# Constructing Enhanced Digital Elevation Maps by Layering on the Spectral and Terramechanical Properties of Planetary Surface Analogues on the Big Island of Hawaiʻi.

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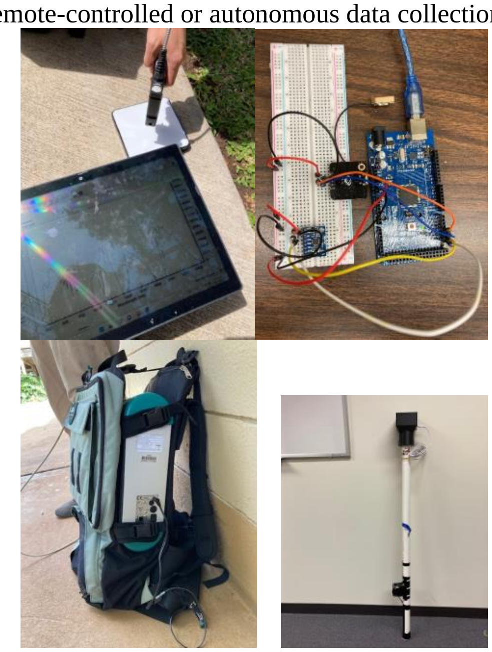
**Introduction:** The lunar South Pole region is a hotspot of exploration in the Artemis era of human lunar exploration, especially the Permanently Shadowed Regions (PSRs). The main scientific interest is to quantify water ice that was confirmed on the surface of the Moon's South Pole, from which the Artemis program can extract oxygen and hydrogen for life support systems and fuel [1]. However, the extreme, contrasting conditions in this uncompromised area, including extreme temperatures and lighting variability, make it challenging for humans to land, live, and work. Unlike where Apollo missions landed, we cannot be exactly sure what the terrain in the Moon's polar regions will be like. Planetary analogs are sites on Earth used in place of locations with similar environments in space, providing a more convenient way to conduct mission field tests. The Hawaiian Islands have many potential analog sites, especially on the Big Island, for the lunar surface rover exploration. The researchers have mostly focused on chemical similarity when evaluating the regolith simulants and planetary analogues based on the return samples and remote sensing data. However, for rover mobility research, we lack information about terramechanical characteristics. Thus, it is critical to measure and map both the chemical and terramechanical properties in a realistic analogue environment for surface exploration vehicles before the mission.

This research aims to construct enhanced Digital Elevation Model (DEM) of the planetary surface analogues on the Big Island of Hawaiʻi by layering on the spectral and terramechanical properties measured from field tests. The tests will include spectra-spatial characterization and sinkage measurements. The outcome of this research will benefit the autonomous lunar rover mobility research and the future lunar surface explorations in the South Pole region.

**Methods:**

*Sensor Suite.* The sensor suite consists of three sensors and additional hardware. The sensor components include a spectrometer, an IMU/accelerometer breakout board, and a GPS breakout board with antenna, the latter two both connected to a printed circuit board (Arduino Uno) (shown top right). The major component, the spectrometer (shown top left), is an ASD FieldSpec4 Standard-Res from Analytical Spectral Devices, Inc., with a spectral range from 350-2500 nm and 15 nm spectral resolution. These three components provide reflectance, tilt, and position measurements for each data point in the field. A PVC pipe is constructed to house the sensor suite and is easy to carry in the field tests (shown bottom right).

The spectrometer used is designed to be in either a laboratory setting or out in the field, so it includes a backpack designed to be worn by an operator while gathering field data, as well as a rechargeable field battery, a grip to orient the spectrometer's fiber optic cable, and a stand to hold the laptop during operation (shown bottom left). The same design of the sensor suite could be integrated into the lunar rover for remote-controlled or autonomous data collection.



*Pressure-sinkage Test.* Bekker developed the formulae that constitute the core of terramechanics in the 1960s allowing the designers of large vehicles to understand and predict vehicle mobility performance [2]. Critical properties of terrain such as density, particle size distribution, angle of repose, cohesion, and compressibility, are usually well documented. However, terramechanical properties such as sinkage, which is fundamental and appears in the calculation of most of the mobility metrics, are not widely available. The later studies proposed a new pressure-sinkage model to improve Bekker's model for small wheels [2].

To measure the sinkage, a testbed was built as shown below, which consists of the linear actuator attached to a wooden platform, the force sensor, and a pressure plate, controlled by an Arduino Uno. Benchtop power supplies at 10 volts. An oscilloscope which connects to the force sensor is utilized to measure voltage data. Force and sinkage are measured using the force/torque sensor. There is also a sinkage box which is a container for samples.

A portable version of the pressure-sinkage test will be carried to the field tests and collect data.

*DEM.* A Digital Elevation Model (DEM) is a representation of the bare ground topographic surface of the planetary excluding trees, buildings, and any other surface objects. The United States Geological Survey (USGS) DEMs of Big Island of Hawai'i are available and serve as the base DEMs, derived from high-resolution lidar and topographic maps [3].

Customized DEMs can be made with ArcScene using data from the field tests tied to coordinates. The final DEMs will save the spectral and terramechanical properties data along with the topographic surface information.

**Discussion:**

After the individual functional tests, an integrated demonstration including the sensor suite and the portable spectrometer has been conducted on the University of Hawai'i at Mānoa campus verifying successful operation and data collection. During these tests, a determined path was followed, obtaining measurements from each data point at regular intervals along the way, with the goal to cover the entirety of an area grid. The observations were made of various materials in the afternoon sun, including concrete, grass, soil, and rocks. The reflectance data from this test was processed using Excel and Python script, with atmospheric noise from the moisture in the afternoon mist removed. The pressure-sinkage test was conducted in the lab with soil samples and lunar simulants from various resources.

The PISCES research sampled and characterized the chemical composition of basalt samples from multiple sites in Hawai'i, from which they determined that the two sites with the most chemically similar basalt to lunar samples are Pu'uhaiwahine (19°45'33"N, 155°27′22″W) and HI-SEAS (19°36'11"N, 155°29′15″W) [4, 5]. Accordingly, these sites are the ideal locations to characterize as geologic analogs for the rover application.

*Future Work.* Before the field tests, a portable pressure-sinkage test will be built and tested. Demo DEMs will be made in ArcScene with sample data from processed sensor suite tests and pressure-sinkage tests.

2-4 field tests in Big Island are scheduled. Once the data are collected from the prospective analog locations, they will be compared against lunar reference data and converted to DEMs. The data from the chosen site can then be used as a spectral baseline reference for future exploration mobility testing.

The measurement of other important terramechanical properties such as lateral slip angle could be added in the same trip. Data storage format with DEMs will be optimized.

There are multiple challenges that we must remain aware of as we move forward with more complex testing and analysis. Although PISCES found basalt at the Big Island locations to be similar to lunar basalt, significant differences are expected in the remaining composition of the terrain. We also expect a difference in the physical distribution of ice – while ice on the Moon is sparsely mixed among the regolith (so-called 'dirty ice'), the field sites will probably see full coverage. However, the method implemented is still validated. It will not only provide a more complete picture of the planetary surface analogues but will also inform data collection and interpretation when searching for ice in the lunar South Pole region.

**References:**

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