Real-Time Vibration Control with Accelerometers for MagAO-X

Parker Johnson, Jared Males, and the MagAO-X team
Steward Observatory, University of Arizona

INTRODUCTION

Mechanical vibrations are a source of wavefront error that degrade image quality and limit high-contrast observations. Detecting faint companions and circumstellar structure at small angular separations requires extreme wavefront stability. The MagAO-X instrument strives to deliver diffraction limited imaging, but is hindered by structural disturbances. In addition, nanometer to micron level motion in optics can translate to milliarcsecond motion in our science cameras. This project integrates accelerometers with the Clay Magellan Telescope, and MagAO-X, to directly measure vibrations and aims to feed them into MagAO-X's control loop for real time correction of tip, tilt, and focus.

Research Goal

Develop a sensor fusion approach using accelerometer data in MagAO-X's predictive control to reduce vibrations and enhance image quality.

METHODS

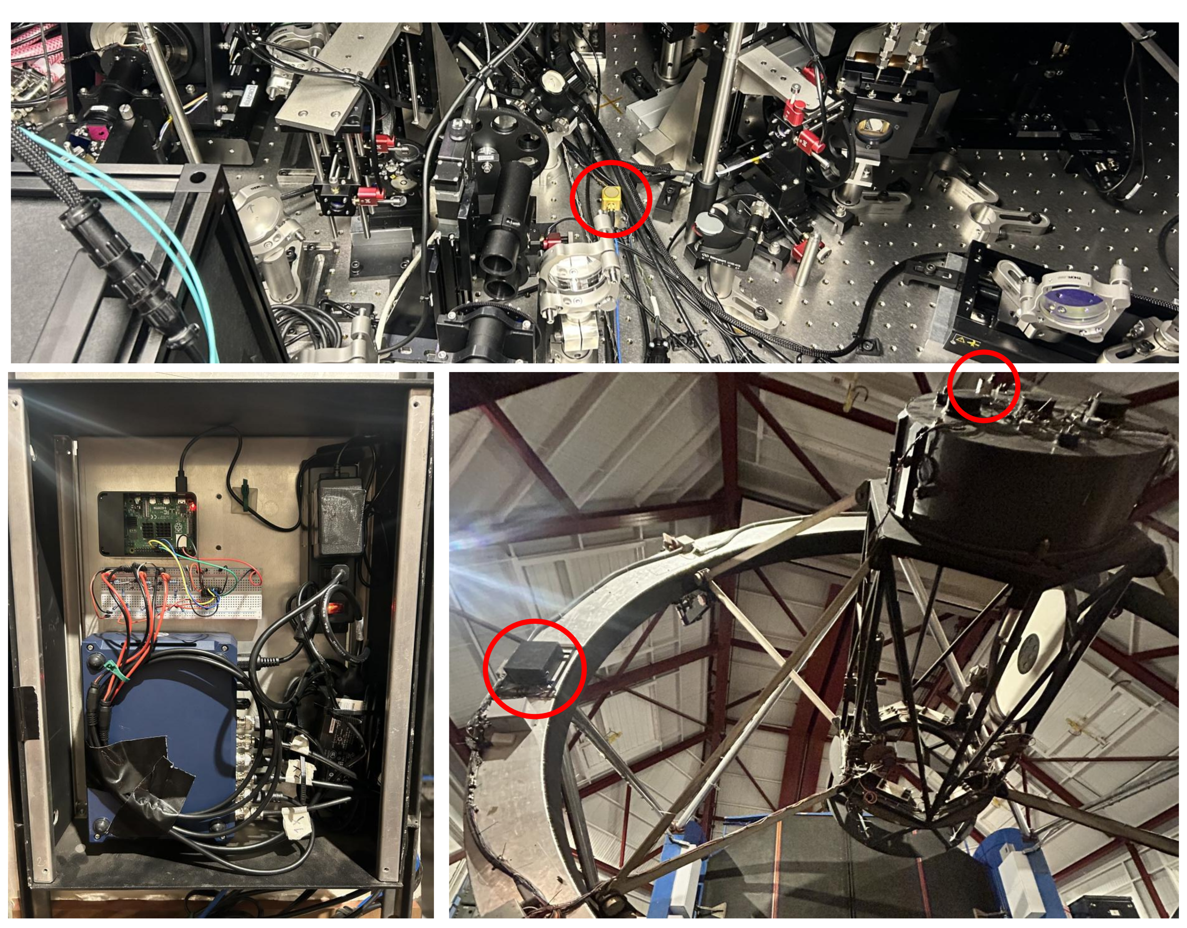

Fig 1: Top – Accelerometer magnetically mounted on MagAO-X. Left – Electronics box for signal acquisition. Right – Clay Magellan Telescope with electronics box (left circle) and three accelerometers (right circle) mounted behind the secondary mirror.

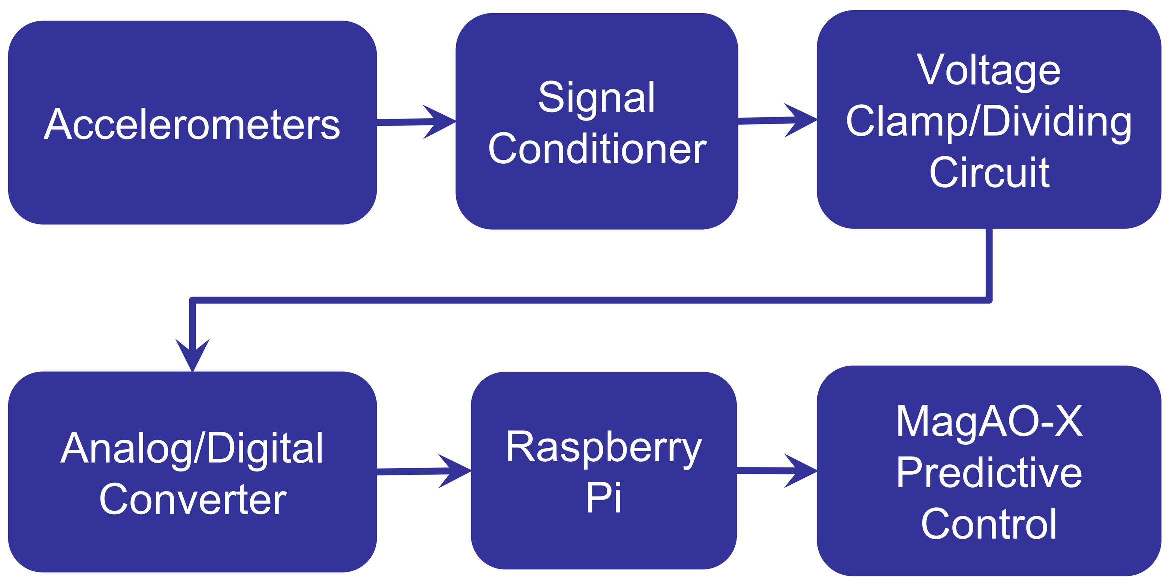

Fig 2: Flow chart for signal acquisition pipeline.

RESULTS

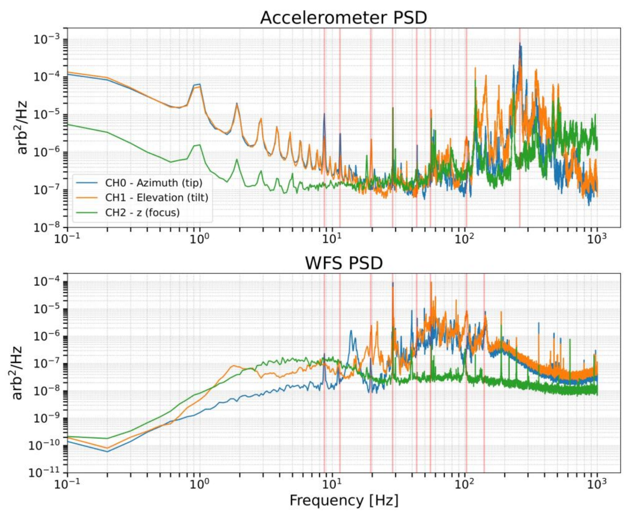

Fig 4: PSDs from 5 minutes of data. Simulations confirm low-frequency spikes in the accelerometer PSD result from circuit-induced offsets, mimicking a low-amplitude square wave.

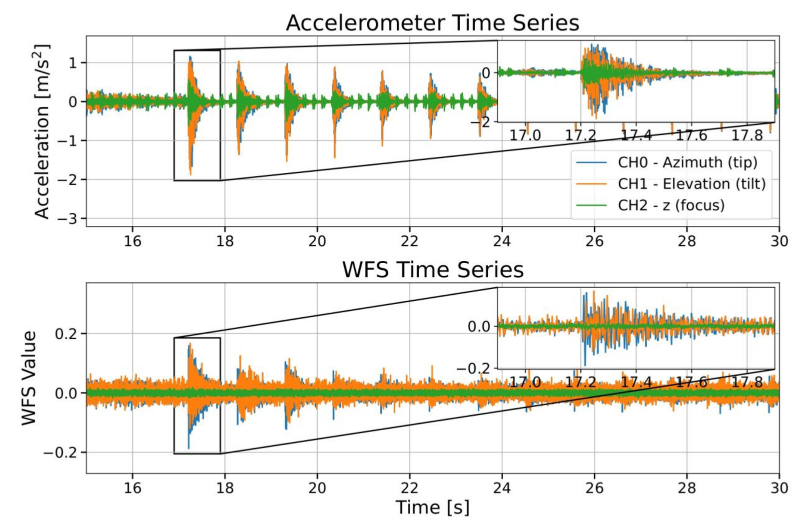

Fig 3: Time series showing periodic 1Hz spikes. Zoom reveals high-frequency oscillations (260Hz in the accelerometer, 140Hz in the WFS), consistent with prominent peaks in their respective PSDs.

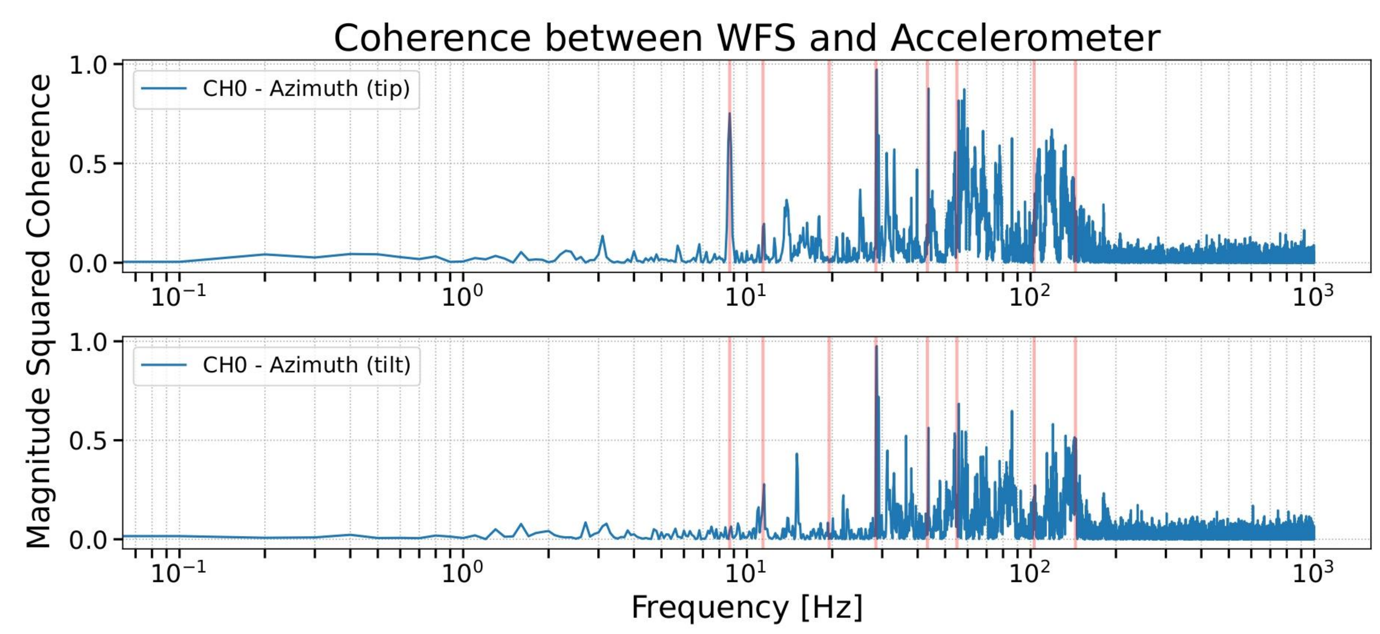

Fig 5: Coherence between the azimuth accelerometer and WFS tip/tilt shows ~ 35% of WFS variance is explained by mechanical vibrations.

Coherence defined as: $C_{xy}(f) = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)}$

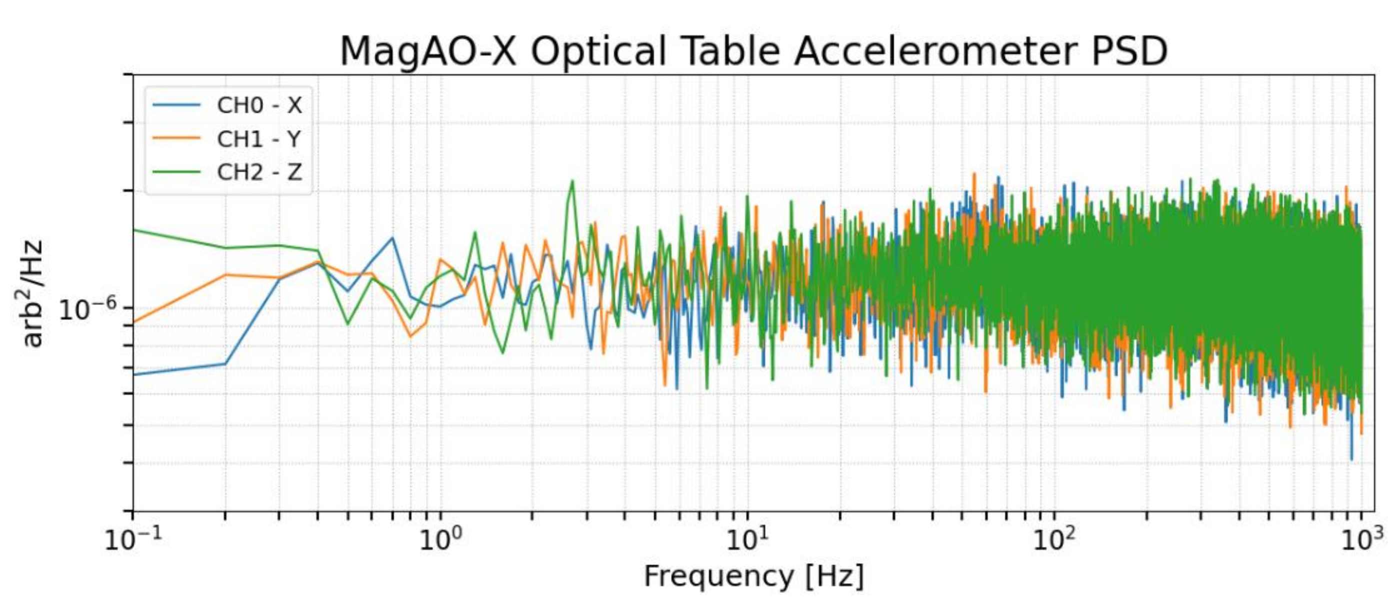

Fig 6: PSD of the three-axis accelerometer on MagAO-X's optical table.

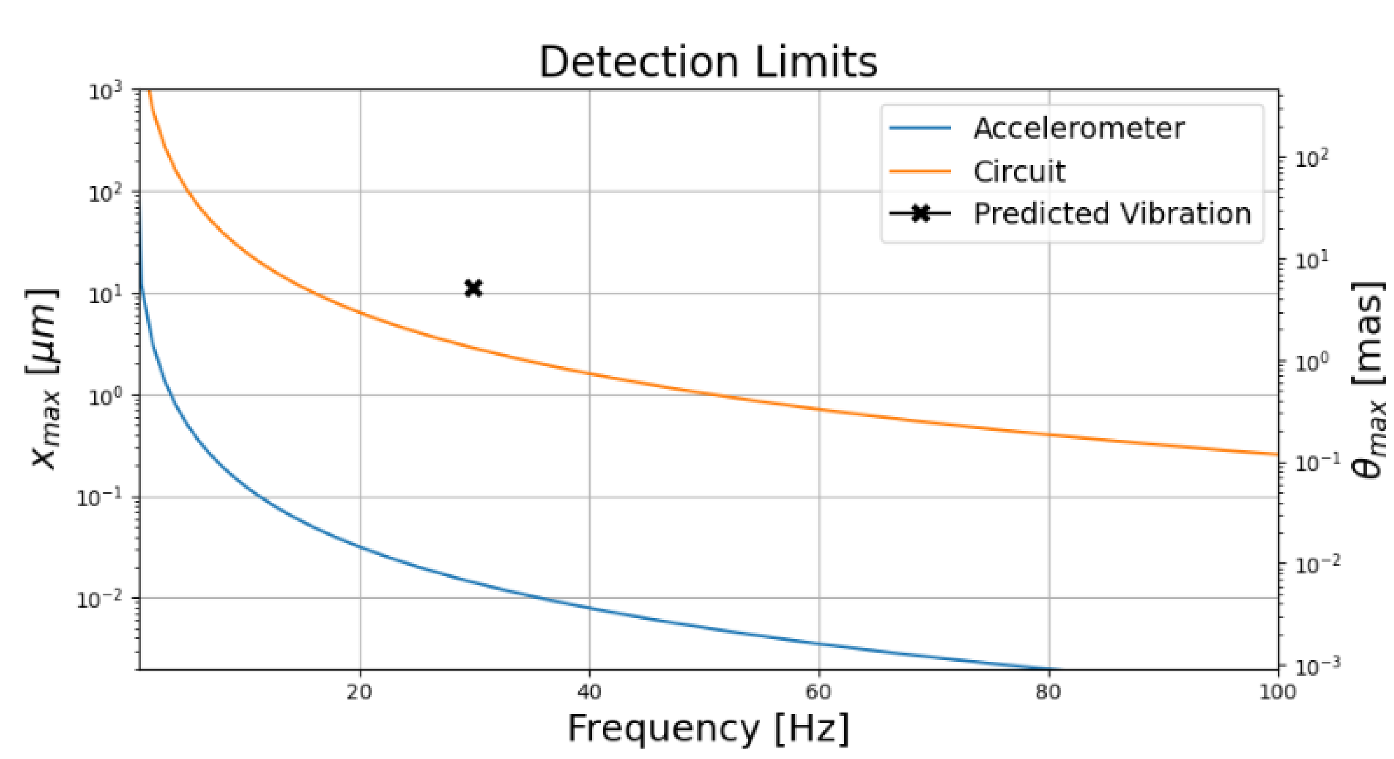

Fig 7: We observe 5 mas jitter at 30Hz in our science camera. The sensitivity curves rule out bulk camera motion as the primary cause. The jitter we observe is likely a result of bench seeing or opto-mechanical amplification.

CONCLUSIONS

1. **Successfully built vibration sensing pipeline**
2. **Accelerometer and WFS data are correlated**
3. **Ruled out motion in the focal plane**
4. **Designed and manufactured PCB**
5. **Identified and mitigated telescope vibrations**
   - **0.2Hz: caused by pressure vacuum control support for secondary**
   - **1Hz : caused by vane end actuation system**

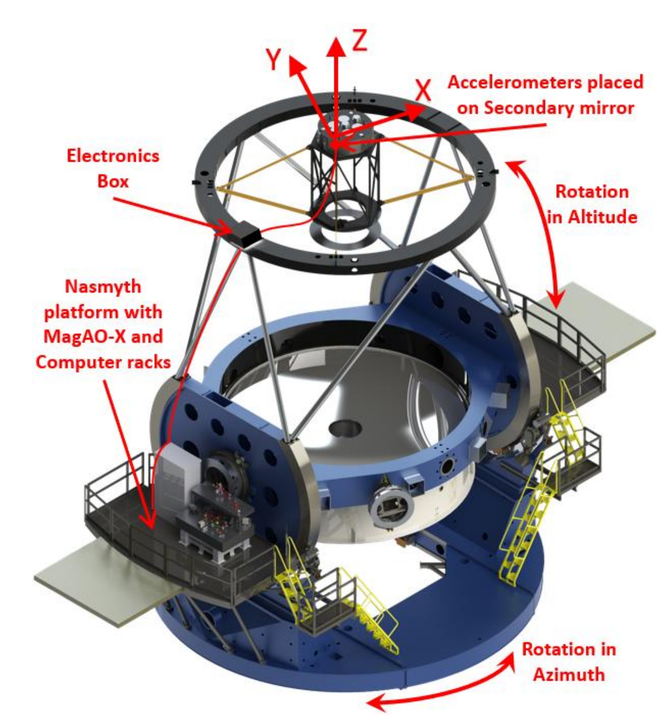

Fig 8: Clay Magellan rendering displaying MagAO-X along with the positioning of the three-axis accelerometer mounting position.

Key Takeaway

This work validates accelerometers as wavefront error predictors and enables robust vibration mitigation for current and future AO systems, including GMT.

FUTURE WORK

1. **Simulate and Implement Multi-Rate Kalman Filter**
2. **Implement and improve PCB**
3. **Add additional accelerometers**

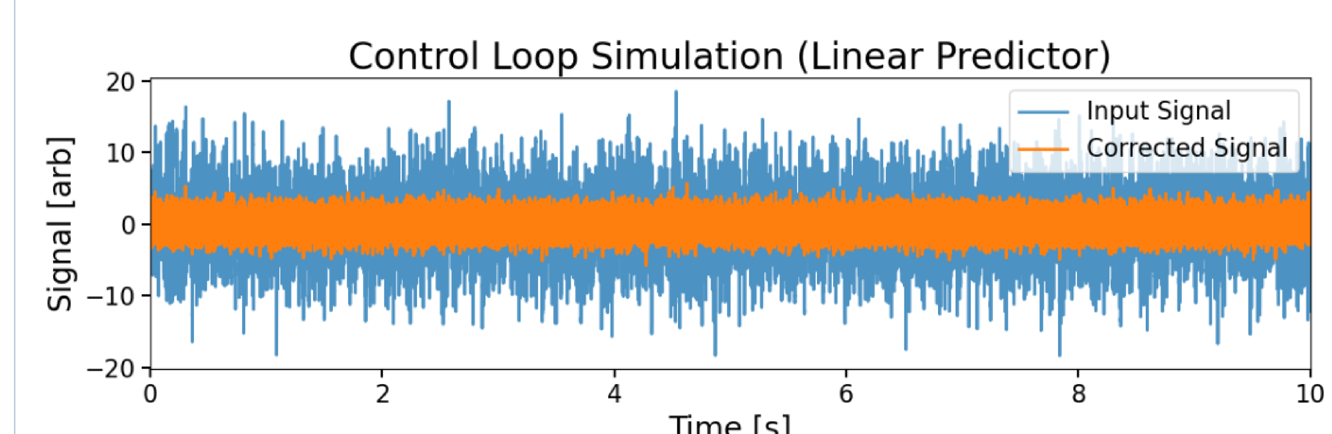

Fig 9: Simulated WFS input and corrected signals using a linear predictor control loop [2]. The corrected signal shows reduced wavefront error after applying DM commands.

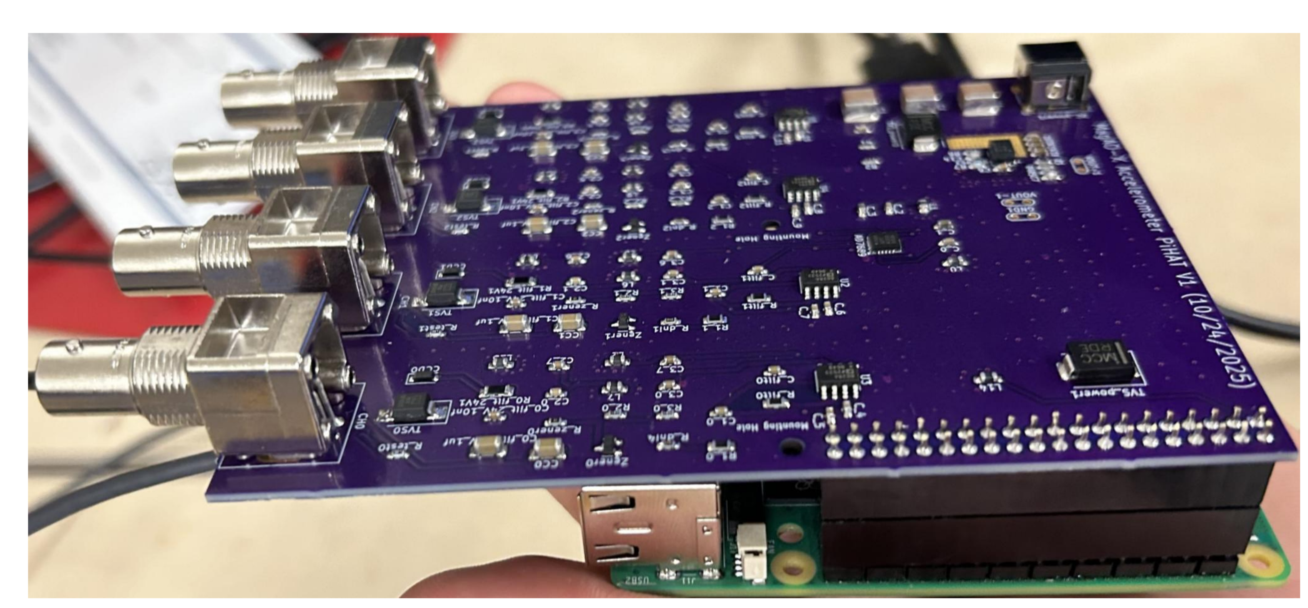

Fig 10: PCB prototype mounted on a Raspberry Pi as a PiHAT to act as the power source, signal conditioner, ADC, and protection circuit

Acknowledgements

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References

[1] Guyon & Males 2017, *Adaptive optics predictive control with empirical orthogonal functions*
[2] Males & Guyon 2018, *Ground-based adaptive optics coronagraphic performance under closed-loop predictive control*
[3] Lozi et al. 2016, *Characterizing and mitigating vibrations for SCExAO*