Rover Concept for Exploring Lunar and Martian Crustal Magnetic Fields

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Introduction

The Moon and Mars have been shown to possess strong crustal magnetic fields. These magnetic fields have historically been studied by orbiting spacecraft. However, the spatial resolution of the crustal magnetic fields inferred from spacecraft measurements is limited due to the distance between the spacecraft and the planetary surface.

Rovers are an ideal instrument for measuring crustal magnetic fields due to their capability of performing magnetic survey near the sources. However, rovers possess internal sources of magnetic interference that must be measured and accounted for when interpreting magnetometer data. This requirement can be very challenging, especially for rovers with multiple instruments and complicated magnetic field sources. The strong interferences that remain in the magnetic field data from the Lunokhod 2 rover on the Moon demonstrate that magnetic surveys by rovers are not a straightforward exercise.

This project aims to develop a rover prototype for conducting magnetic surveys on the Moon or Mars. With an array of magnetometers integrated into the rover chassis, this prototype can be used to develop data processing algorithms for measuring and accounting for the rover's own magnetic interference in measurement results.

Design Goals

In order for a rover to effectively measure the crustal magnetic field of a planet or moon, the rover must:

- Be compact and inexpensive so many rovers can be deployed at once to survey a large area more quickly.
- Have a regular array of magnetometers so magnetic interference from the rover can be measured and accounted for in measured data.
- Possess instrumentation that makes it possible to differentiate the rover's own magnetic interference from the crustal magnetic field when interpreting sensor data.
- Minimize its own emission of magnetic interference, as not to minimize the effect of the crustal magnetic field on sensor readings.

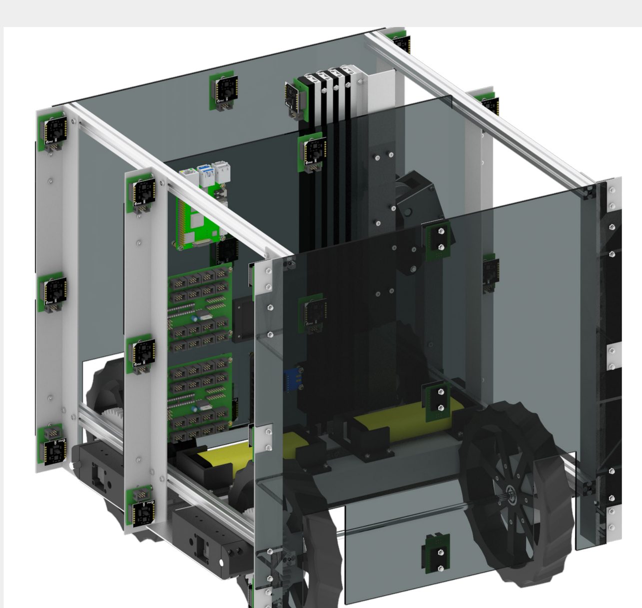

Figure 1. CAD Model of the Prototype Rover

Sensor Array

The rover has an array of magnetometers intended to measure the magnetic field of its surrounding environment.

Various magnetometers were tested by isolating them from magnetic interference and measuring their noise values. By doing this, it was found that most hobby-grade magnetometers like the MLX90303 and ICM20948 are insufficient for measuring ambient magnetic fields, as their noise levels are much too high. With a peak-to-peak noise of ~5 nT in time series found in lab and field tests, the PNI RM3100 magnetometer was chosen for the rover prototype. This sensor also has heritage from the PNI MicroMag3 sensors used in the Radio Aurora Explorer I and II Missions [3] and has been selected for the NEMISIS magnetometer package mounted on the HERMES payload that will be launched with Gateway in 2024. [1]

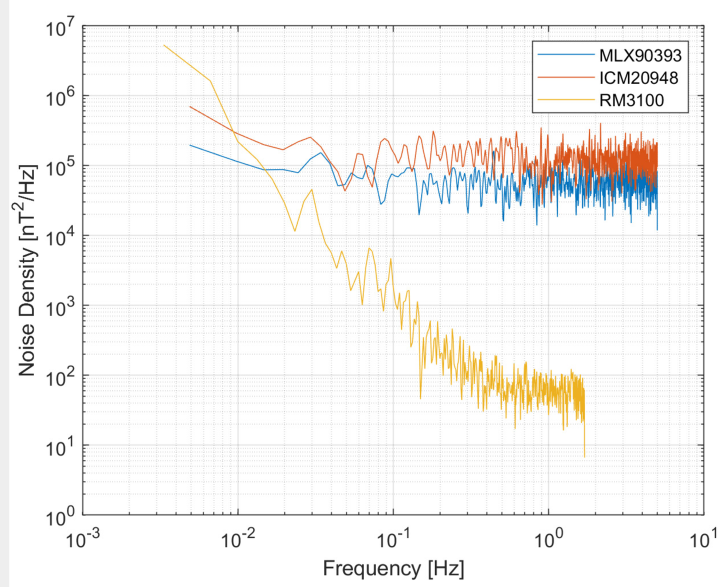

Figure 2. Noise Density of MLX09393 & ICM20948 Hobby-grade Magnetometers (Blue & Red), Noise Density of PNI RM3100 Magnetometer (Yellow)

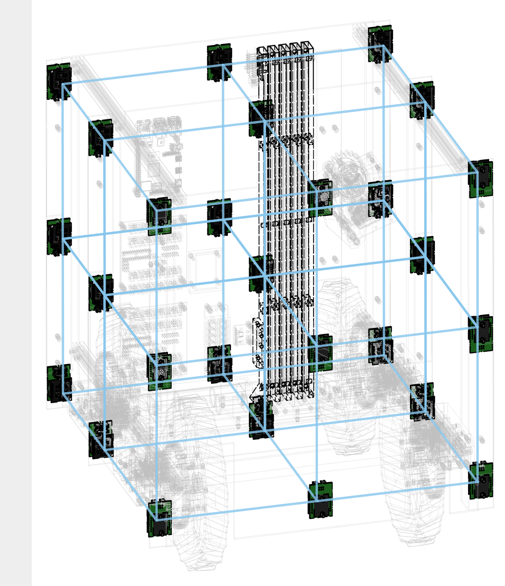

Figure 3. Magnetometer Array Layout

The rover chassis has an arrangement of 27 magnetometers in a 3-dimensional grid, which allows it to infer the multiple magnetic sources on the rover body and deduce the ambient magnetic field. This larger magnetometer array is the next step from the tetrahedral magnetometer array in the upcoming Lunar Vertex rover [2]. The sensors divide the rover into eight cubic sections, simplifying the detailed analysis of the rover's own magnetic sources through data-model comparisons.

Calibration of the magnetic sensors will be done by rotating the rover on its vertical axis. This will allow the rover to identify its own magnetic sources from the magnetic field of the planet or moon. The methodology for deducing the ambient magnetic field will build upon the two-sensor gradiometer technique used in past spacecraft missions [4, 5]. Trials will be performed to test the effectiveness of the rover in determining and eliminating its own interference.

Hardware

A rover prototype was built with a focus on these design goals. It can be packaged into a 500×500×500 mm bounding box, allowing many rovers to be deployed to survey simultaneously. In addition, the prototype's drivetrain is powered with servo motors which allow the rover to drive at 4 inches per second while not creating as much magnetic interference as a larger motor would. Large wheels allow for adequate ground clearance without the size or complexity of a rocker-bogie design. Localization will be achieved with the rover's inertial measurement unit and stereoscopic cameras.

The prototype's sensor breakout system allows for the rover's magnetometers to be changed out quickly without a complete redesign of the sensor subsystem. This will allow for rapid evaluation of magnetometers with different ranges and resolutions. The data can be streamed to a wirelessly connected computer for analysis and stored locally on the rover.

The rover also has a vertical retractable arm that carries a single magnetometer. This arm can extend 1 meter away from the rover, which enables analysis of the rover's magnetic interference as a function of distance and also allows magnetic field measurement at a much greater distance from the rover. This functionality will be used to verify the performance of the data processing algorithms.

Figure 4. Rover Prototype

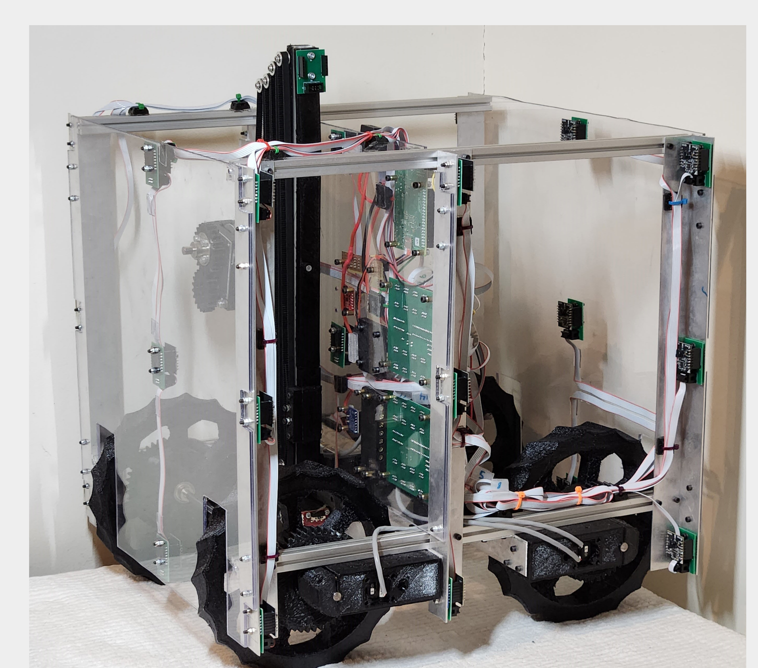

Figure 5. Rover Prototype Telescoping Arm

Figure 6. Extended Arm

Future Trials

The magnetometer array can produce frames of data at a maximum sampling rate of 20 Hz, though tests will be run with a sampling rate of 2 Hz to produce a Nyquist frequency of 1 Hz. Timestamped can be streamed to a connected computer via Bluetooth and written to a file for further analysis.

Four tests have been chosen to provide initial insight into the capabilities of the magnetometer array. Each test will run for more than ten minutes (600 seconds) to produce hundreds of data points for inference.

Trial	Objective
Measuring the magnetic field of the motionless rover	Determine noise of the magnetometer array with minimal interference
Measuring the magnetic field of the rover driving in a straight path	Determine the rover's magnetic field interference under power
Measuring the magnetic field of the rover spinning about its vertical axis	Evaluate this as a possible calibration technique
Measuring the ambient magnetic field while the rover is driving in a straight path, with a magnet nearby	Differentiate between internal magnetic interference and ambient magnetic sources

Current Progress & Future Plans

The prototype rover has been built out of commercially available components and can collect data and drive under pre-programmed or teleoperated control. The Robot Operating System (ROS 2 Humble Hawksbill) was chosen as the foundation for all software modules due to its widespread use and frequent updates. Drivers have been written in Rust and Python to communicate with the magnetometers and motor controllers. Development of computer vision and navigation will continue so the rover can run autonomous tests over a longer period of time.

The tests described above will be performed in the first quarter of 2023. The results of these tests will guide the future direction of the project. They will show whether further hardware revision is required and what data processing techniques can be used for future missions.

References

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