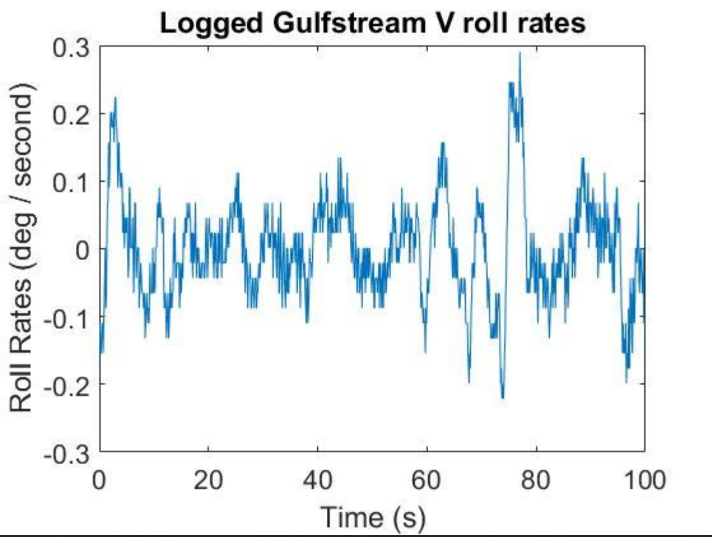


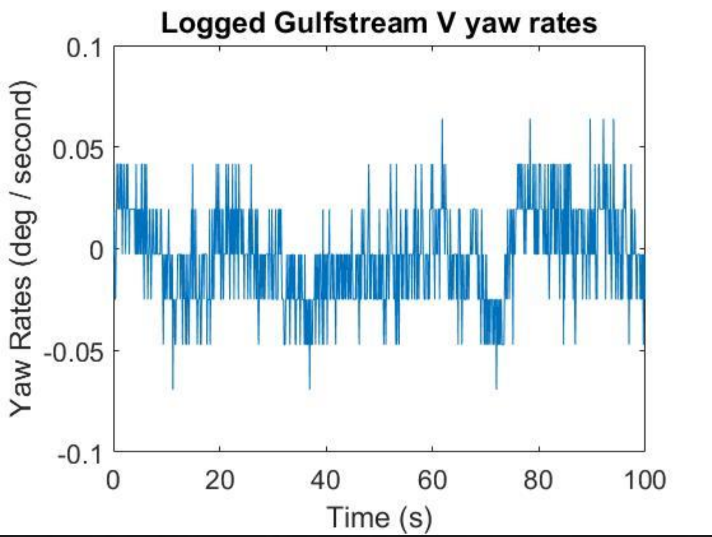


Need for Image Stabilization

- To prevent blur, AIR-Spec requires a movement standard deviation of < 2 arc seconds in a given 1 second exposure time.
- To achieve this goal, an image stabilization system is needed to compensate for the motion of the sun and aircraft.
- Must compensate for angular rates to at least 0.1 deg/sec.

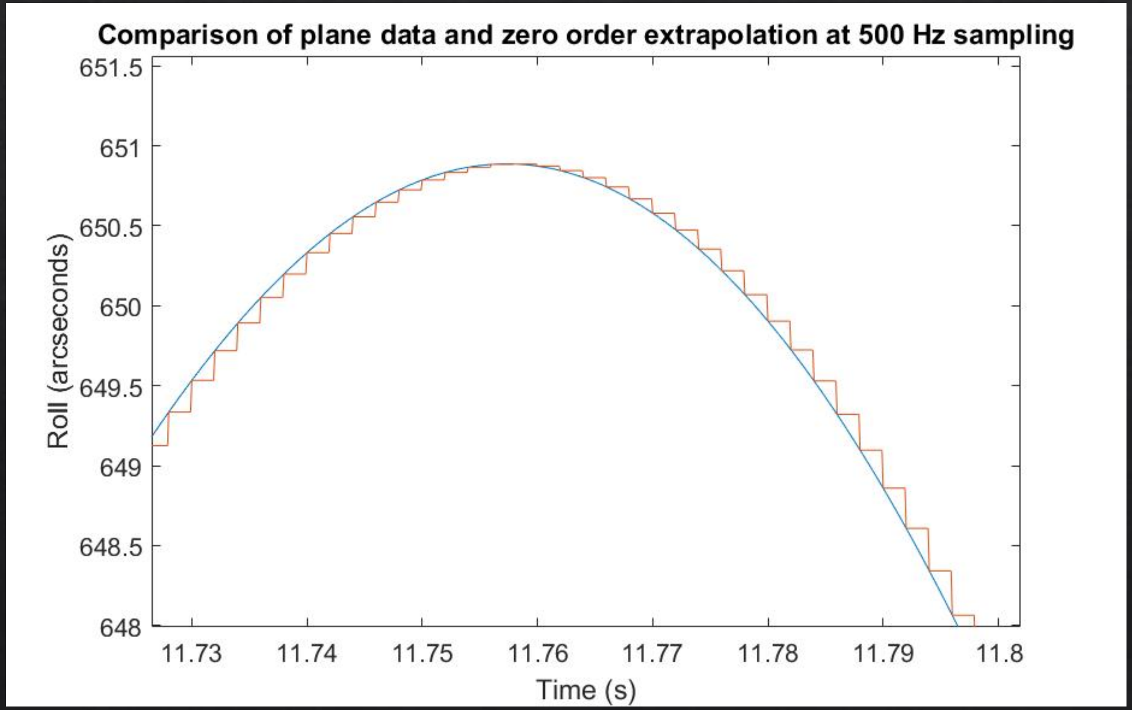




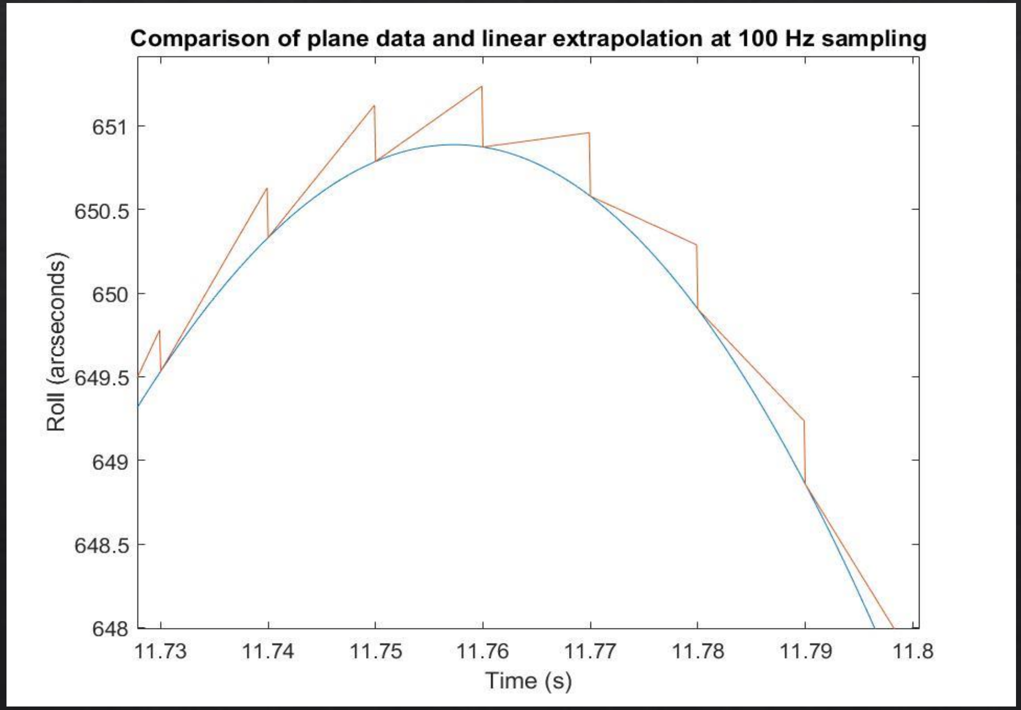


Update Rate Requirements

- Need to make sure the geometry hasn't changed significantly by the time we compensate for it.
  - Determine required image stabilization update rate.
  - Design an extrapolation algorithm to reduce update rate requirements.



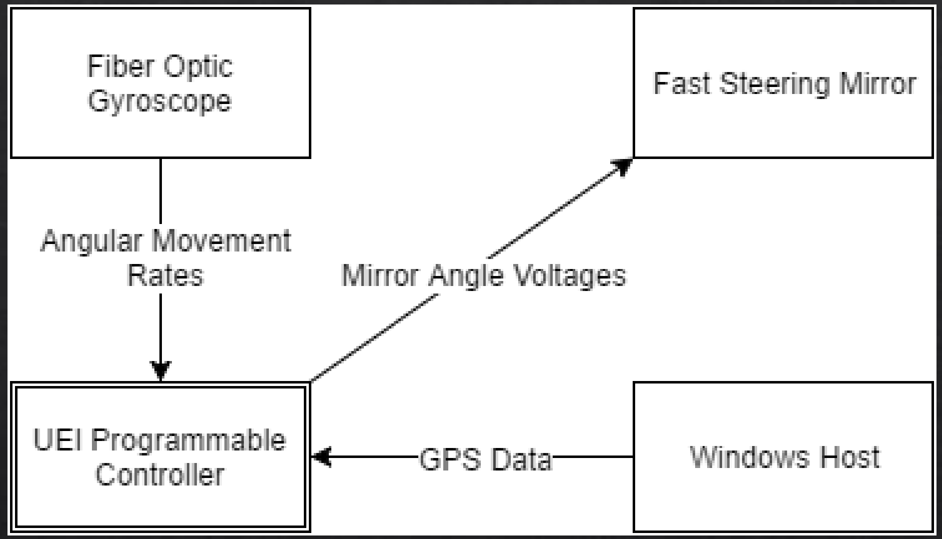
With zero-order hold, >500Hz update rate required.



With linear extrapolation, >100 Hz update rate required.

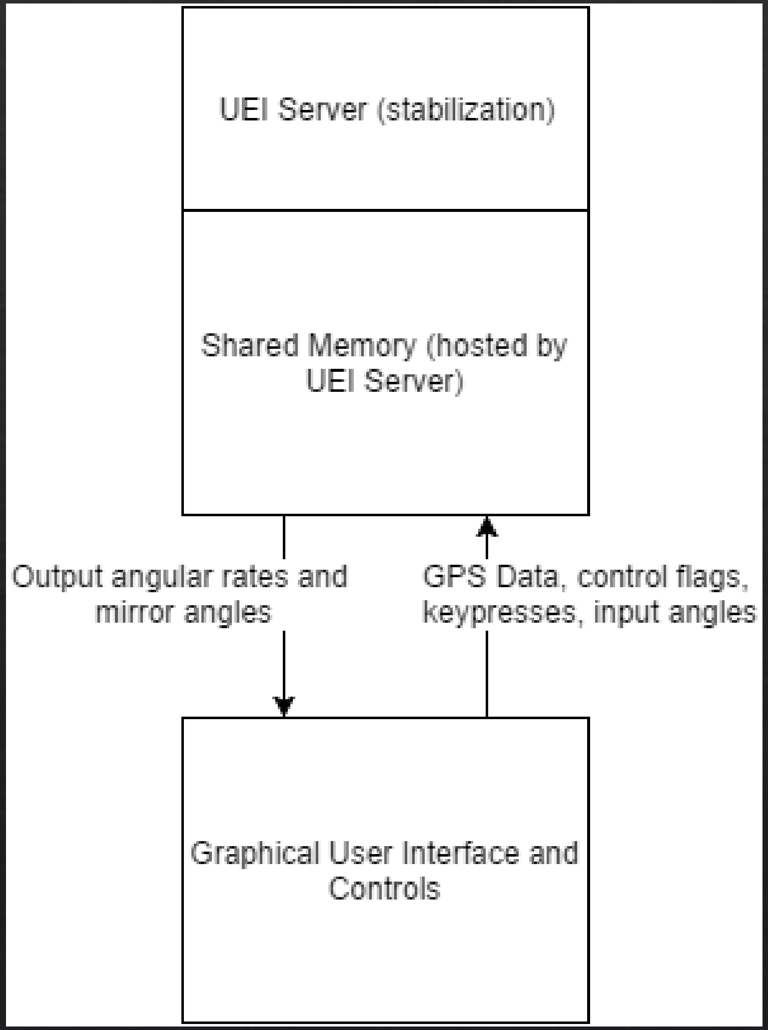
Image Stabilization System Overview

- Gyroscopic input gives angular movement rates, updated at 500 Hz.
- GPS input gives current position, updated at 20 Hz.
- Programmable controller performs calculations and input/output in real time.
- Output angle voltages are sent to the fast steering mirror.



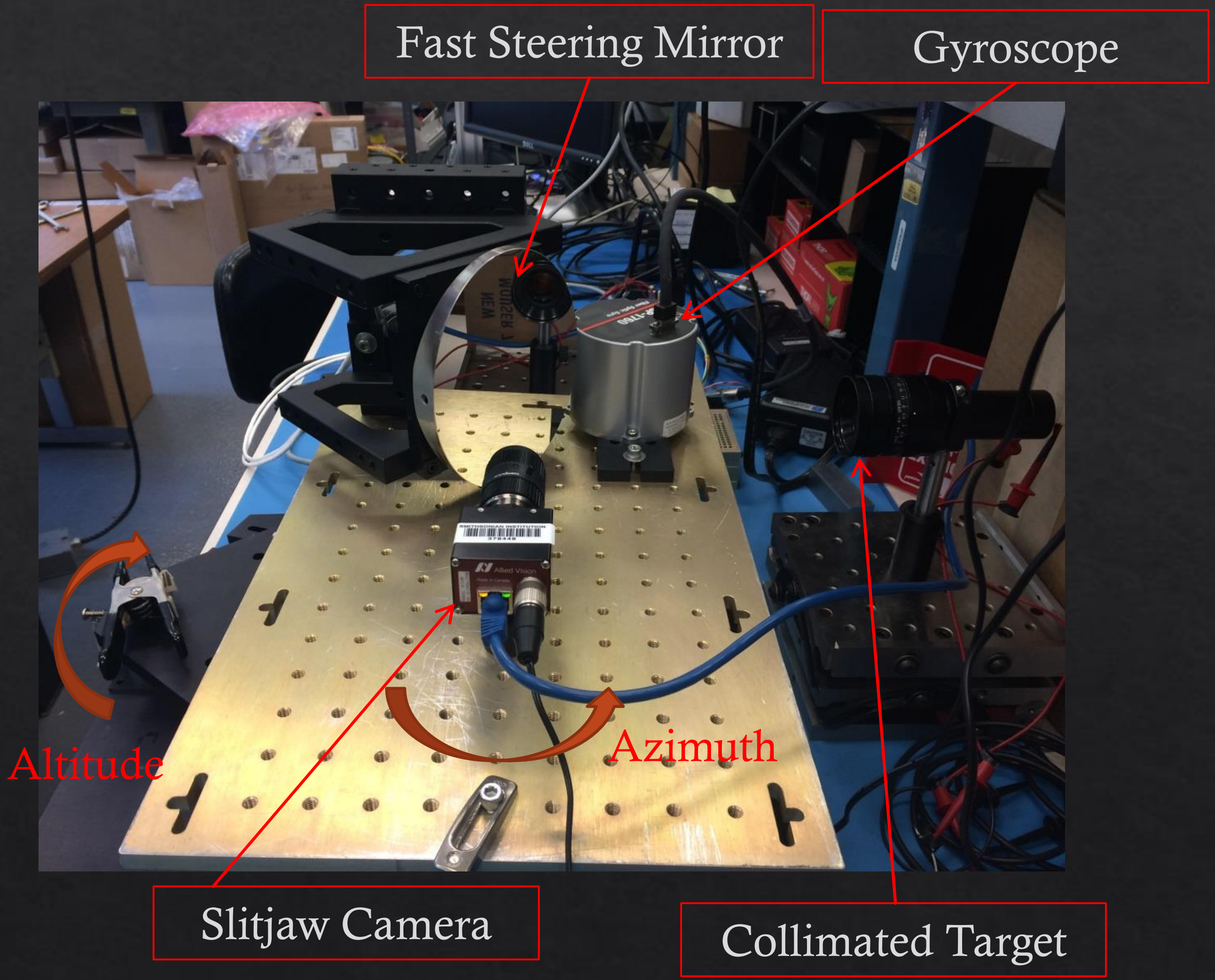
System Architecture

- Eventually, stabilization must be controlled via user interface.
  - Controls were added for:
    - Starting/Stopping stabilization.
    - Changing mirror angles with discrete steps.
    - Absolute mirror movement.
    - Inputting sun zenith and azimuth information.
    - File output.
  - All controls were handled through shared memory.

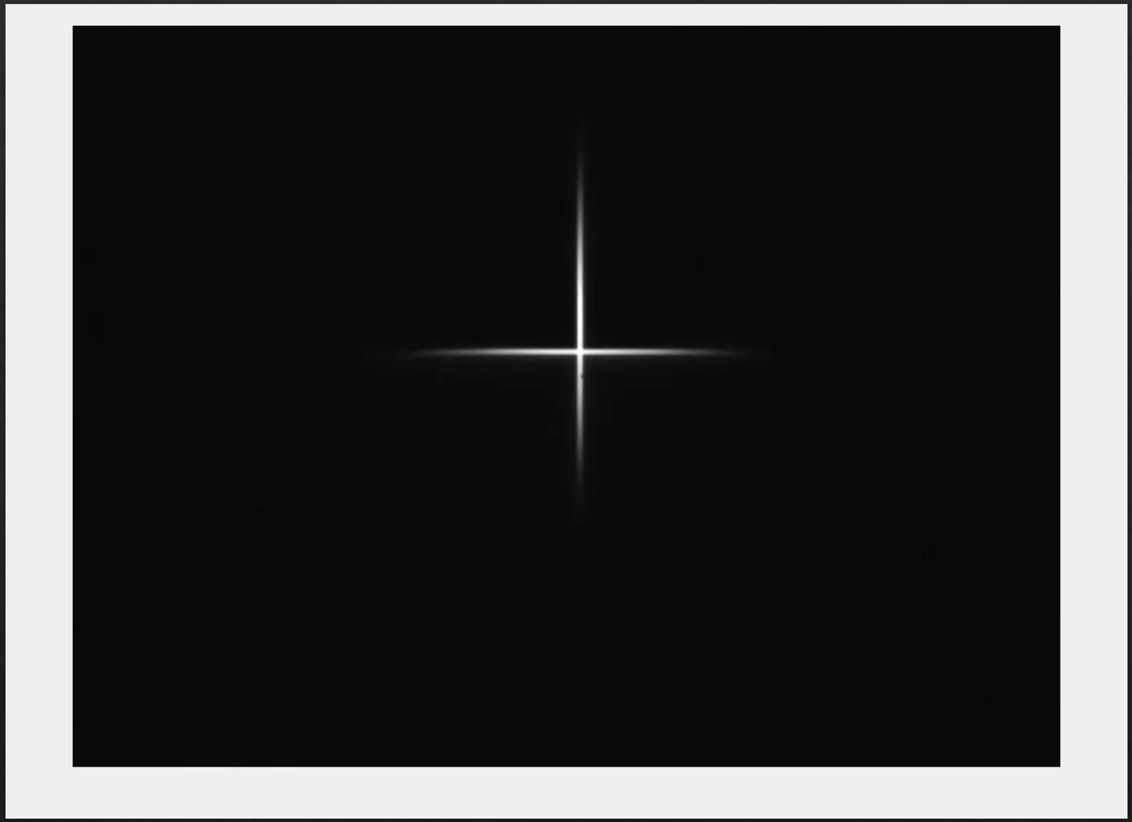


Setup for Stabilization Testing

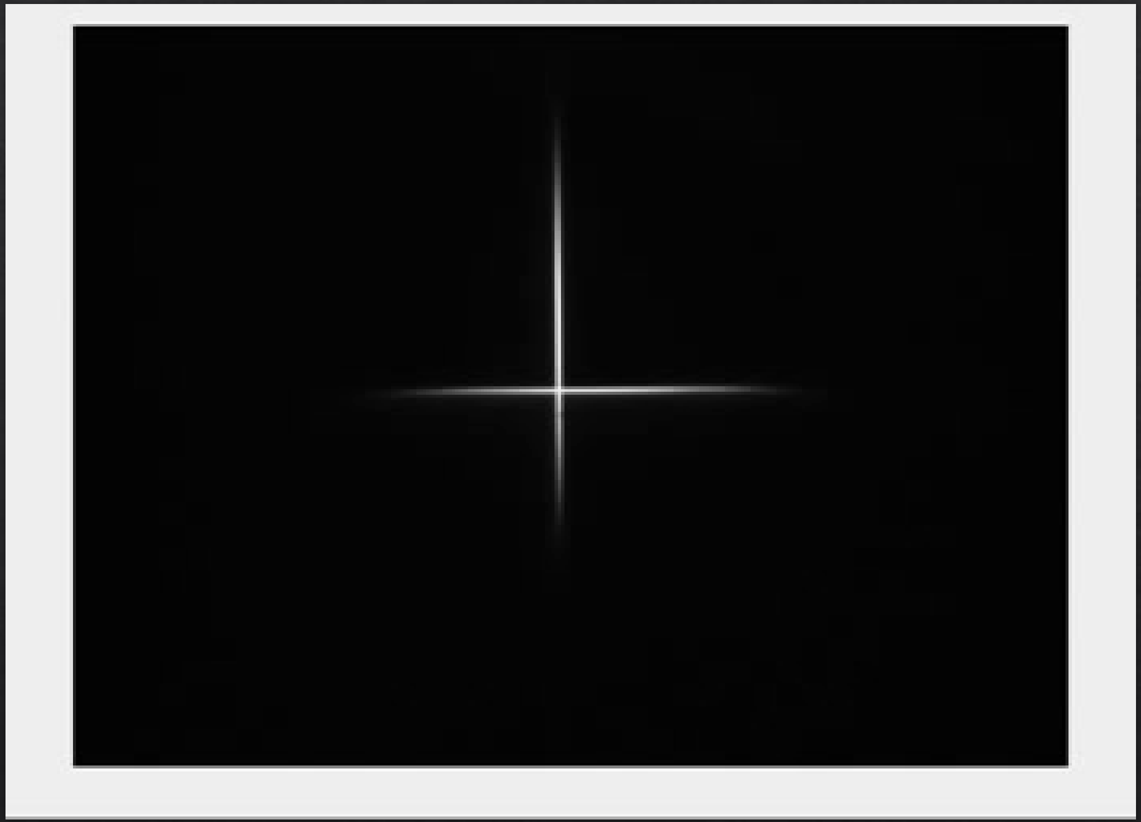
- Parts central to stabilization are mounted on a rotation stage for single axis testing, with motion in azimuth axis.
- The stage can be moved in two axes allowing for altitude adjustments.
- The target is placed at the focal length of a lens to simulate a source from infinity.



Example of Test Output



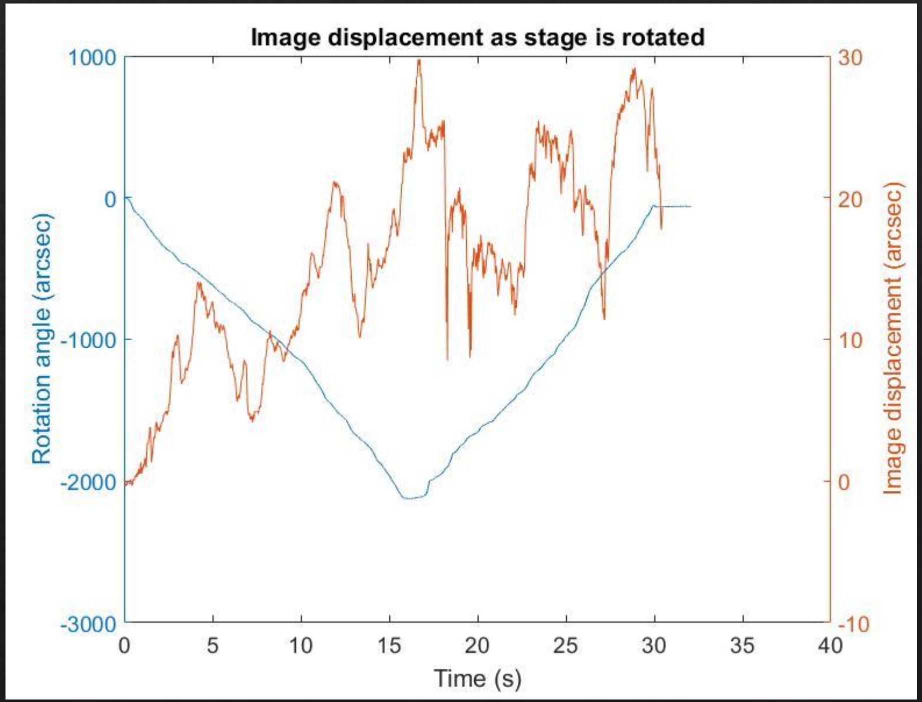
Without image stabilization

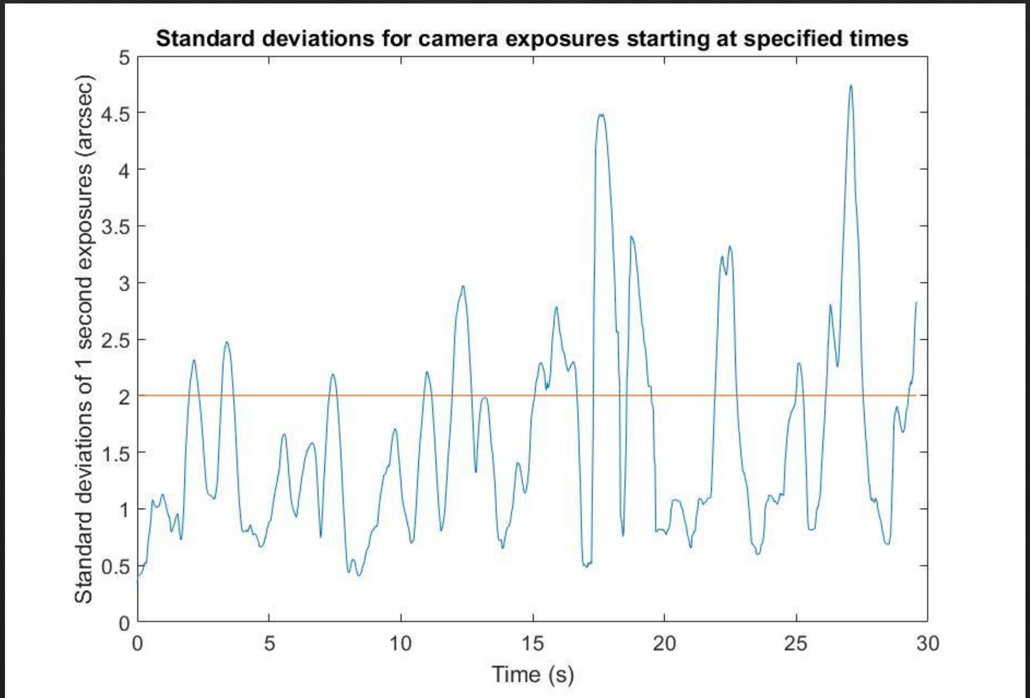


With image stabilization

Single-Axis Tests

- ❖ Simpler Math
- ❖ Initial movement of 1 degree image displacement per degree of table movement. Final effectiveness of 0.009 degrees of image displacement per degree of table movement
- ❖ 71 percent of exposure times meet 2 arc second specification.

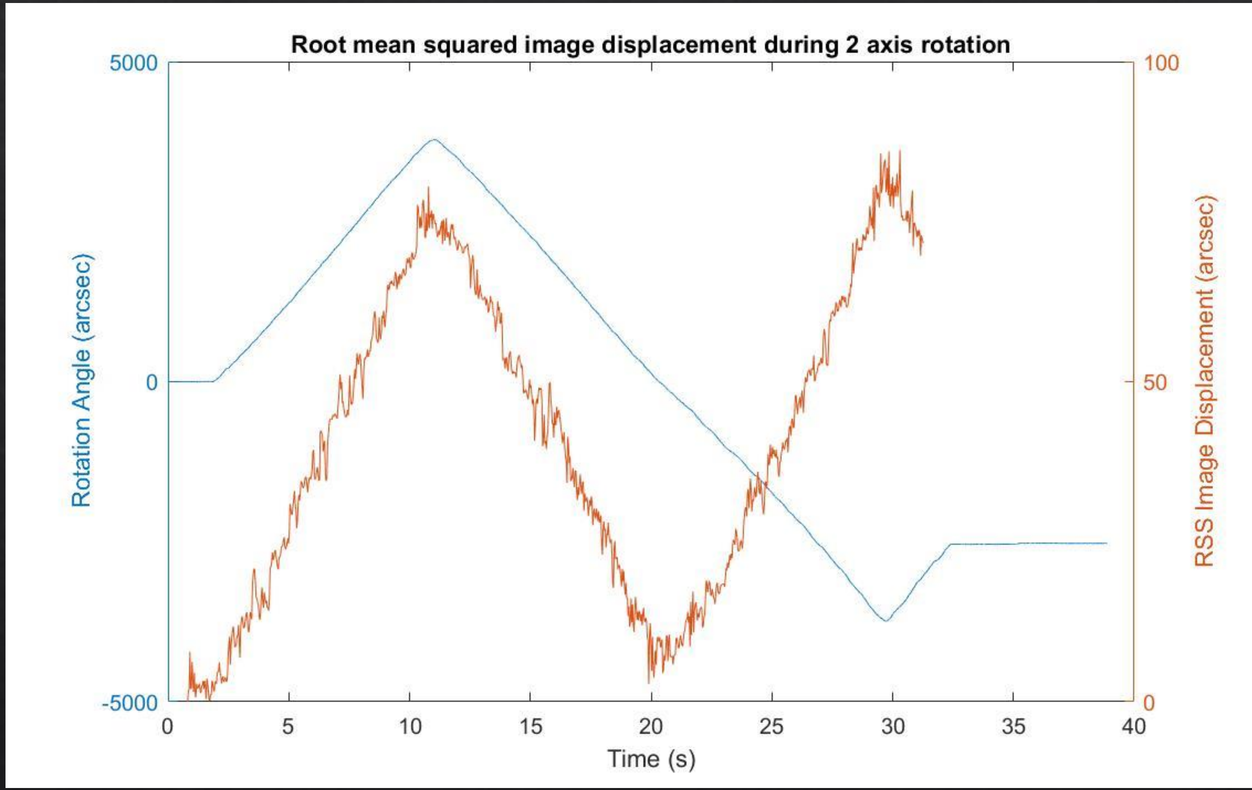


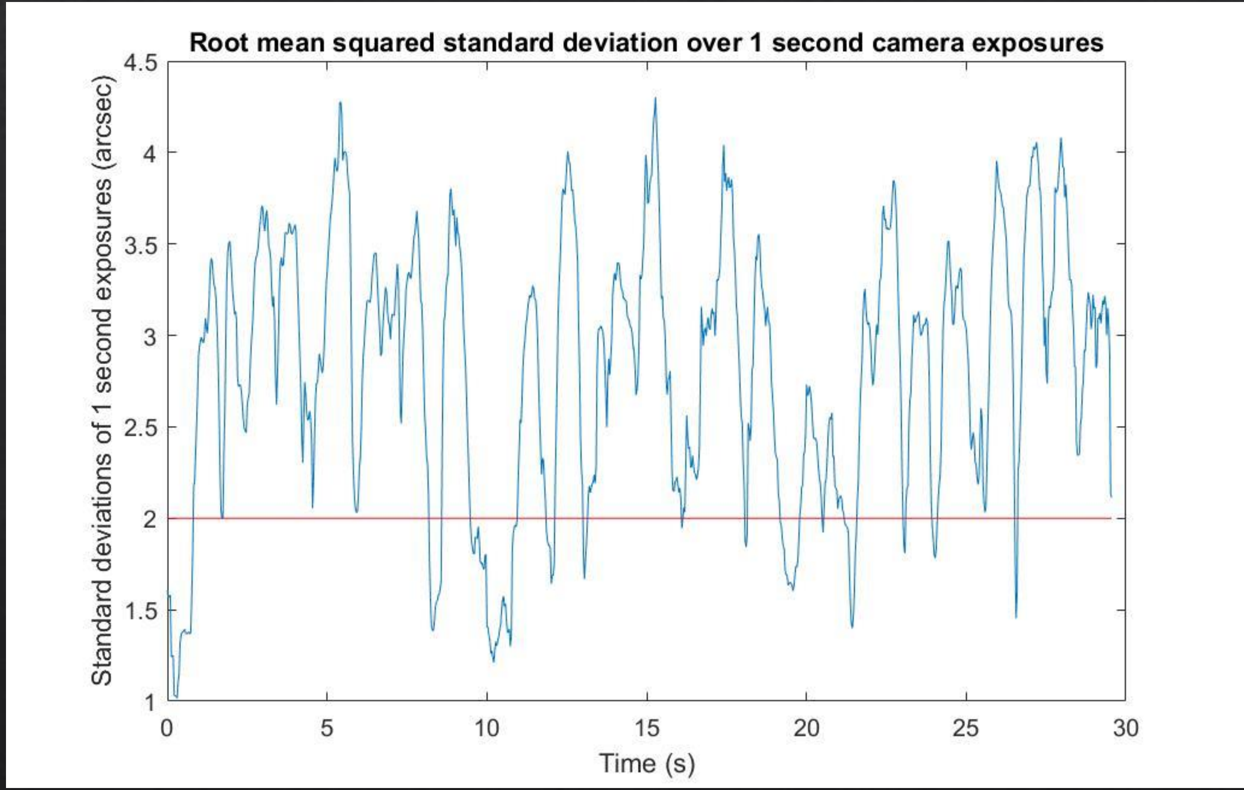


Multi-Axis Tests

- More complex math.
  - Must rotate from local telescope coordinate system to absolute coordinate system. Then, knowing position of the sun in the absolute coordinate system, mirror normal is set to bisect the angle from the telescope to the mirror to the sun.
  - Added difficulty in accounting for the rotation of the Earth.
  - This test is crucial in revealing any potential errors in mirror angle calculation.
- Harder to test – two rotation stages are needed.
- Much better simulation of actual plane motion.

Multi Axis Results

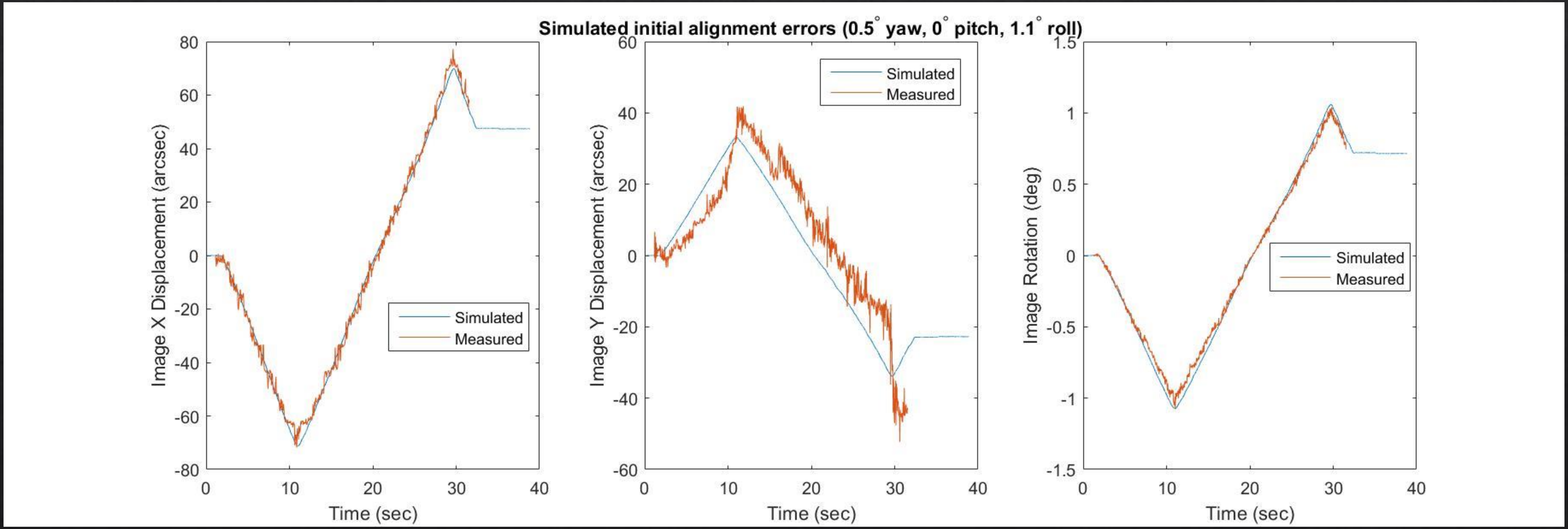




17 percent of camera exposures meet the 2 arc second deviation requirement.

Multi-Axis Errors

- There is much more error in the two axis system. Why?
- The multi-axis system is sensitive to alignment of the camera, mirror, and target.
- The final system must include a way to estimate this alignment on the fly



Summary

- Stabilization was developed for the AIR-Spec project to an accuracy sufficient for 71 percent of one second camera exposures in 1 axis and 16 percent of camera exposures in multiple axes.
- Control systems allow full interaction between the stabilization system and user interface.
- Next steps before the October 2016 flight test:
  - Measure the delay in the mirror response.
  - If needed, compensate mirror delay by tuning the mirror controller or extrapolating.
  - Implement alignment calibration tool.
  - Create image analysis tool that works for any target (not cross-hair).
  - Assemble the system in its flight configuration and test stabilization with the sun as a target.

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