PHOTODOCUMENTING SAMPLE SITES BY CLOSE-RANGE PHOTOGRAMMETRY ON A NEW CREWED MISSION TO THE MOON. Ronald A. Wells[1], Lee F. DeChant[2], Benjamin P. Weiss[3] and Harrison H. Schmitt[4]; [1]Tranquillity Enterprises, s.p., 445 Fairway Drive, Abingdon, VA 24211-3634 (ron.wells42@comcast.net); [2]DeChant Consulting Services – DCS Inc., P.O. Box 3261, Bellevue, WA 98009-3261 (lee@photomeasure.com); [3]Dept. Earth, Atmospheric, & Planetary Sciences, M.I.T., 77 Massachusetts Avenue, Cambridge, MA 02139-4301, (bpweiss@mit.edu); [4]Dept. of Engineering Physics, Univ. of Wisconsin-Madison, P.O. Box 90730, Albuquerque, NM 87199-0730, (hhschmitt@earthlink.net).

Introduction: Six stereo up-sun and cross-sun Hasselblad photos taken by Apollo 17 astronaut Harrison H. Schmitt of a ~3 m diameter crater containing the glass-coated rock breccia 70019 were used in the close-range photogrammetry program *iWitnessPro* (*iWP*) to determine the rock's orientation [**1**]. The motivation for this study was to determine an accurate position of this sample in lunar space in order to obtain a complete specification of the breccia's remanent magnetization properties. Since the rock is glass-coated, insufficient time had elapsed for micrometeoritic abrasion to be significant enough to have moved the rock. Thus, cooling of the glass through the Curie temperature likely froze in place any magnetic signature imposed by a possible lunar magnetic field. Because the orientation of samples of lunar bedrock had never been previously determined, these photogrammetric results were an important first step in providing evidence for a possible time dependent lunar paleomagnetic field. Other photos of older samples immobile until collection also exist, e.g., 75055 and 75075 from the Camelot boulder field, and are currently being processed for orientation by this technique.

Triangulation Process: Details of the use of the *iWP* software were described in [**1**]. Basically, target points are identical rocks in the first 2 of 6 sequential photos (***Fig. 1***).

Fig. 1. *Display screen of iWP showing triangulated targets (green numbers) in the first 2 stereo photos.*

The program [**2**] triangulates the positions of feature points (targets) that are cursor-marked in a process called "referencing" in the two initial photos measured. More feature points are added in the initial set of photos for a stronger camera orientation before proceeding in referencing the third and subsequent photos. The measurement process is repeated by selecting the same feature points visible in the 3rd photo, now presented as back-projected points after the photo is oriented through the process of photogrammetric resection. The referencing process is repeated in subsequent photos until a sufficient number of feature points are defined in the area of investigation. Orientation of 70019 is determined with respect to the mean x,y plane through all the X,Y,Z point values and with the solar azimuth on the date, time and place of the photos. A line drawn through the 70019 end points and, lacking a gnomon, a shadow line cast by a nearby prominent rock provided the results of ***az.*** = 247.9°, ***i*** = 9.7° [**1**].

Fig. 2. *Perspective view of the 70019 crater determined from the TIN triangulated by the iWP program.*

Mesh vs. Cloud Point 3D Models: The points in X,Y,Z space form a mesh, or Triangular Irregular Network (TIN) which *iWP* can also use to produce a 3D

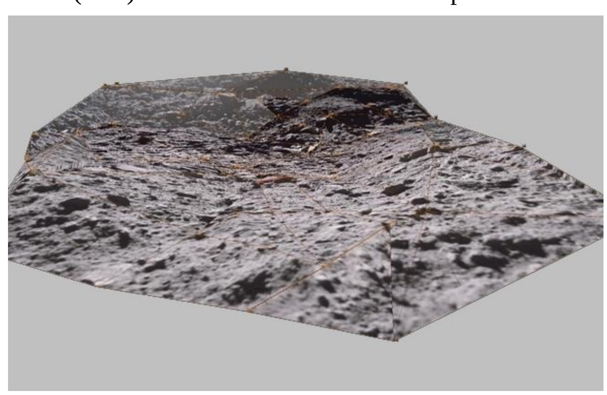

Fig. 3. *View of the TIN 3D model created by iWP, rotated into the up-sun direction.*

model or perspective view of the area under investigation (***Figs. 2, 3***). One advantage of such a model is to obtain a visual representation of the accuracy of the triangulation process. The appearance of a TIN model, however, is limited by the number of points measured and by the size of the triangles. A more realistic model

Fig. 4. *A photorealistic model produced using cloud point software. Elevation is ~30° compared with **Fig. 2**.*

can be prepared by using the stereo photogrammetry approach, where photos have an overlapping amount of surface area in common, for producing point clouds. Software like *iWitnessPRO-Agilis*™, an upgrade of *iWP* with Digital Surface Model (DSM) algorithms, can then generate the point cloud based on creating millions of X,Y,Z points, as illustrated in ***Fig 4***.

Fig. 5. shows the DSM rotated to approximately match the orientation of ***Fig. 3***. Only 4 of the 6 photos could be used for generating the point cloud, based on the requirement of stereo overlap in the common photos. The point cloud illustrated in ***Figs. 4*** and ***5*** was based on a Dense Cloud output consisting of 4,100,000 points. The photogrammetric point cloud was saved in the LASer (LAS) file format where it was exported and further reviewed in CAD, using the *FARO Zone-FZ3* software [**3**].

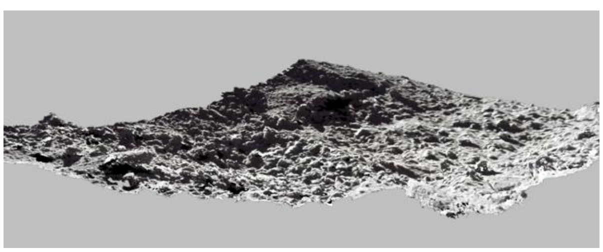

Fig. 5. *The cloud point model rotated to match the approximate view in **Fig. 3**.*

Conclusions: While a number of experiments were deployed on the lunar surface by the Apollo astronauts, the principal science return consisted of the 842 lbs of lunar rocks and associated materials from 2200 separate samples [**4**] of all 6 missions. Except for Apollo 11, all these samples were documented by Hasselblad photographs *in situ*. Only for Apollos 15,16,17 were the photos more consistently limited to "before" and "after" exposures taken in the up-sun or down-sun and cross-sun directions, usually 4 in number. A fifth photo, called the locator, attempted to include the sample, or something recognizable nearby, and the LM in the distance. Occasionally, however, stereo pairs of the sample were also made in each direction. The site coverage therefore encompassed only about 90° with just a few photos. Although the 6 photos used with *iWP* were sufficient to position 70019 accurately in X,Y,Z space, a larger number of camera positions gathered in a ring pattern around the site would have been preferable for using both measurement approaches of convergent and stereo photogrammetry and especially to reconstruct a movable 3D model of the area.

In the case of the 70019 crater, for example, which had a circumference of ~10 m, a circular traverse of it, 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. If they have a scale bar, i.e., 2 known points in the scene, then the project units will be to real-world scale (see next paragraph).

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. Fortunately, modern digital cameras can take and store many hundreds of high resolution photos on a small chip than film-based cameras of 50 years ago. Accurate distances measured by included laser rangefinders will also provide a photogrammetric scale for the generation of real-world virtual reality scenes for scientific and public use.

Future metric cameras with built-in photogrammetric software will produce accurately scaled, high resolution DSM models, which will be generated in near real time instead of today's post-processing computer requirements.

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References: [**1**] Schmitt, H. H. *et al*., 2017, *Icarus*, **298**, 2-33, §7.0. [**2**] For *iWitness* photogrammetry software systems, see: http://www.iwitnessphoto.com/. [**3**] The Faro 3D software description is given at:: https://www.faro.com/products/public-safety-forensics/faro-zone-3d/. [**4**] Curator, Johnson Space Center Lunar Sample Laboratory, Houston, TX https://curator.jsc.nasa.gov/lunar/.