LROC stereo data – results of initial analysis.

Ross A. Beyer[1,2], B. Archinal[3], Y. Chen[4], K. Edmundson[3], D. Harbour[3], E. Howington-Kraus[3], R. Li[4], A. McEwen[5], S. Mattson[5], Z. Moratto[2], J. Oberst[6,7], M. Rosiek[3], F. Scholten[6], T. Tran[8], M. Robinson[8], and the LROC Team. [1]Carl Sagan Center at the SETI Institute; [2]NASA Ames Research Center, Mail Stop 245-3 (Bldg. N245), Moffett Field, CA, USA (Ross.A.Beyer@nasa.gov); [3]Astrogeology Science Center, United States Geological Survey; [4]Ohio State University; [5]The University of Arizona; [6]German Aerospace Center (DLR), Institute of Planetary Research; [7]Technical University Berlin; and [8]Arizona State University. `http://lroc.sese.asu.edu`

The Lunar Reconnaissance Orbiter Camera (LROC) [1, 2] is currently capturing multiple overlapping images in order to derive digital terrain models (DTMs) of the lunar surface [3]. There are already ∼ 200 narrow angle camera (NAC) stereo sets with ground scales between 1.5 and 0.5 m/pixel which can be used to create DTMs.

The LROC team has representatives from six different groups (ASU, DLR/TUB, NASA Ames, OSU, U of A, and the USGS) using four different methods for creating terrain models. All of these groups have been able to process LROC images to create DTMs. Models have been made of many locales, but all groups have made models of the Apollo landing sites, as they contain useful landmarks for absolute positioning [4–6], are of operational and scientific interest as ground truth sites, and are of general interest due to their historical importance.

This analysis by different groups using different techniques on similar data allows an important initial comparison of derived camera parameters and an assessment of LROC DTM quality. Deriving DTMs of areas that include positioning landmarks [5] allows us to tie together various LRO and other lunar datasets, and to assist the Lunar Mapping and Modeling Project (LMMP) [7] in deriving DTMs and controlled mosaics of the Constellation Program's 50 regions of interest [8].

The USGS group has geodetically controlled and created DTMs from stereo pairs of images near the Apollo 16 landing site, and from a stereo triplet of images at the Apollo 15 site. Software and procedures have been developed and are being refined, which use the BAE Systems SOCET SET® [9] system in conjunction with the USGS ISIS software (`http://isis.astrogeology.usgs.gov`). An important aspect of this work is that the auxiliary software and procedures are being made available to other groups who are working with these software tools, including ASU [10], U of A, and NASA Ames. As LROC images are delivered to the PDS, other SOCET SET users will benefit from this work, as well. The USGS group is investigating methods to choose the best images for mapping, geodetically control such images to absolute lunar coordinates, and mask shadowed areas.

The OSU group uses Orbital Mapper, a software system they developed to analyze data from orbital pushbroom imaging sensors, which has proved successful in mapping the Martian surface with HiRISE stereo pairs [11]. With this system, the OSU team built a terrain model covering the Apollo 16 landing site. Terrain editing was performed manually using the Leica Photogrammetry Suite 9.3 to improve the mapping quality.

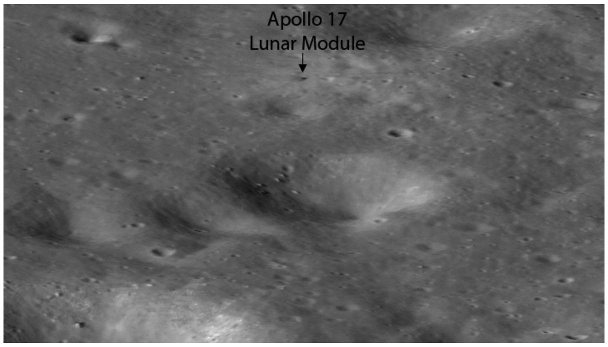

Figure 1: LROC topography at Apollo 17 from DLR/TUB.

The DLR/TUB group uses their own photogrammetry software that has been applied for many years to a variety of Solar System data [12]. They have built a model of the Apollo 17 landing site (fig. 1 and detailed in [6]) and another site.

The NASA Ames group primarily uses the NASA Ames Stereo Pipeline [13] on LROC images (fig. 2). This software has also created terrain from MOC, CTX, and HiRISE, as well as Apollo Metric Camera frames.

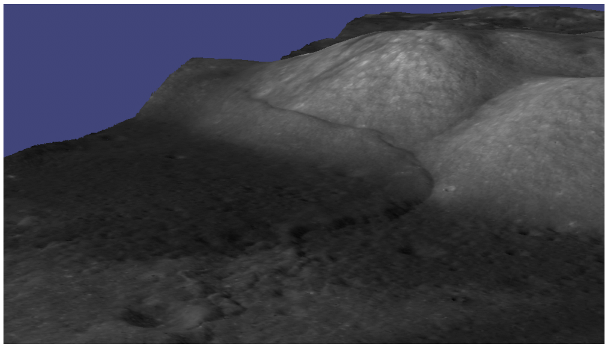

Figure 2: Lee Lincoln scarp near Apollo 17 from NASA Ames.

Improved derivation of camera parameters

LROC uses its two NACs in a side-by-side arrangement to gather a wide swath of imagery. Precisely understanding the in-flight rotation angles of the NACL and NACR telescopes relative to each other and the spacecraft is important in constructing seamless, accurate mosaics from NACL and NACR images. It is even more important when trying to reconstruct terrain from two or more stereo observations.

The DLR/TUB and OSU groups performed independent camera alignment calculations. The DLR/TUB group used the location of the Apollo 17 lander and a process of minimizing stereo ray intersection variations across another stereo model to derive one set of camera alignment angles [6]. The OSU group matched feature points across three images covering the Apollo 15 landing site and performed a bundle adjustment. This triplet of images was acquired from three adjacent orbits (left side-looking, nadir-looking, and right side-looking) providing multiple stereo geometries of the same scene. The parameters derived by DLR/TUB and OSU from different LROC images are in close agreement, and show some differences from the pre-flight measured alignment (as expected). As more of these measurements from many different images are performed in the coming months, additional refinement of the alignment parameters will be performed which will be folded into updates of the SPICE Frame Kernel.

The USGS group has created 6 DTMs from various combinations of the images from each observation of the Apollo 15 triplet set. They have confirmed that the current preferred NAC camera distortion models (S. Brylow, et al., unpublished) are correct. If the model is not applied and the 6 DTMs are merged, there are RMS height errors of up to 47 m and a similar size in bias (with numbers of points in common between models ranging from $\sim 54,000$ to ~ 5 million). If the distortion models are applied the RMS errors are at most about 5 m, and biases are at most about half that, with similar numbers of points in common (e.g. fig. 3).

Spacecraft motions during image acquisition are also a concern and can sometimes impact terrain generation. Analysis is currently underway to explore and correct this spacecraft jitter [14].

Summary

Our initial analysis indicates that the accuracy and precision of LROC stereo-derived topography are very good. The analysis resulting in 5 m RMS height errors is similar to the expected vertical precision [15] of the stereo data (e.g. with ~ 1.5 m/pixel ground scale), indicating that application of the distortion model provides subpixel precision. Similarly, an independent measure via a bundle-adjustment also shows sub-pixel precision.

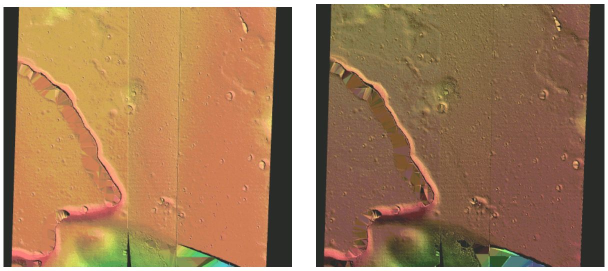

Figure 3: Color coded height (orange low, green high) merges of the Apollo 15 DTMs with (left) no distortion models and (right) the models applied. Seams are obvious in the left image and much reduced in the right image. These unedited DTMs are not combined optimally, so artifacts appear in shadowed areas. Produced by the USGS.

These initial measurements are very encouraging, and plans are underway to do more comprehensive comparison work, similar to [16]. Several strategies will be used to validate the DTMs: (1) compare terrain created from several different LROC stereo pairs of the same site, (2) compare DTMs made from the same LROC images from different groups, (3) compare LROC DTMs with DTMs from other data sets (Apollo Metric, Apollo Panoramic, Kaguya, Chanrayaan-1, etc.), and (4) use LOLA data to tie the images to ground control.

References

[1] M. Robinson, et al. In *LPSC 41*, this meeting. 2010.

[2] G. Chin, et al. *SSR*, 129:391–419, 2007. doi:10.1007/s11214-007-9153-y.

[3] R. A. Beyer, et al. In *LRO Science Targeting Meeting*, volume 1483 of *LPI Cont.*, p. 15–16. 2009.

[4] M. E. Davies and T. R. Colvin. *JGR*, 105:20277–20280, 2000. doi:10.1029/1999JE001165.

[5] B. A. Archinal, et al. In *LPSC 41*, this meeting. 2010.

[6] J. Oberst, et al. In *LPSC 41*, this meeting. 2010.

[7] S. K. Noble, et al. In *LEAG*, volume 1515 of *LPI Cont.*, p. 48. 2009.

[8] J. E. Gruener and B. K. Joosten. In *LRO Science Targeting Meeting*, volume 1483 of *LPI Cont.*, p. 50–51. 2009.

[9] S. Miller and A. Walker. In *ACSM/ASPRS Ann. Conv. 3*, p. 256—263. 1993.

[10] T. Tran, et al. In *LPSC 41*, this meeting. 2010.

[11] R. Li, et al. In *Intl. Arch. of Photogram., Remote Sens. and Spatial Inf. Sciences*, volume 37 Part B4. Beijing, 2008.

[12] Klaus Gwinner, et al. *PE&RS*, 75(9):1127–1142, 2009.

[13] Z. Moratto, et al. In *LPSC 41*, this meeting. 2010.

[14] S. Mattson, et al. In *LPSC 41*, this meeting. 2010.

[15] A. C. Cook, et al. *P&SS*, 44:1135–1148, 1996.

[16] C. Heipke, et al. *P&SS*, 55:2173–2191, 2007. doi:10.1016/j.pss.2007.07.006.