Surface Gravimetry Using Rover Navigation Systems. C. S. Lawson[1,2], P. D. Ilhardt[1,2], A. H. Stoken[1,2], M. E. Evans[2] [1]Jacobs Technology/JETS II 2101 E NASA Pkwy, Houston, TX 77058, [2]NASA Johnson Space Center 2101 E NASA Pkwy, Houston, TX 77058.

Introduction: This prototype seeks to demonstrate the utility of repurposing a Micro-ElectroMechancical (MEMS) Inertial measurement Unit (IMU) to perform surface gravimetry on a rover. Gravimetry is a common analytical tool used for probing density distributions in the subsurface of a planetary body. Historically, extraterrestrial gravimetry has been confined to orbital platforms. While orbital surveys allow for the construction of global gravity models, the spatial resolution of the data is constrained by the platform's orbital altitude and high inherent speed. Data collected at or near the surface would increase spatial resolution and allow finer-scale crustal structure to be resolved. To date, there have been only two extraterrestrial surface gravity surveys: the Apollo 17 Traverse Gravimeter Experiment and a survey using the MEMS accelerometers contained within the Curiosity rover's IMUs [1,2].

The Curiosity survey highlighted the potential of using MEMS technology to perform planetary gravimetry, albeit with lower sensitivities than traditional surface gravimeters. MEMS accelerometers are included on every rover platform as part of the IMU navigation systems. MEMS accelerometers have low mass, cost, and power requirements while being robust across a range of environments, whereas traditional gravimeters are fragile, costly, and relatively massive (≥8kg versus ≈50g for MEMS IMUs). Thus, the emergence of MEMS gravimeters provides a low-risk and cost-effective method for performing planetary surface gravimetry [3,4]. Here, we present a method to recalibrate the MEMS accelerometers in rover IMUs to collect gravimetric measurements. Such measurements could assist current and future rover missions and support wider efforts to mature MEMS gravimeters.

MEMS Accelerometers: MEMS devices encompass a wide range of microscopic mechanical sensors fabricated using silicon. Such devices can be batch fabricated with exceptionally low cost, size, and power requirements. The principal challenges associated with using MEMS accelerometers for gravimetry:

1. Accelerometers measure the superposition of all accelerations acting on the sensor, not just gravitational acceleration.
2. Low signal-to-noise ratios due to thermo-mechanical white noise.
3. Long-term drifts induced by non-gravitational environmental factors.

The long-term drifts include a time-dependent unidirectional drift, a thermal drift dependent on ambient and sensor temperature variations, and a barometric pressure induced drift likely due to an air buoyancy effect [5].

Method: We have assembled an instrument suite (Figure 1) that contains a tactical-grade MEMS IMU that improves upon a previous platform that had a lower sensitivity [6]. The IMU data is internally sampled at 2000 Hz and decimated by a factor of 16 to create 125 Hz samples. The 125 Hz data are then averaged into 1 Hz data which is then output by the IMU. This data can be further averaged into 5-minute bins to reflect actual rover gyrocompassing activities.

A ground-truth test for demonstration of this capability is planned to identify a salt dome structure near Galveston, Texas. The IMU results will be compared to historical gravity data collected in the same region.

We use wavelet shrinkage denoising to partition the signal into different scales based on its frequency components and remove noise from the dataset. This allows us to preserve frequencies and features of interest within the signal, whilst removing features that lie outside the frequency range of gravity. Results are shown in Figure 2.

Non-linear least squares regression is used to model the response of each accelerometer axis to changes in sensor temperature, ambient temperature, barometric pressure, and a time-dependent linear drift. Modeled accelerometer responses are shown in Figure 3.

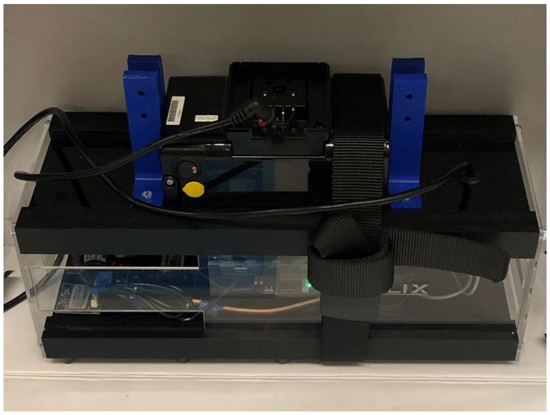

Figure 1 – Enclosure containing IMU and Environmental Sensors.

Future work:

The recalibration of rover IMUs is the first step toward performing planetary gravimetry via in-situ measurement. Proposed future work includes the following:

1. Integrate sensors into a prototype rover platform [7].
2. Validate system performance and investigate additional calibrations through field analog studies.
3. Support VIPER data analysis with methods developed from field studies.
4. Work to identify, develop, or support new technologies and methods for surface or near-surface planetary gravimetry.
   a. Maturation of MEMS gravimeter hardware.
   b. Moving-base gravimetry using rovers.
   c. Drone-based airborne gravimetry for Mars, Titan, etc.
   d. MEMS-based gravity gradiometry.

Conclusion: Recalibrating IMU accelerometer data on planetary surface rover missions effectively transforms the navigation systems into a science platform. This dual-purpose instrumentation, supporting both engineering and science operations, adds no mass, power requirements, or costs to the vehicle. The enhanced resolution provided by surface gravimetry will aid in the characterization of subsurface structures, identifying regions of interest for in-situ resource utilization, and advance our understanding of crustal composition. In addition to enhancing scientific return, this method provides a test bed for the development of new technologies and mission concepts for planetary gravimetry.

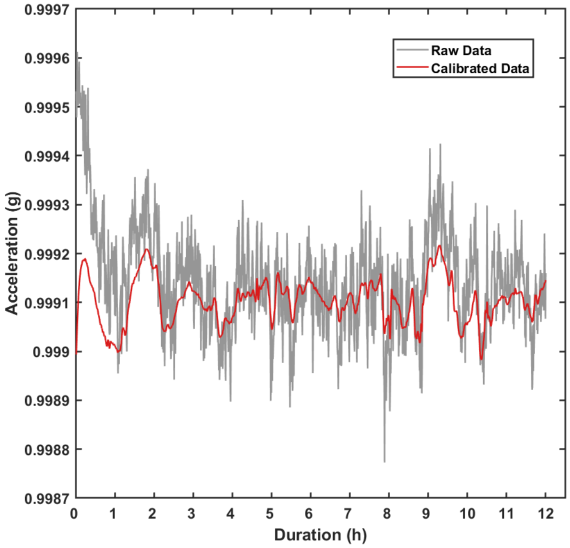

Figure 2 – Accelerometer data shown as the magnitude of the three accelerometer axes. Raw accelerometer data (grey) and calibrated data (red).

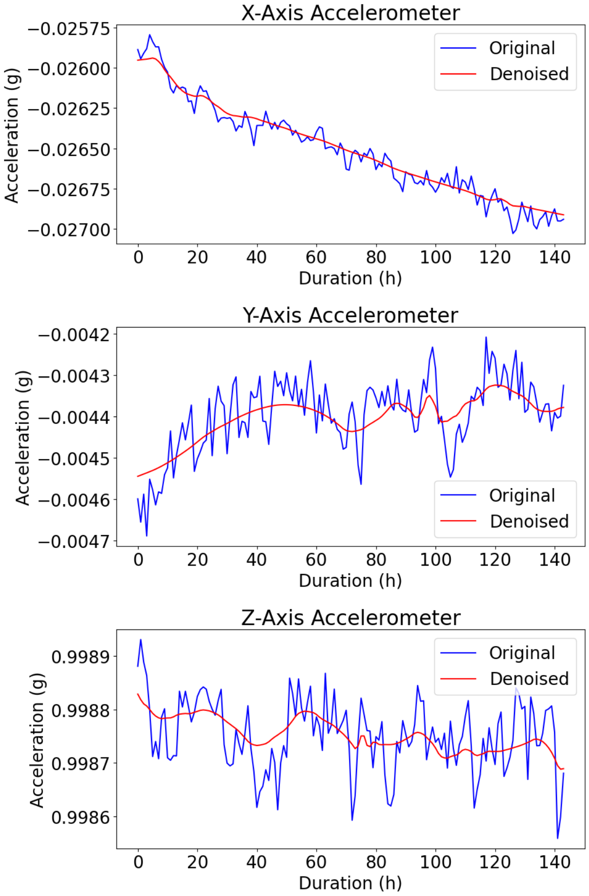

Figure 3 – Results of wavelet decomposition and denoising.

References:

[1] Talwani M. et al., (1973) Apollo 17 Preliminary Science Report. [2] Lewis K. W. et al. (2019) *Science,* 363, 535-537. [3] Middlemiss R. P. et al. (2016) *Nature*, 531.7596, 614-617. [4] Mustafazade A. (2020) *Sci Rep*, 10, 10415. [5] Xu X. et al. (2021) *IEEE Sensors Journal,* 21.20, 22480-22488. [6] Lawson C. S. (2021) *Texas A&M University*. [7] Evans M. E. et al. (2021) *LPSC LII*, Abstract #1754.