Using a MEMS Inertial Measurement Unit for Planetary Gravimetry.

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GOAL

- Test a proof-of-concept sensor package, named HELIX, that utilizes the triaxial accelerometers of a micro-electromechanical (MEMS) inertial measurement unit (IMU) to measure gravitational anomalies produced by subsurface structures (inertial gravimetry).

Inertial Gravimetry Overview

- First survey using an IMU was conducted in 1995 over the Rocky Mountains [1].
- First extraterrestrial survey using an IMU performed on Mars using MEMS accelerometers on Curiosity Rover IMUs [2].
- Development over the last two decades has mostly focused on geodetic applications and has proven to be an effective, low-cost alternative to traditional gravimeters [3].
- Major drawback is poor long-term stability.
- Raw measurements typically have insufficient accuracy for geophysical applications, necessitating the need for proper calibrations and signal processing procedures.

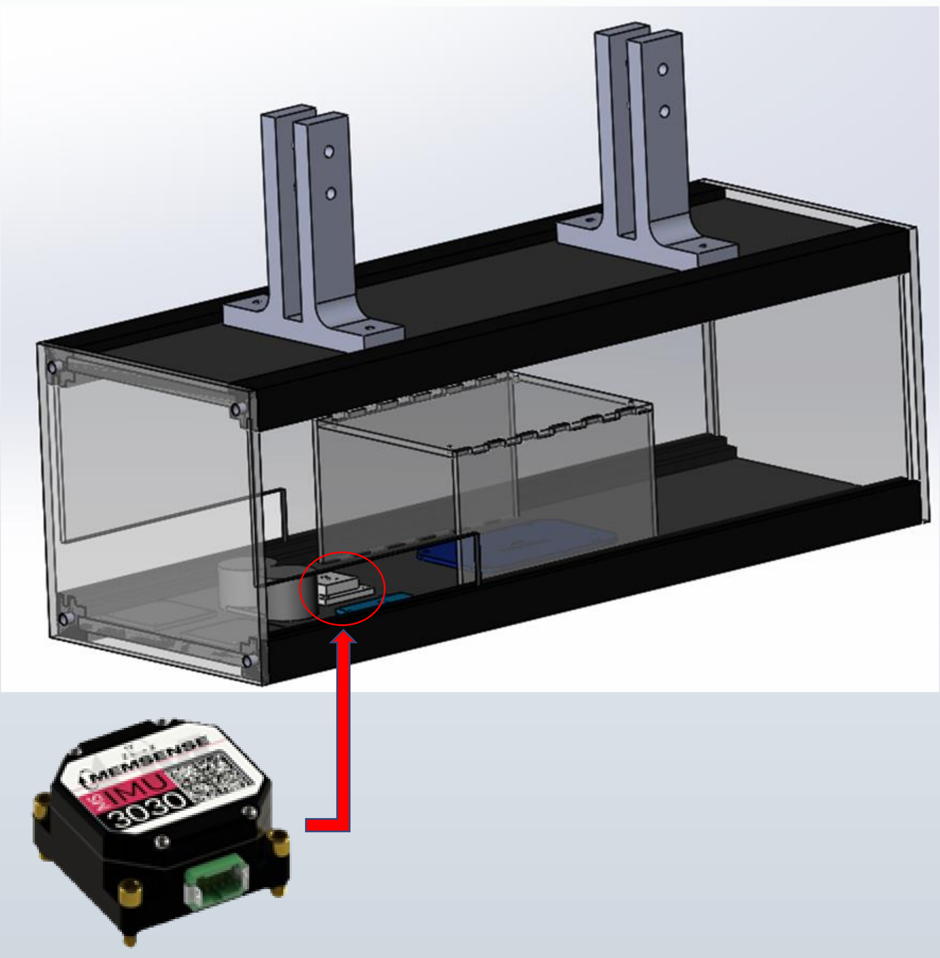

Figure 1: IMU position within mechanical enclosure.

Instrument Background

- Low-drift IMU-3030 manufactured by MEMSense.
- Groves GPS module.
- Internal and external temperature sensors.
- Originally designed to be a balloon-mounted system. However, to provide a more stabilized platform, will instead be mounted to a rover for ground-based surveys, which have shown resolutions suitable for geophysical purposes [2,4].

Internal Error Parameters

- Inherent systematic errors in silicon IMUs include offset biases and scale factors along each axis which can be modeled deterministically [5].
- When negating stochastic errors, the output of the accelerometers can be modeled with eq. 1 where, b_i and s_i are the bias and scale errors acting on the true acceleration measurement a_i.
- A mathematical model of the system can be established as a function of the raw accelerometer outputs and the corresponding errors as shown in eq. 2. Where, p is a 1 x 6 vector of the error parameters [6].
- Using eq. 2 with the fact that the output should equal the normal gravity at the survey location, the error parameters can be solved for with eq. 3. Where, $\widehat{p}(-)$ is the previous error estimate and, g is the normal gravity [6].

$$\begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix} = \begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & s_z \end{bmatrix} \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} + \begin{bmatrix} b_x \\ b_y \\ b_z \end{bmatrix} \qquad (1)$$

$$h(A,p) = \sqrt{\left(\frac{A_x - b_x}{s_x}\right)^2 + \left(\frac{A_y - b_y}{s_y}\right)^2 + \left(\frac{A_z - b_z}{s_z}\right)^2} \qquad (2)$$

$$g - h(A, \widehat{p}(-)) = \frac{\partial h(A,p)}{\partial p}\Big|_{p-\widehat{p}(-)} \qquad (3)$$

External Error Parameters

- Many IMUs are subject to temperature drifts [2,7].
- Laboratory data indicates that the output of HELIX accelerometers are heavily dependent on ambient temperature. Horizontal accelerometers show a correlation with internal IMU temperature.
- Temperature effects for the vertical accelerometer can be modeled with a regression polynomial.
- 4th degree polynomial shows best fit, higher orders have negligible effect on goodness-of-fit.
- Multiple polynomial regression can be used to model both the internal and ambient temperature effects on the horizontal accelerometers.

Noise Parameters

- Low signal-to-noise ratio of the system means that the calibrated results will not be sufficient enough to measure small changes in gravity.
- Can be overcome in two steps: 1) Smoothing/filtering to average high-frequency noise and 2) use wavelet shrinkage denoising to reduce noise and improve the signal-to-noise ratio [8].

Field Test

- The initial test site for HELIX will be the High Island Salt Dome located southeast of Houston, Texas.
- Salt domes are diapiric structures that migrate upward through the subsurface due to density differences with the surrounding rock. This difference should provide an apparent gravity anomaly.
- Control data will be interpolated from National Geodetic Survey gravity data for ground-truthing [9].

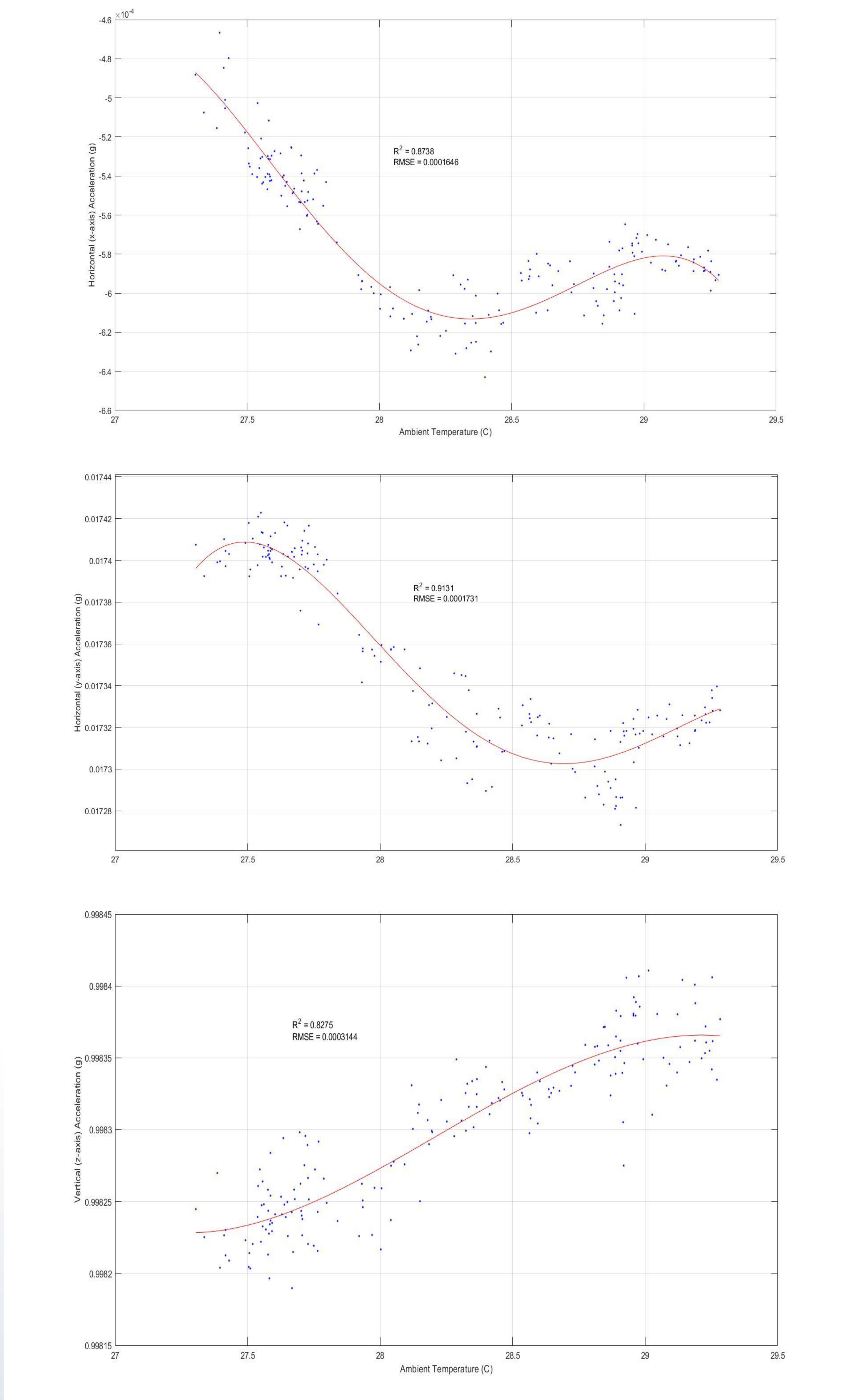

Figure 2: Accelerometer temperature dependencies over 23 hours averaged into 5 minute intervals.

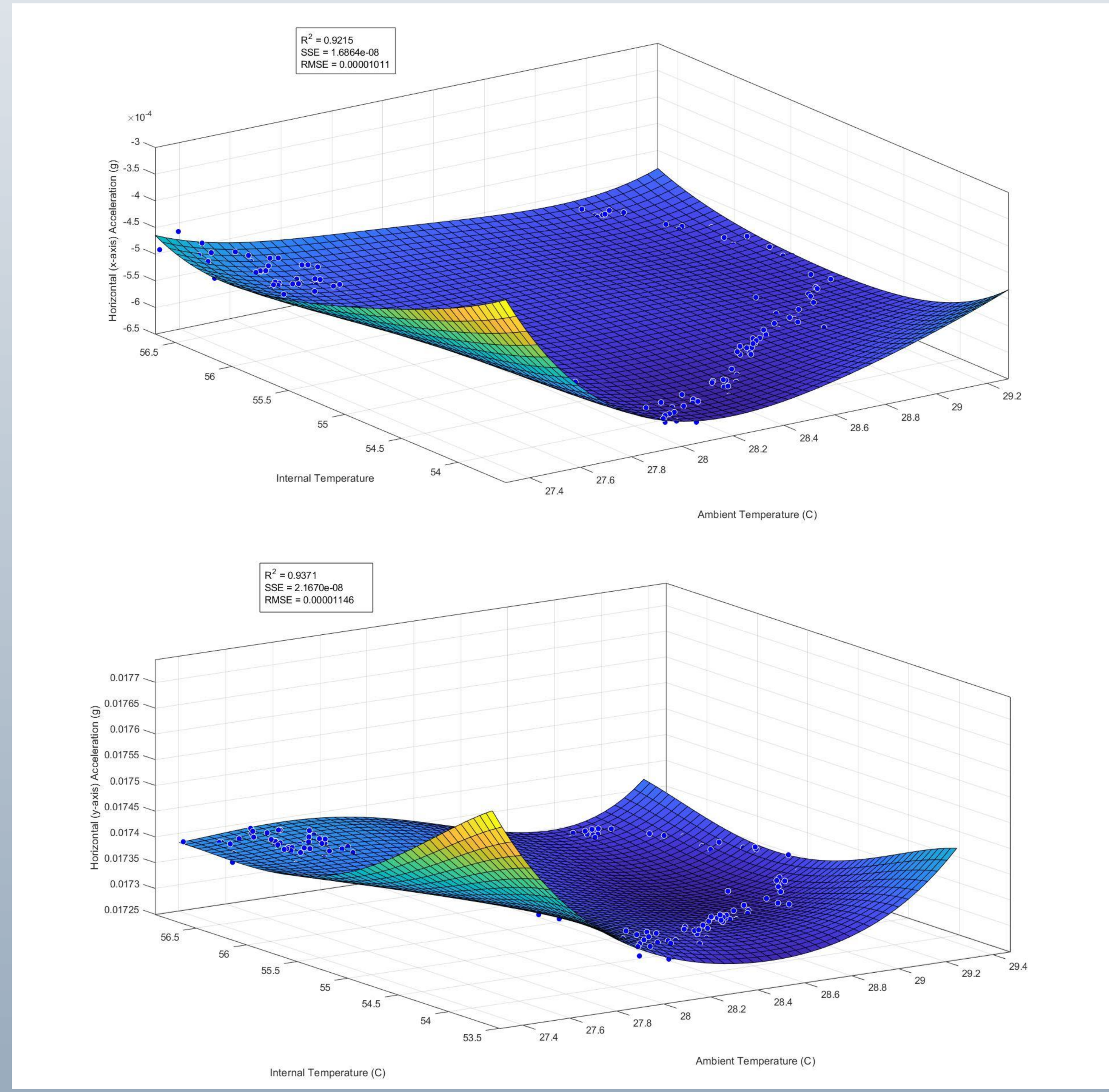

Figure 3: Horizontal axes improved temperature models.

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