APPLICATION OF EARTH-ANALOG SITES FOR LUNAR SIMULATED DIGITAL ELEVATION MODELS

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Abstract. *Surface features below the current resolution of orbital images are potential hazards for landing spacecraft on the Moon. Successful Terrain Relative Navigation (TRN) workflows therefore require testing on synthetic and/or analogous terrain data that have decimeter scale resolution. We bridge this critical gap with libraries of Earth analog data that include terrain maps and individual features, such as boulders.*

Introduction. Knowledge of surface features such as craters, boulder distribution, and other surface characteristics help to strategize hazard avoidance during human and robotic space exploration of rocky planetary bodies. Recent successes were demonstrated by the use of optical terrain relative navigation for the recent landing of NASA's Perseverance rover on Mars [1] and sample collection from the asteroid Bennu by the OSIRIS-REx mission [2,3]. Future missions to the Moon and other target bodies will use these technologies, including LiDAR [4]. As they improve, scientists and engineers will explore new features on the Moon that are more challenging to explore, with ever rougher surfaces, higher rock abundance, and steeper slopes.

Lunar Exploration. Geologists, data scientists, and navigation engineers are working together to overcome challenges to landing on unknown terrain by utilizing synthetic and real Digital Elevation Models (DEMs) to understand surface properties and simulate scenarios for entry, descent, landing and navigation (EDLN). The data are also important for determining targets of interest. Our ability to identify hazards and achieve navigation solutions for lunar exploration is dependent on image and DEM data resolution and quality, as well as the realism of synthetic DEMs, which are used in simulation scenarios. In general, the resolution of DEMs produced for the Moon are between 1 – 4 m/pixel [5,6], whereas the scale of relevant hazards is < 0.1 m. High-resolution DEM data is needed to validate EDLN strategies and workflows for both robotic and crewed missions to planetary surfaces.

Lunar-Like Analog Data. Earth has been an ideal testbed for creating analog digital terrains for rocky planetary bodies where similar surface processes occur [7]. The application of small Uncrewed Aerial Systems (sUAS) and stereophotogrammetry are heavily utilized in the science community to produce DEMs with centimeter-scale resolution and accuracy, which are being used to aid the interpretation of ancient volcanic processes and geological mapping on other planets [8].

We are bridging a critical gap by building a library of lunar-like DEMs of surfaces at Earth analog and Apollo Training sites. For example, the Potrillo Volcanic Field, NM has pits that resemble lunar pits (Figure 1) and shape data of these features can help test ingress/egress concepts for relevant lunar missions [9,10], and Central Iceland has abundant volcanic plains with lunar-like rock distributions (Figure 2). We have several DEMs in hand, and future DEM additions to the library will have large areas from small uncrewed aerial systems with spatial resolution as low as 0.01 m/pixel. Using these data, we can analyze parameters such as rock distribution, make comparison between Lunar and analog data, and ground-truth DEMs (Figure 3, Table 1). Ground-based techniques produce sub-cm data where needed [11]. We can combine terrestrial, lunar and synthetic DEM data to produce state-of-the-art fusion products. These can be made available for analysis, EDLN simulations, illumination analysis, visualization, and advanced planning/simulation/training for EVA surface ops. Advantages of these data are the realism to natural surfaces, shape, and scale. DEM production was supported by NASA RISE2 and GIFT projects [12].

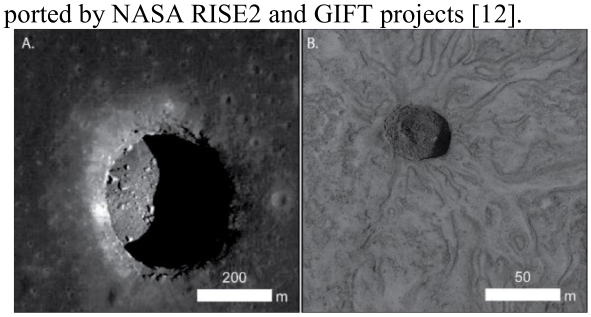

Figure 1 A) Mare Tranquillitatis pit (LROC NAC image M126710873R). B) sUAS image of lava tube skylight near the Potrillo Volcanic Field, NM.

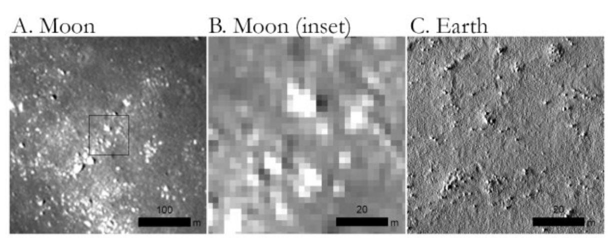

Figure 2. a) Impact crater ejecta (LROC NAC image M126710873R). b) Inset view of ejecta. c) Boulder field on a sand sheet in northern Iceland near the Askja and Holuhraun eruptions. Hillshade of 5 cm/pixel resolution sUAS-generated DEM at the same scale.

Conclusion. Accurate maps will be needed for upcoming lunar lander missions, in particular missions to the South Pole region. These prototype high spatial resolution DEMs, developed from terrestrial analog and Lunar data, have the potential to be a benchmark component in the development and testing of TRN and hazard detection algorithms [13].

Table 1. Rock statistics extracted from terrestrial analog DEM data, count (N) = 1,278.

Boulder Height (cm)	
Mean	9.7
Standard Error	0.1
Median	8.0
Mode	6.0
Standard Deviation	5.3
Sample Variance	0.3
Minimum	1.5
Maximum	37.9
Confidence Level(95.0%)	0.3

Boulder Cross Sectional Area (sq cm)	
Mean	30.3
Standard Error	1.3
Median	18.0
Mode	4.0
Standard Deviation	45.3
Sample Variance	20.5
Minimum	1.0
Maximum	774.0
Confidence Level(95.0%)	2.5

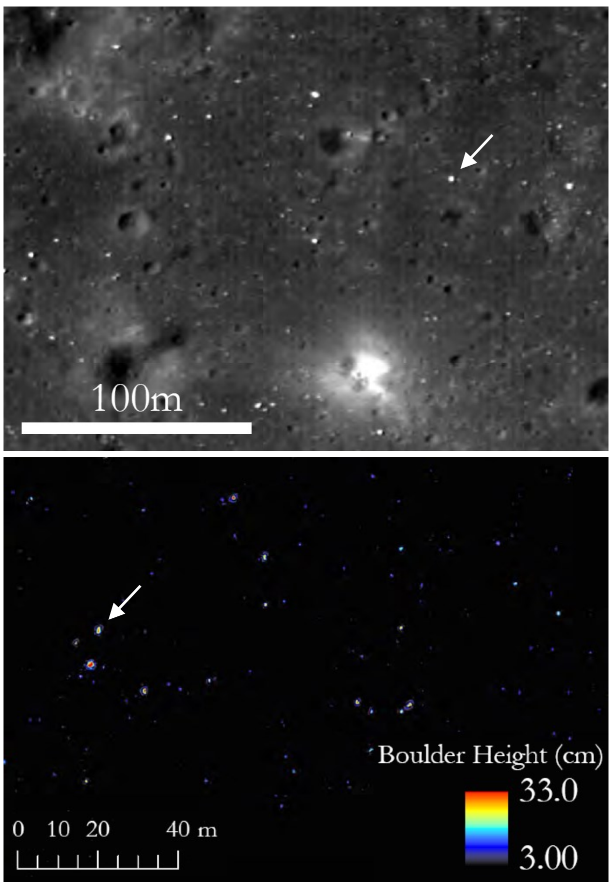

Figure 3. Top: Image showing the distribution of boulders from impact crater ejecta seen in LROC NAC image M126710873R. Bottom: A DEM with a distribution of boulders on a sand sheet in Iceland as a terrestrial analog for Lunar rocks the distribution of the rocks and their shape, size and dimensions; boulders are color-ramped by height, and statistics were extracted and could be validated in the field [12]. White arrows point to examples of individual boulders.

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