MODERN IMAGING TECHNOLOGIES TO SUPPORT GEOLOGIC FIELD WORK AND EVA OPERATIONS ON THE LUNAR SURFACE.

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Introduction: Imaging will be part of next-generation extravehicular activities (EVAs) on the lunar surface. Better imaging hardware and image processing capabilities exist now compared to the Apollo era. These capabilities create new opportunities for operations, science, and public engagement that require design choices with regard to cameras; data collection procedures; and data management.

Several types of data can be collected during an 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. Documentation of planetary geologic fieldwork should include each of these [1].

One way to document field activities is with imagery. Cameras are a basic 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 synthesizing that imagery [2]. Similarly, current EVA operations have not fully taken advantage of what can 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) image processing to construct three-dimensional (3D) models. SfM (and other techniques) can be used to fully address all four documentary needs of planetary field geology and EVA operations in general.

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 [2]. Images 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 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, higher-resolution terrain models can be obtained with SfM than with high altitude aerial or satellite methods.

SfM enables geologists to generate virtual rock, outcrop, and traverse models [2,4]. For planetary exploration, these 3D models are relevant for: (a, b) field data and sample collection by aiding visualization of critical relationships and the precise, visual representation of that information to EVA crews and science mission support; (a) collection of additional, post-EVA/-mission data and insights by allowing exploration of a high-fidelity, high-resolution, reproduction of a field site; (b) geolocation of field data/observations and samples by preserving vital 3D context; (c) documentation of the environmental effects of science procedures (e.g., sample collection) by capturing “before and after” data; and (d) reconstruction of traverse paths through computation of camera attitudes and positions. In addition the models have curatorial value in recording the state of the terrain before extensive modification by subsequent exploration. The models also have compelling use in education and public outreach, enabling virtual exploration of the lunar surface.

Examples: SfM models at mm- to Dm-scales can be obtained using imagery from Mars rovers, Apollo EVAs, International Space Station (ISS) EVAs, and terrestrial fieldwork. Figs. 1-4 show anaglyph renderings of point clouds generated with *Agisoft Metashape* [3], with the number of points and image sources indicated for each. Blue polygons show camera positions. Figs. 1-3 illustrate that useful results can be obtained even with sub-optimal (low-resolution, insufficient overlap, poor geometry) imagery.

Mars Science Laboratory (MSL) data can be used to produce microscope- to hand sample-scale models [4] as well as outcrop- to traverse-scale models (Fig. 1), the latter including the rover traverse path [4]. MastCam images with higher spatial resolution than NavCam are available, but the central-point panorama imaging geometry is not optimally favorable for SfM.

Apollo procedures emphasized close-range sample site photography and far-range panoramas, so much of the imagery lacks the necessary overlap and geometry. Fig. 2 documents a sample site that also includes anthropogenic modification (footprints) potentially interesting for geotechnical and surface change analyses. High-resolution scans of Apollo photographs are available (e.g. Fig. 2) [5], but Apollo TV camera footage from the lunar roving vehicle (LRV), potentially ideal for SfM in terms of overlap and perhaps geometry, has insufficient resolution.

ISS crewmembers have used GoPro cameras during EVAs. Fig. 3 shows the result of processing a ~1 min. clip of 4K/60fps video. This model – made from imagery with higher spatial resolution than spacesuit helmet camera video and with more frame-to-frame overlap than 35mm stills – represents what may be achievable at the outcrop scale on the Moon.

Terrestrial fieldwork increasingly uses SfM, often applied to imagery from uncrewed aerial systems (UAS) [2]. Fig. 4 shows the quality of 3D model possible with optimized instruments and procedures. It represents what may be achievable at the outcrop- to traverse-scale on the Moon.

Other Approaches: Astronaut-mounted/operated cameras can be used to obtain close-range, instantaneous, 1^{st}-person views for SfM. Another documentary approach is stand-off video imaging (i.e. remote camera, UAS) for capturing 3^{rd}-person views (3PV) of field operations from a distance over a period of time. While not typically done for terrestrial fieldwork, 3PV has been applied in analog studies (DRATS, RIS^{4}E, [1]; Fig. 4), and it was an important dataset for Apollo (LRV TV camera). 3PV is directly applicable to data types (a)-(d), so it should also be included in future planetary surface science EVAs. 3PV imagery with the appropriate overlap and geometry can also be used for SfM and the production of traditional panoramas or GigaPan-type mosaics.

Proposed 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 1^{st}-person and 3PV imagery to temporally reconstruct the events of an EVA and to spatially reconstruct the study site with SfM, in so doing capturing vital context data.

Instrumentation: (A) Suit-mounted cameras would collect 1^{st}-person imagery for traditional purposes and 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. (B) A robotic camera, on an LRV-type vehicle but possibility on other/additional platforms, would collect 3PV imagery. 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. (C) A data system needs to automatically ingest, process, display, and communicate large volumes of data, to include SfM software and interfaces for exporting SfM and 3PV products to a time-coded ground data system [6].

Constraints & Requirements: Mass, volume, and power requirements are minimal for (A) since cameras will likely continue to be part of EVA suit design. Added constraints will be procedures to ensure proper image geometry (and, for stills, overlap) and crew time for capturing 1^{st}-person imagery. Those requirements for (B) are potentially larger. A crew rover would likely already include a camera system. Otherwise, an imaging robot could be similar in mass, volume, and power requirements to a small UAS (e.g. [7]). The impact of these requirements can be mitigated if the robot has other tasks/sensors. The requirements for (C) can also be shared among other investigations requiring similar computational infrastructure.

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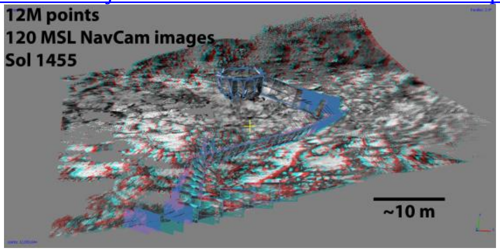

Fig. 1. Murray Buttes, Mars. Note rover path.

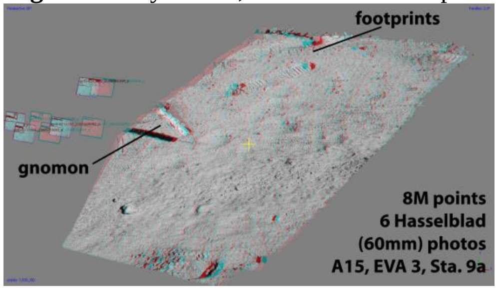

Fig. 2. Apollo 15, EVA 3, Station 9a.

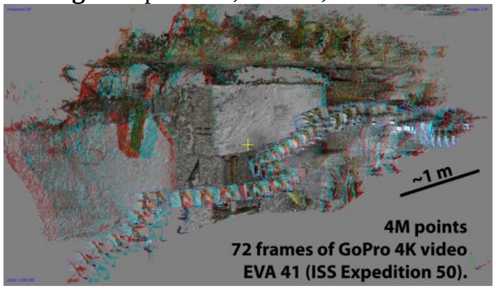

Fig. 3. ISS External Stowage Platform 2 (ESP2).

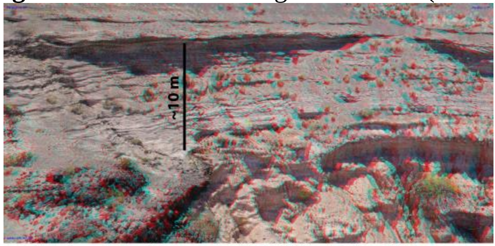

Fig. 4. Volcanic layering at Kilbourne Hole, NM.