DEMKIT & LUNARAY: TOOLS FOR MISSION DATA GENERATION AND VALIDATION

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Abstract. *Capabilities such as terrain relative navigation, hazard detection, landing site selection, and surface analysis are key components of the successful planning and execution of any mission. These functionalities rely on having sufficient, verified planetary data for algorithm development and testing, analysis, and mission execution. Astrobotic has developed two products to generate and verify mission data, enabling Astrobotic and customers to meet mission requirements. DEMkit is a suite of applications used in the generation, analysis, and verification of terrain data, while LunaRay is used to capture photometrically accurate renderings of the lunar surface.*

Introduction. Planetary data is a critical component of the planning, development, and execution of a variety of space mission capabilities. The ability to produce and verify various types of data specific to the lunar surface is mission enabling, allowing for the rapid development and testing of advanced algorithms and robotic systems, as well as the execution of precision landing and surface activities. To meet data needs, Astrobotic has developed two tools that encompass the tasks of employing remotely sensed data, and simulation of illumination conditions. DEMkit is a suite of tools developed to generate, analyze, and validate lunar terrain data (digital elevation models), while LunaRay provides physics-based photometrically accurate rendering, enabling the capture of scenes under desired illumination conditions.

Terrain Relative Navigation. Terrain relative navigation (TRN) is a mission critical capability that uses computer vision techniques to reduce spacecraft navigation uncertainty from the order of kilometers to the order of meters, enabling precision landing. Many TRN solutions require a set of reference maps covering the swath of potential approach azimuths and illumination conditions to match terrain features in camera images acquired during descent[1,2]. As such, it is critical that TRN map data is accurate, geodetically aligned, and free from artifacts that may produce false features or inaccuracies in pose estimates. To improve geodetic alignment, terrain data can be aligned to alternative sparse or dense elevation data sources using DEMkit tools. This iterative optimization routine enables in-plane translations and tilts to minimize residual elevation error. Additionally, image data can be aligned to optimized elevation data via tie point selection, increasing confidence in the geodetic alignment of resulting data products while ensuring consistency in the placement of surface features between terrain model and image. DEMkit also includes a seam editing tool to address these concerns and reduce the artifacts that stem from uncertainties in terrain data. Additionally, a photometric correction technique leveraging lunar-specific reflectance functions is used to extract surface features from the illumination effects induced by topography captured in orbital images (Fig. 1), enabling high-resolution renderings with surface texture under mission-relevant illumination conditions[3].

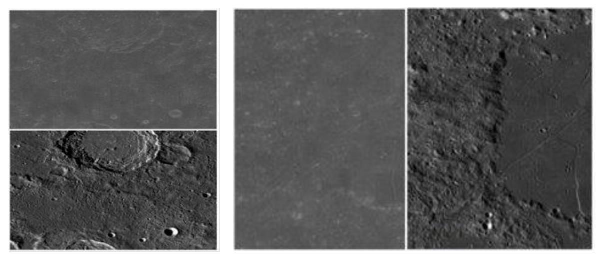

Figure 1. Sample results from the shadow removal application in DEMkit.

LunaRay simulates the illumination conditions across this terrain data at a given date, time, and viewing condition. The output map data is geodetically tagged and can subsequently be employed by a TRN system to perform 3D pose estimation. LunaRay also serves as a scene generator for software- and hardware-in the-loop testing of vision-based systems. Simulated camera images can be produced that incorporate the intrinsic properties of the camera to provide realistic test datasets, accelerating algorithm development and refinement.

Hazard Detection. Available orbital data of the lunar surface do not necessarily capture features on the scale of what is hazardous to a lunar mission. For example, the Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) nominally captures images at 0.5 meters per pixel, enabling 1- to 3-meter lunar surface features to be resolved. However, rocks and craters on the order of tens of centimeters can present obstacles that could result in mission loss. DEMkit includes an application to procedurally generate rocks and craters at parameterized distributions, enabling customization of distributions specific to the region of interest (Fig. 2). Craters are added in age order to simulate the effects of impacts over time, and each crater is given a relative age to appropriately model the crater degradation. Craters and rocks are overlaid onto existing lunar terrain models to appropriately capture low frequency characteristics.

Figure 2. Left: Original, low resolution lunar terrain. Center: Upsampled lunar terrain with crater features. Right: Crater with procedural rock hazards.

Landing Site Selection & Surface Analysis. Together, DEMkit tools and LunaRay illumination maps aid in the selection of landing sites, dates, and times that maximize the likelihood of avoiding hazardous rocks, craters, and slopes, while maximizing the likelihood of success for precision landing algorithms. DEMkit also includes tools to track the visibility of Earth ground stations and orbital relays above the local horizon to assess communications availability at a specified height above the surface. Cost maps (Fig. 3) can be generated to automatically identify potential landing regions that maximize the criteria for safe landing. In addition to helping with the identification of safe landing sites, these tools can be used in the planning of surface operations, including rover traverses, solar asset emplacement, and science operations.

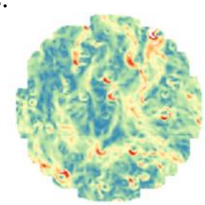

Figure 3. Cost map of a landing site, accounting for terrain properties and Sun/Earth visibility.

Data Verification. DEMkit employs a comprehensive suite of tools for quantitative dataset verification relative to other data sources (Fig. 4). The tools for verifying geodetic translations and rotations, elevation errors, and distortions help quantify errors in terrain data and identify map regions with high uncertainty. In addition, scenes generated by LunaRay are validated against reference images of the lunar surface captured by orbiters. LunaRay products are additionally validated against DEMkit tools for measuring the visibility of the solar disk to ensure accuracy.

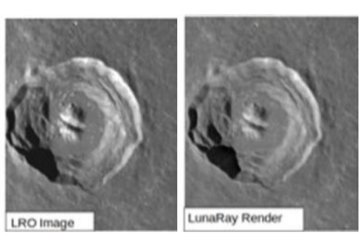

Figure 4. LunaRay rendering compared to LRO WAC M119666881ME.

Dataset Generation for Machine Learning. DEMkit and LunaRay enable the automated generation of large datasets facilitate the development of learning-based algorithms in several different realms. Databases of simulated terrain data have been collected and used to enable the development and testing of advanced hazard detection algorithms. Beyond lunar terrain, LunaRay can load additional 3D models, including satellite models, while varying the background scene (Fig. 5) to produce diverse data for satellite identification, segmentation, and pose estimation tasks (e.g., Fig. 6).

Figure 5. LunaRay renderings of various satellites over a Moon, Earth, and Earth night sky background.

Figure 6. Sample machine learning-based segmentation of LunaRay-simulated image of Cygnus.

Conclusion. Validated and refined planetary data is critical to the successful planning and execution of missions ranging from safe and precise landing at the lunar poles to long distance rover traverses. To meet such objectives and support the design and development of advanced in-space robotic systems, Astrobotic has developed DEMkit and LunaRay, two software products that operate on remotely sensed lunar terrain data. DEMkit provides data preprocessing tools, including terrain model alignment, augmentation, and verification, while LunaRay addresses the complex problem of predicting illumination of the Moon’s surface given time and other ephemeris information.

References.

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[3] Macdonald, K., et al. “Validation of Photometrically Corrected Lunar Images”, *5th Planetary Data and PSIDA,* 7091, 2021.