IMAGING CONSIDERATIONS FOR ARTEMIS EVAs AT THE LUNAR SOUTH POLE.

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Introduction: Cameras are a fundamental instrument for planetary exploration and images are a foundational data product upon which other science investigations build by recording context or by providing observational and/or quantitative data. Images are also critical for maintaining operational situational awareness for achieving mission safety and success. Imaging will be part of Artemis extravehicular activities (EVAs), and two circumstances present challenges and opportunities: (1) the complex illumination conditions at the lunar south pole; and (2) advancements in imaging technologies that have been made in the decades since Apollo that create new use case opportunities.

Imaging Use Cases: The primary function of a camera in geologic field work is to take images of field sites, outcrops, samples, and field activities. These images serve an important role in recording science context, without which samples and field data are of limited use. For planetary exploration, documentation of operations is also important because, unlike with conventional field geology, the astronauts themselves will not be the principal investigators for the research being done. Rather, they are part of a team based on Earth. The remote supporting team needs as much scientific and operational context as possible to build and maintain situational awareness.

For Artemis it will be essential to have ubiquitous and largely automatic acquisition of still images and video to capture spatially- and temporally-comprehensive views of EVAs at multiple scales and from multiple perspectives, while capturing vital context for crew activities, collected data, and samples [1-4]. Suit-mounted or crew handheld cameras will be important tools for capturing first-person perspective views of EVA activities, particularly sampling and rock- to outcrop-scale science observations [1-4]. Another way of maximizing situational awareness of crew activities will with a stand-off imaging capability, using tripod- or rover-deployed cameras, to monitor and recorded EVAS from a third-person perspective [1-4].

A key difference between Apollo and Artemis EVA imaging is the modern capability of capturing still images and video using digital cameras. This opens possibilities not feasible during Apollo. For example, without the constraint of film stock, there will be no physical limit on the number of photos or videos that can be obtained, although storage and power constraints remain and communications bandwidth will limit the amount transmitted back to Earth in real-time. Also, without the need to develop film, there will be no lag between when images are taken and when they are available for viewing/analysis. Digital images can be readily manipulated with computers, so photogrammetric (3D); color and spectral; machine learning-assisted; and other image processing can be possible, potentially in (near) real time.

South Polar Lighting Conditions: The small inclination of the Moon's rotation axis means the Sun will always be no more than a few degrees above the polar horizon. This produces a complex illumination environment (Fig. 1) with deep, transient shadows that continually change direction as the Sun's azimuthal position changes over the course of a lunar day. Topography, then, becomes a key control on lighting conditions. Topographically low areas at the poles, such as the interiors of deep impact craters, can be in permanent shadow, while other areas, such as ridges, can experience near-permanent sunlight (Fig. 2).

The effects of these conditions on the quality and usability of visible-wavelength images is not fully understood. The complex illumination conditions will be particularly important for photography and videography during EVAs. For example, transient shadows will change direction, shape, and length as a function of time, making image-to-image comparisons, mosaicking, and photogrammetry challenging. Permanently shadowed regions (PSRs) will have very little, but perhaps sufficient [5], illumination for imaging their interiors (Fig. 2). Scenes with brightly lit areas directly adjacent to shadowed areas (Fig. 1) will require a large (and uncompressed) dynamic range in order to completely capture details and will be difficult for astronauts to appropriately frame and focus.

The start of the first EVA of Apollo 12, when the Sun was 7.4° above the horizon, approximated lunar polar illumination conditions. Photogrammetric processing of images from Apollo 12 EVA 1 can successfully yield 3D images at the sample scale (Fig. 3).

Low-Light Imaging Instruments: Viewing the interiors of PSRs that cannot be accessed directly could be facilitated by deploying low-light imaging systems and/or imaging instruments that either use active illumination or are sensitive to a wide range of wavelengths. Such imaging can be done between crew EVAs and/or between crewed missions. While some PSRs may be sufficiently illuminated [5] for highsensitivity cameras currently commercially available (e.g., [6]) to be used, beyond-visible wavelength (ultraviolet, infrared, etc.) imaging sensors could also be employed. In addition to multispectral imaging, other instruments to consider include: low-light imaging technologies (forward-looking infrared, FLIR; photomultiplier cameras; etc.); integration with other spatial instruments, such as LiDAR, which can operate in darkness and provide 3D data [7, 8]; and traditional and/or machine learning-assisted image de-noising methods [9].

Motion Compensation: Images obtained by cameras on mobile platforms (such as suited astronauts, rovers, etc.) can suffer from motion-related artifacts and degradation. This was the case for the footage acquired with the 16-mm motion film cameras and the TV footage acquired with the rover-mounted TV camera during Apollo. Much, but not all, of this can be mitigated by post-processing with motion-compensating software [10], but software and hardware approaches to image stabilization while the images are being collected are superior. For Artemis, avoiding, reducing, and removing motion-related image degradation will be important, particularly for mobile cameras operated in complex lighting conditions.

Image Calibration: EVA images will need geometric or radiometric calibration, or both. During Apollo EVAs, calibration requirements for film photography were met by using a deployable target (the gnomon) that integrated a scale bar, a color reference, and a rod indicating local vertical and illumination direction. For the types of imaging instruments that could be used on Artemis EVAs, the equivalent of the Apollo gnomon, potentially with additional (or alternative) calibration functions (e.g., color chips, standardized graphics) will be needed. In addition, ground control tools and procedures will be required for modern photogrammetric applications. Tools will also be needed to provide the required size and color scale and other contextual annotations (e.g., sample number, location, orientation, illumination conditions) in-frame so that images, particularly of samples and outcrops, is of optimal archival utility. Concepts of operations will be required for radiometric image calibration in the complex lighting environment of the lunar south pole (e.g., timing of when calibration is performed).

Recommendations: In preparation for Artemis, it will be important to test imaging under conditions that approximate lunar polar illumination conditions, both in controlled laboratory conditions as well as at analog field sites. This should include deployment of low-light imaging solutions, including active sensors and multispectral cameras. Technologies and techniques for motion compensation/image stabilization and image calibration will also be important in the complex lighting conditions of the lunar south pole and should be prioritized for development and testing.

References: [1] Hurtado, J.M.(Jr.) (2020) *LSSW 1*, #5130. [2] Hurtado, J.M.(Jr) (2021) *LSSW 8*, #3029. [3] Sweeney (2021) *NESF*. [4] Sweeney (2021) *LEAG*, #5050. [5] Lucey (2021) *Acta Astro.*, v.180, p.25. [6] https://global.canon/en/technology/support19.html. [7] Pilles (2021) *Earth & Space 2021*, p.541. [8] Osinski (2010) *Plan. & Space Sci.*, v.58, p.691. [9] Bickel (2021) *Nature*, v.12, #5607. [10] https://www.space.com/moon-landing-footage-remastered.html. [10] Kring D.A. et al. (2022) *LPSC LIII*, submitted.

Fig. 1. Illumination conditions at the human scale will be challenging, requiring artificial lighting as well as capabilities for imaging both brightly lit and deeply shadowed areas. Credit: NASA JSC.

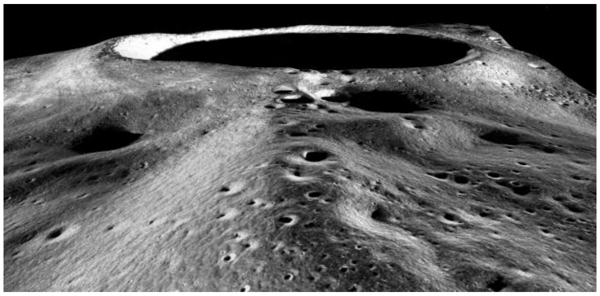

Fig. 2. Overall illumination conditions at the regional scale are illustrated in this 3D perspective view of Shackleton crater [11]. A low-light-imaging station on the crater rim, pointing into the shadowed recesses, could be used to view the interior PSR. LROC-NAC images draped over LOLA topography.

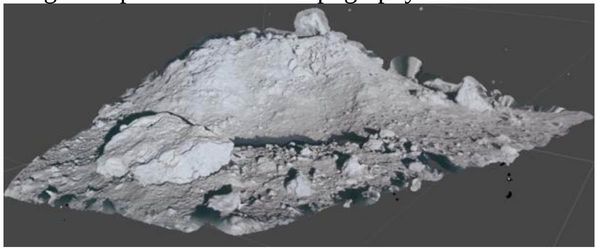

Fig. 3. 3D model photogrammetrically obtained from 4 sample documentation photos of a rock examined during Apollo 12 EVA 1, under low-sun angle conditions. Processed with Agisoft Metashape Pro.