Compact Rover for Exploring Lunar and Martian Crustal Magnetic Fields

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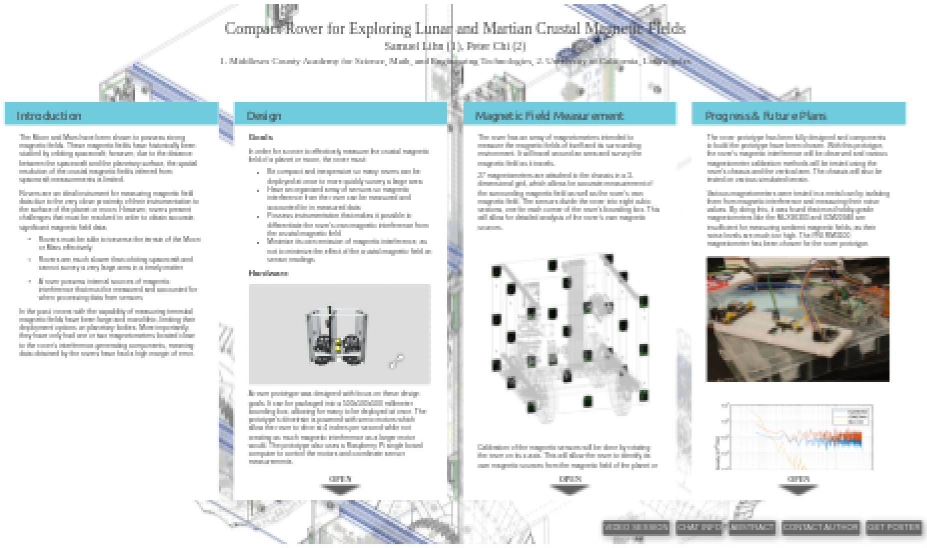
Abstract

The Moon and Mars have strong regional crustal magnetic fields as shown by the observations of orbiting spacecraft. These crustal magnetic fields indicate that a core dynamo was present in the past, and it is believed that rocks formed from cooling lava retain a memory of the strength and orientation of the magnetic field that existed during their solidification. However, a major hurdle in understanding the crustal magnetic field structure is the low spatial resolution limited by the altitude of the orbiting spacecraft. Rovers are well suited for exploring the detailed structure of the crustal magnetic fields, but they also present a technical challenge due to the necessity that sources of magnetic interference from the rover be removed from the measurements. We designed a compact rover dedicated to measuring the detailed spatial distribution of the surface magnetic field. The rover is equipped with an array of magnetic sensors mounted in a rectangular grid that aims to differentiate the rover components' own magnetic fields from the ambient magnetic field. Another magnetic sensor is placed on top of an extendable arm to provide additional measurements for verifying the ambient magnetic field inferred from grid-point measurements. The rover consists of four wheels, a Raspberry Pi single-board computer, control circuitry, and a chassis that holds the magnetometers in a rectangular array. In the prototype of the rover, commercial small-scale microelectromechanical systems (MEMS) magnetometers are used for magnetic field measurements. The test results from these design features can provide a useful reference for future lunar or Martian surface missions with rover-based experiments that measure crustal magnetic fields.

Compact Rover for Exploring Lunar and Martian Crustal Magnetic Fields



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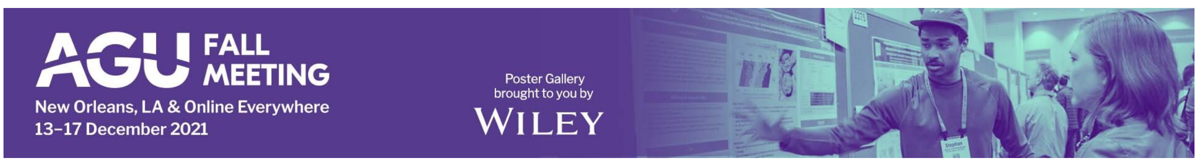


INTRODUCTION

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

Rovers are an ideal instrument for measuring magnetic field data due to the very close proximity of their instrumentation to the surface of the planet or moon. However, rovers present challenges that must be resolved in order to obtain accurate, significant magnetic field data:

- Rovers must be able to traverse the terrain of the Moon or Mars effectively.

- Rovers are much slower than orbiting spacecraft and cannot survey a very large area in a timely matter

- A rover possess internal sources of magnetic interference that must be measured and accounted for when processing data from sensors

In the past, rovers with the capability of measuring terrestial magnetic fields have been large and monolithic, limiting their deployment options on planetary bodies. More importantly, they have only had one or two magnetometers located close to the rover's interference-generating components, meaning data obtained by the rovers have had a high margin of error.

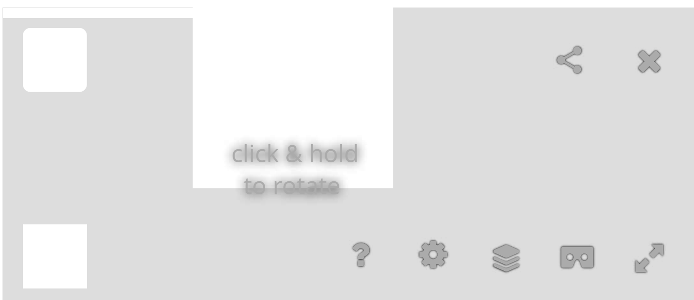
DESIGN

Goals

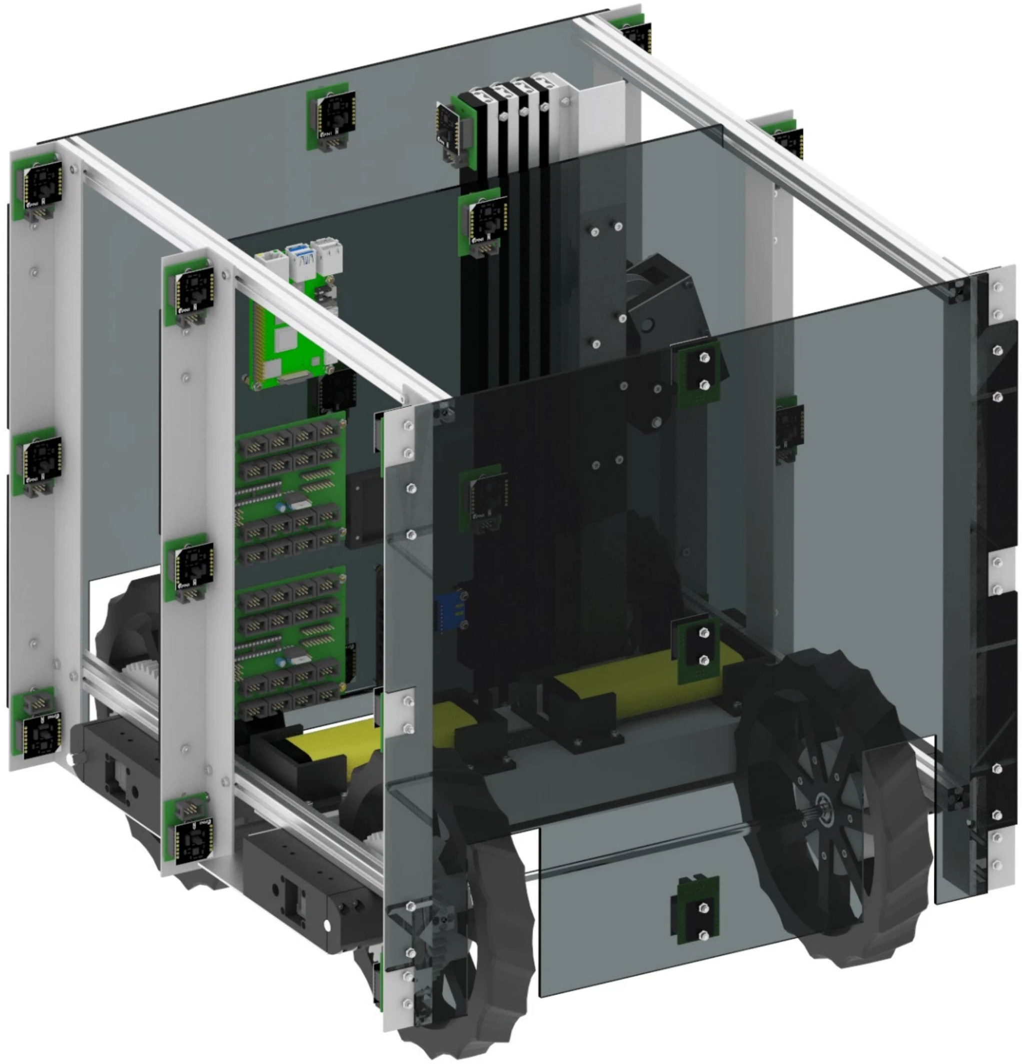
In order for a rover to effectively measure the crustal magnetic field of a planet or moon, the rover must:

- Be compact and inexpensive so many rovers can be deployed at once to more quickly survey a large area
- Have an organized array of sensors 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
- Minimize its own emission of magnetic interference, as not to minimize the effect of the crustal magnetic field on sensor readings

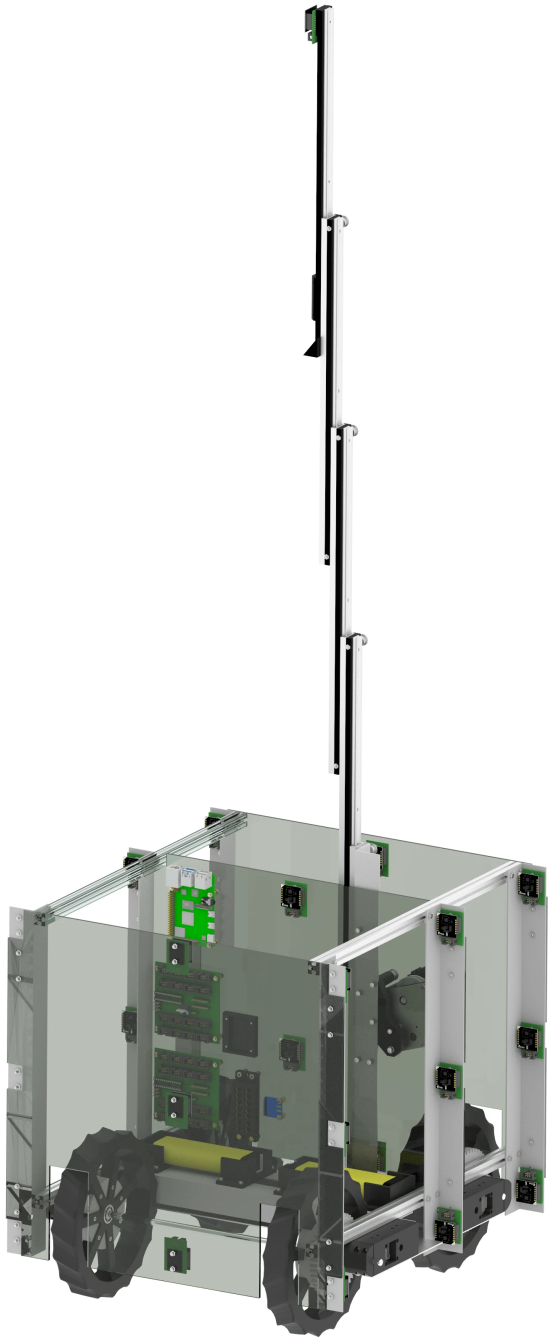
Hardware



A rover prototype was designed with focus on these design goals. It can be packaged into a 500x500x500 millimeter bounding box, allowing for many to be deployed at once. 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. The prototype also uses a Raspberry Pi single board computer to control the motors and coordinate sensor measurements.



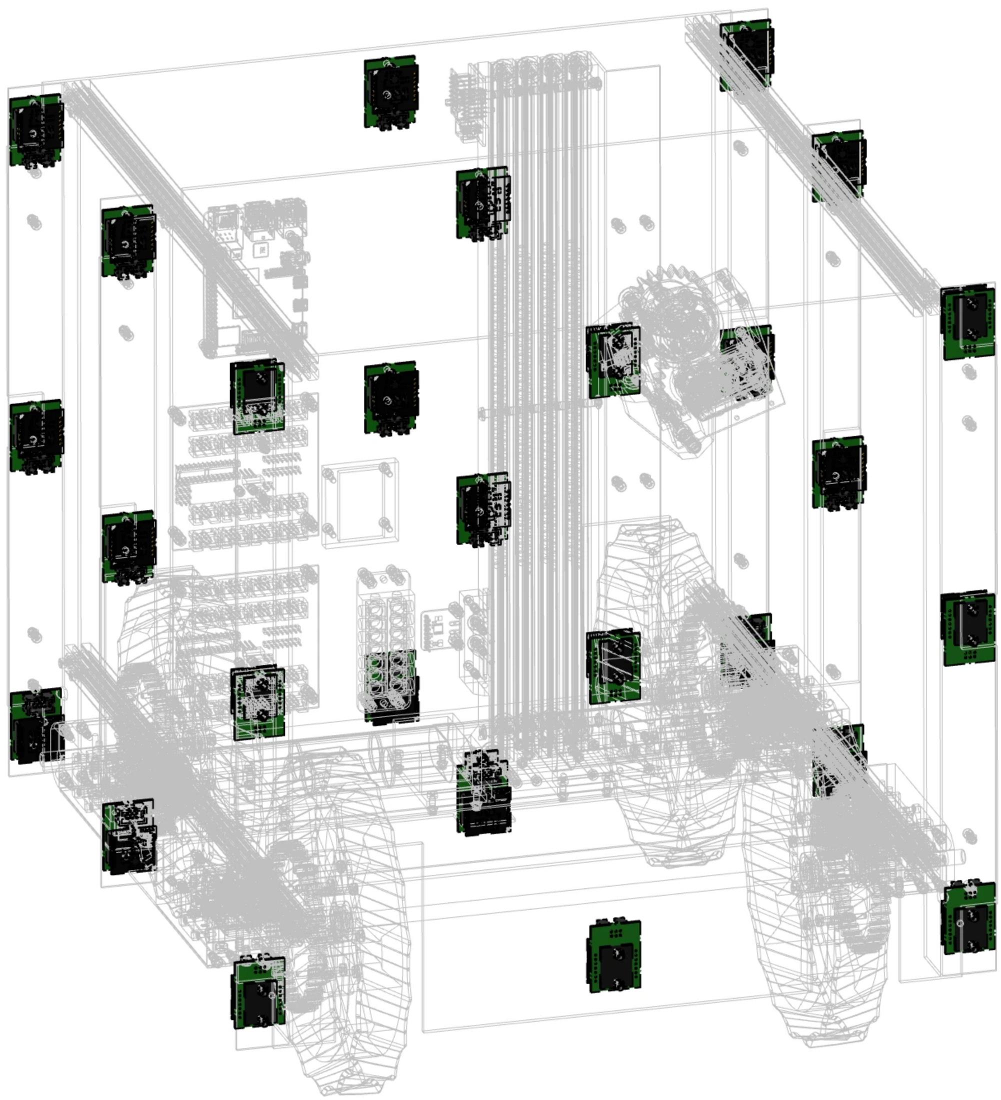
The rover also has a vertical retractable arm that carries a single magnetometer. This arm can extend 1 meter away from the rover, which enables analysis of the rover's magnetic interference as a function of distance and also allows magnetic field measurement at a much greater distance from the rover.



MAGNETIC FIELD MEASUREMENT

The rover has an array of magnetometers intended to measure the magnetic fields of itself and its surrounding environment. It will travel around an area and survey the magnetic field as it travels.

27 magnetometers are attached to the chassis in a 3-dimensional grid, which allows for accurate measurement of the surrounding magnetic field as well as the rover's own magnetic field. The sensors divide the rover into eight cubic sections, one for each corner of the rover's bounding box. This will allow for detailed analysis of the rover's own magnetic sources.



Calibration of the magnetic sensors will be done by rotating the rover on its z-axis. This will allow the rover to identify its own magnetic sources from the magnetic field of the planet or moon.

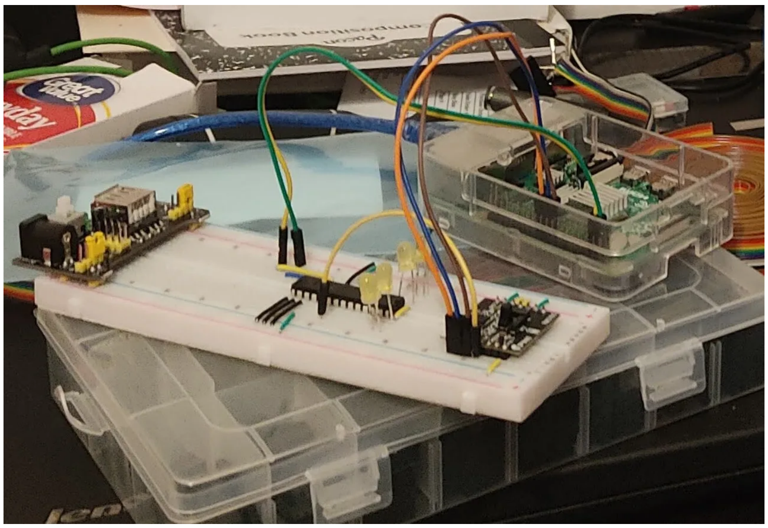
On the prototype, 27 PNI RM3100 magnetometers are used in the sensor array and trails will be performed to test the effectiveness of the rover in determining and eliminating its own interference.

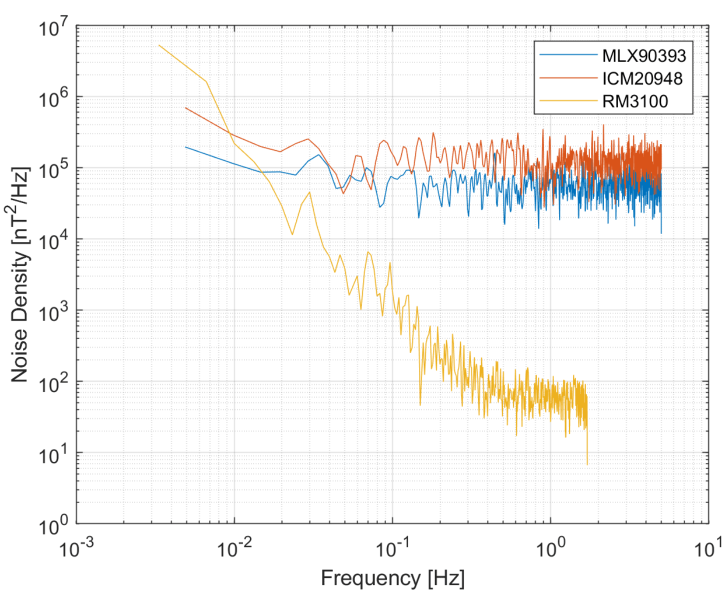
The magnetometer mounted on the rover's vertical arm will be used to take magnetic field measurements that are not as significantly affected by the interference of the rover. It will also be used to determine how the rover's interference changes based on the distance from the rover, and may also be used for calibration purposes.

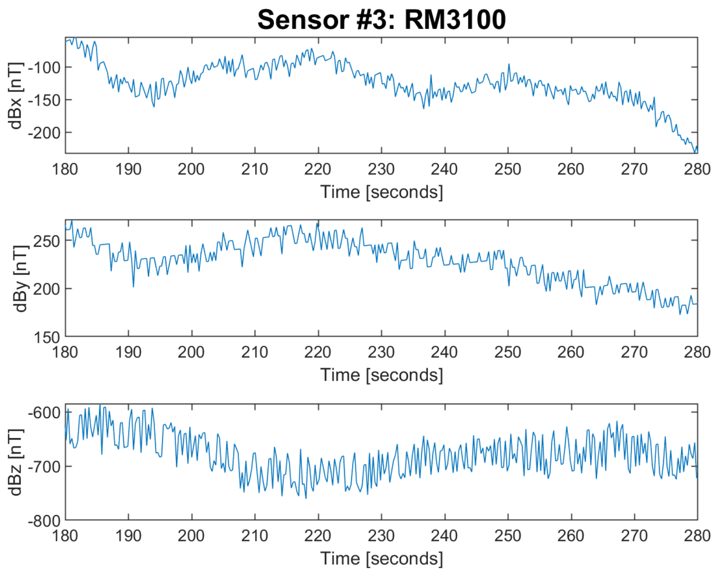
PROGRESS & FUTURE PLANS

The rover prototype has been fully designed and components to build the prototype have been chosen. With this prototype, the rover's magnetic interference will be observed and various magnetometer calibration methods will be tested using the rover's chassis and the vertical arm. The chassis will also be tested on various simulated terrain.

Various magnetometers were tested in a metal can 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. The PNI RM3100 magnetometer has been chosen for the rover prototype.







Software has also been written for the sensor array and drivers have been written for the RM3100 magnetometer and custom multiplexer board. Software is also currently being developed for the chassis and navigation system.

The rover prototype is planned to be built during Q1 2022 and the aforementioned tests will be run on it as soon as it is built. It will be built using consumer-grade components and used as a proof-of-concept for the magnetic measurement techniques outlined in the previous section.

A fully autonomous navigation and computer vision system is also planned, as well as remote control and data streaming from a connected computer. This will allow for fully autonomous measurement tests, which will help determine how an autonomous deployment and survey will be performed.

ABSTRACT

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