Photogrammetry to Support Geologic Field Work and Extravehicular Activity (EVA) Operations on the Lunar Surface, J. M. Hurtado, Jr., UTEP (jhurtado@utep.edu)

Introduction: Several types of data should be collected during an Artemis field geology extravehicular activity (EVA): (a) primary data/observations; (b) context metadata for observations and samples; (c) science operations metadata (e.g. methods/procedures, specific events); and (d) operational situational awareness data. Items (a)-(c) are critical for maximizing science return and for maintaining scientific situational awareness [1]. Item (d) allows science operations to be tied to other mission events. One key way to document field activities is with imagery. Cameras have become a fundamental tool of terrestrial field geology and have been nearly ubiquitous on both robotic and crewed Solar System exploration missions. For crewed exploration (e.g. Apollo, Earth analogs), still images and video have been key data streams to obtain (a) and (b), and, to a limited extent, (c) and (d). While modern camera hardware exceeds capabilities that existed during Apollo, only recently has terrestrial field geology taken advantage of modern methods for collecting and processing field imagery [2]. Similarly, EVA operations on the International Space Station (ISS) have not fully taken advantage of what can now be done with imagery, although robotic missions have done so to some extent. Among the new approaches is structure-from-motion/multi-view stereo (SfM) photogrammetric image processing to construct three-dimensional (3D) models.

SfM: SfM photogrammetry achieves simultaneous: (i) estimation of the position/pose of an arbitrary number of images; and (ii) construction of a 3D point cloud of the scene from which other data products (meshes, grids, etc.) can be generated [2]. Images for SfM can be acquired from still or video cameras, including multispectral sensors, as long as they are high-spatial resolution, with sufficient (>~50%) inter-image overlap and favorable geometry (a translating camera and stationary target) [3]. The resulting 3D models can be rendered with or without a true-color texture map, useful for visualization of subtle textures and shapes that would otherwise be obscured. When using ground-based or low-altitude aerial imagery, very high-resolution terrain models (mm-scale) can be obtained with SfM.

SfM can be used to generate models at a range of scales, from hand sample to outcrop to entire traverses [2,4]. These 3D models are relevant for each of the four documentary needs of planetary field geology listed above, and for EVA operations in general: (a, b) field data and sample collection is aided by visualization of critical geospatial relationships and the precise, visual representation of that information to EVA crews and science mission support; (a) post-EVA collection of additional field data and insights is enabled by the capability to virtually explore a high-fidelity, high-resolution, reproduction of the field site; (b) precise geolocation of field data and samples is aided by the 3D context provided by the models; (c) quantitative and qualitative documentation of the environmental effects of science procedures (e.g., sample collection, disturbance of regolith by walking or vehicles, etc.) is enabled by capturing "before and after" data of the field site; and (d) reconstruction of EVA traverse paths can be done through simultaneous computation of camera attitudes/positions and detailed terrain models. A number of science applications of mm-scale topography of a study site are also enabled by SfM, including, but not limited to, geotechnical assessments of regolith and landscape evolution processes. In addition, 3D models of the lunar surface and detailed reconstructions of EVA events will have compelling uses in education and public outreach, enabling virtual exploration of the lunar surface and vicarious participation in the Artemis program.

SfM models at mm- to Dm-scales have been made using imagery from Mars rovers, Apollo EVAs, International Space Station (ISS) EVAs, and terrestrial fieldwork [4-6]. Figs. 1-3 show examples of 3D models generated with SfM software (*Agisoft Metashape* [3]). Blue polygons show camera positions computed along with the 3D model. These examples illustrate that useful results can be obtained from sub-optimal (low-resolution, insufficient overlap, poor geometry) imagery not purposefully acquired for SfM.

Proposed Science Investigation: Astronauts and robots would obtain complete documentation of EVA activities on the Moon at multiple scales and from multiple perspectives. The goal would be to collect 1st-person and 3rd-person imagery to temporally reconstruct the events of an EVA and to spatially reconstruct the study site. A data system would automatically ingest, process, display, and transmit the large volume of image data and 3D models to a time-coded ground data system [8]. EVA suit-mounted cameras would collect 1st-person imagery of crew activities for traditional purposes as well as for SfM. These could be devices similar to a GoPro, capable of capturing at least 4K-resolution video and stills. Stereo is not required for SfM, but would be beneficial. Similarly, geolocation data is not required, but would be necessary to produce geolocated models. At the outcrop- to traverse-scale, this can be done with surveyed ground control points. Simultaneously, a robotic camera, on an LRV-type vehicle but possibility on other/additional platforms, would collect 3rd-person, standoff imagery of field operations from a distance over a period of time. One possibility is a small, rolling robot with at least one mast-mounted, 4K-resolution, video/still camera with zoom (~500mm) and autonomous astronaut tracking capability. Harsh, low-angle illumination conditions at the Artemis III landing site could pose a challenge to photogrammetric processing. However, preliminary experiments at UTEP show that the SfM method is surprisingly resilient as long as the illumination conditions remain uniform over the time period the imagery is acquired. External illumination sources will also mitigate these effects. Other methods, such as LiDAR are complementary, but require more complex instrumentation and are not capable of capturing visible-wavelength imagery without a paired camera.

References: [1] Hurtado, J.M.(Jr.) et al. (2013) *Acta Astronautica*, 90, 344-355. [2] Westoby, M.J. et al. (2012) *Geomorphology*, 179, 300-314. [3] https://www.agisoft.com/. [4] Ostwald, A.M and Hurtado, J.M.(Jr.) (2017), *48th LPSC*, abst. #1787. [5] Hurtado, J.M.(Jr.) (2020), *Lunar Surface Sci. Wkshp*, #5130. [6] Le Mouelic et al. (2020), *Remote Sens*., 12, 1900. [7] http://apollo.sese.asu.edu/. [8] Feist, B. et al. (2019), *NASA Expl. Sci. Forum*, NESF2019-005.

Figure 1. High-resolution scans of Apollo Hasselblad photographs are available [7], but Apollo procedures emphasized close-range sample photography and far-range panoramas, so much of the imagery lacks the necessary overlap and geometry. Some imagery, such as shown here [also 6], is workable. This model includes 3D context for an important sample and anthropogenic modification (footprints, trench). Most Apollo TV camera footage from the lunar roving vehicle (LRV), potentially ideal for SfM in terms of overlap and perhaps geometry, unfortunately has insufficient resolution for producing high-quality 3D models.

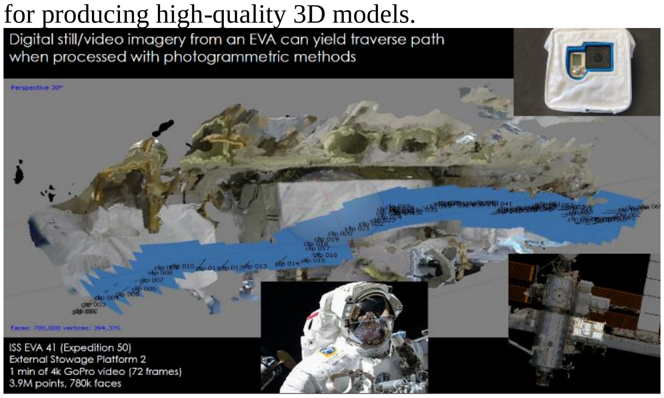

Figure 2. ISS crewmembers have occasionally used GoPro cameras during EVAs. This model and the associated traverse path on the exterior of the ISS was made from GoPro imagery with higher spatial resolution than spacesuit helmet camera video and with more frame-to-frame overlap than the 35mm stills typically shot during EVAs. It represents what may be achievable at the outcrop scale on the Moon using continual, first-person EVA video.

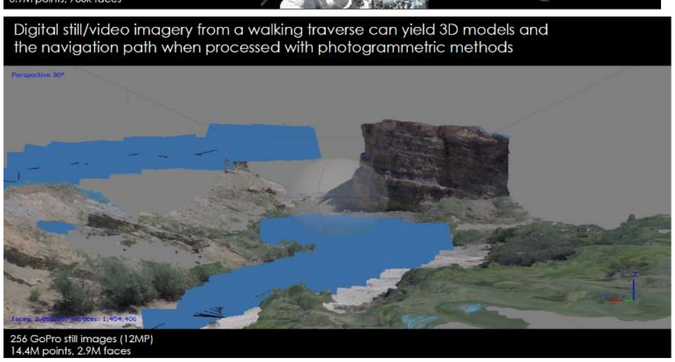

Figure 3. Terrestrial fieldwork increasingly uses SfM [2]. This example shows the quality of 3D model possible with optimized instruments and procedures (high resolution, continually recording, crew-mounted video camera on a walking traverse). It represents what may be achievable at the outcrop- to traverse-scale on the Moon.