PHOTODOCUMENTING SAMPLE SITES ON ARTEMIS MISSIONS TO THE MOON BY CLOSE-RANGE PHOTOGRAMMETRY.

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Introduction: The most important, single 'instrument' for a return mission to the Moon will be the camera. It affects practically all other science objectives by documenting not only returned samples *in situ*, but also other instrument deployment as well as specific near-by surface features of interest, but not returnable to the Earth.

During the Apollo explorations, co-author Schmitt and his 11 colleagues utilized simple documentation techniques on the lunar surface, restricted by film-based camera type, space suit limitations and lunar gravity. The Hasselblad cameras were chest mounted (to free hands), had no sighting mechanism, and, because of the gravity effects on body/suit mass, required the astronaut to make a small backwards-leaning hop to level the camera sight each time an overlapping picture in a circular panorama was taken. Or at least a bending of the knees and leaning backwards to raise the camera sight to take pictures of a sample. For these latter photos, two were usually made in the down-sun direction with slight spacing and two more in the cross-sun direction before and after the sample was removed.

In those early days, investigators assembled a panorama piecemeal by hand from prints of the individual images. Later on, computer processing enabled seamless panoramas to be made from these same images. It was also possible to extract 3D content in the form of anaglyphs from the overlaps between images as, for example, described in [**1**].

Mesh and Point Cloud 3D Models: The desire to obtain orientations of rock samples more precisely, e.g., in remnant magnetization studies, later led to a computerized close-range photogrammetric approach, which enables the production of a photorealistic model of the sample site movable in X,Y,Z space **[2]**, called a Digital Surface Model (DSM) or Digital Terrain Model (DTM). ***Fig. 1*** shows the initial sparse point cloud (FBM), before final second-stage dense point cloud generation **[3]**. The rectangles displayed in the right panel above the point cloud show the relative camera positions, which were aimed in the cross-sun direction by Schmitt of an ~3 m diameter crater that contained glass-coated rock samples near the center.

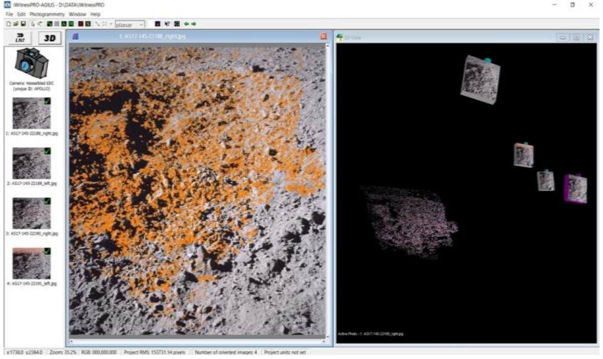

Fig. ***1.*** *The display screen of iWitness. The left sidebar shows 4 photos used in the photogrammetric process of target-free network orientation; the left panel shows thousands of automatically determined feature-based matched (FBM) points (yellow); and the right panel shows the sparse point cloud w.r.t. the computed camera-aim positions in X,Y,Z space.*

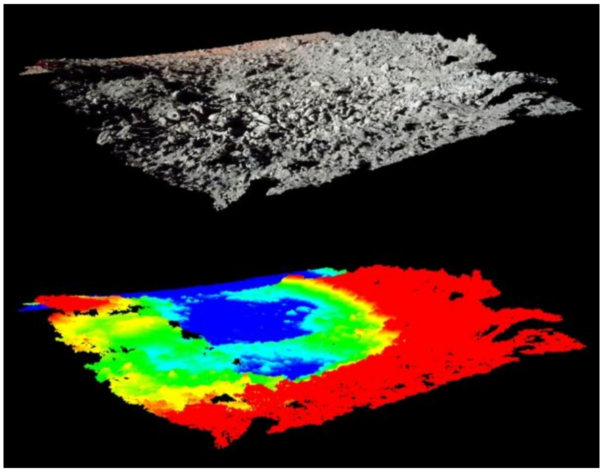

Fig. 2. *(Upper): A photorealistic display of the DSM in which millions of X,Y,Z points have been triangulated into a dense point cloud (a.k.a., LAS file). (Lower) The same point cloud displayed as a topography elevation map by assigning the R,G,B values for red, yellow, blue, etc. colors.*

Fig. 2 displays the results in two forms: one, as a photorealistic model of the scene; and two, as a color topography map. The latter shows at a glance the crateriform, circular nature of the shallow crater. This particular model is, however, restricted in movement because of the sparsity of the photo coverage. Rotation of the model much beyond the limits shown by the end positions of the 4 cameras produces distortions in the model. This problem is alleviated by increasing the number of camera positions around the crater.

A circular traverse of the crater, which had a circumference of ~10 m, with camera stations ~1 m apart would yield 10 photos, each of which should be aimed at the same center-point so that there is a good overlap with minimal perspective tilt in the images.

The result would yield a model of the site which can be rotated into any desired direction. If the photos have a scale bar, i.e., 2 known points in the scene, then the project units will be to real-world scale. It depends, in part, on camera-to-object distance, a stable lens with ideally a fixed focal length with focus set to infinity (or other pre-set focus depending on camera to object distance), preferably a prime lens. Fortunately, modern digital cameras can take and store many hundreds of high resolution photos on a small chip vs. film-based cameras of 50 years ago. Accurate distances measured by included laser rangefinders can also provide a photogrammetric scale for the generation of real-world virtual reality scenes for scientific and public use.

Because terrain characteristics of sample sites or other local areas highly differ, astronauts destined for lunar landings in the next 10 years, or on later missions to Mars, will need to go through a rigorous documentation training program to ensure adequate photogrammetric coverage in minimal time. An important aspect of the site documentation, as emphasized here, is to obtain multiple photos completely around the sampled site rather than limiting the number of exposures to up- or down-sun and cross-sun photos, 4 to 6 in number.

Modeling a larger area would also be possible, e.g., the deployment area of an ALSEP (Artemis Lunar Surface Experiment Package), either *in toto* or around each deployed package from the suite.

This white paper has not concentrated on camera type, except in a general manner related to photogrammetry. Future metric cameras with built-in photogrammetric software may produce accurately scaled, high resolution DSM models, which will be generated in near real time instead of today's post-processing computer requirements. These datasets can then be telemetered back to Earth after a particular EVA.

On the other hand, the paper has mentioned specific software because it is relatively inexpensive, very robust, and can even be used to produce point cloud models from either surface or orbital analog photographs or digital camera images. For example, ***Fig. 3*** shows the display screen of *iWitnessPROv4* after mapping 8 Apollo 17 nadir orbital photos. The resulting textured mesh (a.k.a., PLY file) is shown in ***Fig. 4***.

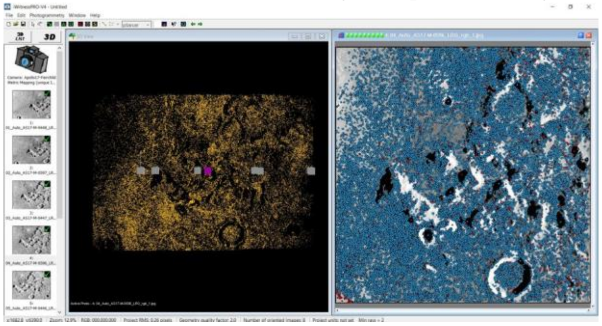

Fig. 3. *The display screen of iWPROv4 showing 5 of 8 images in the left sidebar. The 3D view in the left panel is the sparse point cloud from 8 Apollo 17 photos with their oriented camera positions above. The right panel shows one of the 8 photos (pink box in left panel) of the sparse cloud's FBM points before second stage dense point cloud generation.*

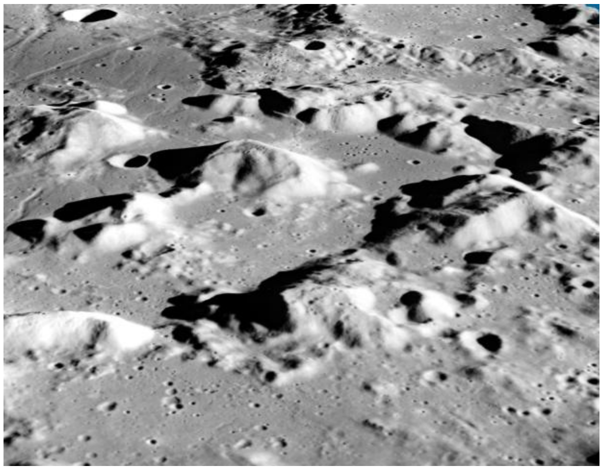

Fig. 4. *A zoomable, rotatable textured mesh DTM from 8 nadir Apollo 17 metric mapping photos showing the Valley of Taurus-Littrow. The scale is not exaggerated.*

It is assumed, of course, that the Service Module of the *Orion* Crew Vehicle will have a SIM bay containing at least an orbital mapping camera as did the Apollo CSMs. Given the colors observed by Schmitt in orbit after returning from the surface **[4]**, it is suggested that such a camera have color and multispectral sensors.

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References: **[1]** Wells, R. A., 2018. *Apollo on the Moon in Perspective: 3D Anaglyph Composites by Ronald A. Wells*, vol. 1., Apogee Books, Burlington, Ont. (http://www.apogeebooks.com). **[2]** Schmitt, H. H. *et al*., 2017. *Icarus*, **298**, 2-33, §7.0.; Wells, R. A. *et al*., 2018. 49th Lunar & Planetary Science Conference (LPI Contrib. No. 2083). **[3]** The *iWitness* photogrammetry software systems were developed by Photometrix, see: https://www.photometrix.com.au/. **[4]** Schmitt, H. H., 1974. *Geology*, v. 2, p. 55-6; Wells, R. A., & Schmitt, H. H., 2018, Color-balancing of *in situ* documentation photographs of the Apollo 17 orange and Apollo 15 green volcanic ashes. GSA, 2018 Ann. Meeting, Indianapolis, IN, https://gsa.confex.com/gsa/2018AM/webprogram/Paper317759.html; Wells, R. A. & Schmitt, H. H., 2020. Colors Across the Moon. In: Wells, R. A., *Apollo Over the Moon in Perspective*, vol. 2, p. 171 ff., Apogee Books, Burlington, Ont. In press.