LATEST RESULTS OF 3D TOPOGRAPHIC MAPPING USING LUNAR RECONNAISSANCE ORBITER NARROW-ANGLE CAMERA DATA. R. Li[1], W. Wang[1], S. He[1], L. Yan[1], X. Meng[1], J. Crawford[1], M.S. Robinson[2], T. Tran[2], B.A. Archinal[3], and the LROC Team. [1]Mapping and GIS Laboratory, CEEGS, The Ohio State University, 470 Hitchcock Hall, 2070 Neil Avenue, Columbus, OH 43210-1275, li.282@osu,edu, [2]School of Earth and Space Exploration, Arizona State University, [3]U. S. Geology Survey.

Introduction: The Lunar Reconnaissance Orbiter Camera (LROC) [1,2], as one of seven remote sensing instruments on board of Lunar Reconnaissance Orbiter (LRO), consists of a Wide Angle Camera (WAC) and two Narrow Angle Cameras (NAC) for systematic lunar surface mapping and detailed site characterization for potential landing site selection and resource identification [3]. While global topographic information can be derived from LROC WAC images (~100 m/pixel), high-resolution (0.5 to 2 m/pixel) NAC images [1] provide high-precision topographic mapping of local areas with topographic postings of 1.5 to 5 m.

Studies on optimal methods for processing NAC stereo images to generate topographic products (DEMs, orthophotos, etc.) have been conducted since LRO was launched on 18 June 2009. A research team at the Mapping & GIS Laboratory (Lab) of The Ohio State University has developed a methodology for high-precision topographic mapping of the lunar surface. A rigorous camera model of the NAC has been developed that, along with boresight calibration and bundle adjustment, provides highly accurate geometric information [3]. A coarse-to-fine hierarchical stereo matching process provides high quality, densely matched 3D terrain points. These steps have been codified in a software package, OrbiterMapper, capable of automatic high-quality mapping of the lunar surface.

Here we present a quantitative analysis of DEM quality. With an eventual nominal vertical accuracy of 1 m after crossover solutions are performed [2,4], Lunar Orbiter Laser Altimeter (LOLA) data is an ideal control for DEM generation and a reference for DEM quality assessment. This paper first presents an evaluation of LOLA ranging accuracy at Apollo 15 landing site. For the acquisition of high-accuracy exterior orientation (EO) parameters, LOLA observations were incorporated in a bundle adjustment (BA) to resolve the issue of scale inconsistency remaining after a regular BA [3,5]. Finally, DEM quality assessment was conducted by comparing a DEM vertical profile with LOLA tracks registered with the DEM.

Evaluation of LOLA Quality: Before incorporating LOLA data into the BA and conducting a comparison between DEM and LOLA ranging, the repeatability of LOLA measurements was evaluated. In the region (latitude: 25° N – 27° N; longitude: 3.5° E – 3.7° E), preliminary (non crossover solution corrected) LOLA data (PDS, 2010-12-14) obtained on 15 orbits were selected; there are 55,273 points in total (Figure 1). Out of the 15 orbits, 12 orbits have crossover observations. Overall, 2609 pairs of crossover observations were found; their maximum, average and standard deviation of absolute ranging difference were 74.6m, 3.2m and 3.8m respectively.

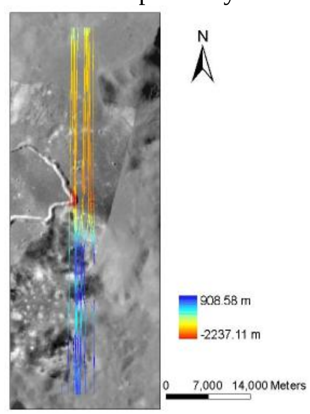

Figure 1. Distribution of LOLA tracks (25°-27° N, 3.5°-3.7° E) used for preliminary LOLA data quality evaluation. Image credit: NASA/GSFC/ASU/USGS.

LOLA Integrated Bundle Adjustment: A boresight calibration between the two NAC cameras was first performed. To remove inconsistencies between corresponding observations of the same ground point from stereo orbits and to obtain highly accurate exterior orientation (EO) parameters, a bundle adjustment (BA) must be performed before the DEM is generated. As the NAC cameras are push-broom sensors, their positions and orientations are time-dependent. Therefore, polynomial functions with time as a parameter were adapted to model the EO parameters [6]:

$$\begin{aligned} X_j^C &= a_0 + a_1 t + a_2 t^2 & \omega_j &= d_0 + d_1 t + d_2 t^2 \\ Y_j^C &= b_0 + b_1 t + b_2 t^2 & \varphi_j &= e_0 + e_1 t + e_2 t^2 \\ Z_j^C &= c_0 + c_1 t + c_2 t^2 & \kappa_j &= f_0 + f_1 t + f_2 t^2 \end{aligned} \quad (1)$$

where t is the time-dependent index number of the image line and (X_j^C, Y_j^C, Z_j^C) and ($\omega_j, \varphi_j, \kappa_j$) are the position and orientation angles of the perspective center of the NAC camera in the lunar body-fixed frame at time t when the j^{th} line of the image was acquired. The polynomial coefficients are $a_0 \ldots f_2$.

With its high level of accuracy (1 m vertical) [2,4], LOLA data, when combined with NAC imagery, should significantly increase the accuracy of ground positions determined for high-precision topographic mapping of the lunar surface [7]. The Lab has developed an algorithm for integrating LOLA data with two other types of observations, tie points and six EO parameters as pseudo observations. Verification of the LOLA-integrated BA has been performed by evaluating the residuals of tie points before and after adjustment. In addition, comparison between a DEM based on BAed EO parameters and LOLA data (next section) further demonstrates the effects of BAed EO parameters on DEM quality.

DEM Generation and Comparison: The Lab has been involved in the collaborative efforts by ASU, DLR/TUB, NASA Ames, OSU, U of A, and the USGS to assess the overall quality of LROC-derived terrain model located at the Apollo 15 landing site and Tsiolkovskiy Crater using NAC stereo imagery in both the commissioning and the nominal phases [8]. We have finished one Apollo 15 DEM using EO parameters generated by applying calibrated boresight parameters to a SPICE kernel-derived trajectory. This DEM and a perspective view are shown in Figure 2. Products of other sites are in preparation.

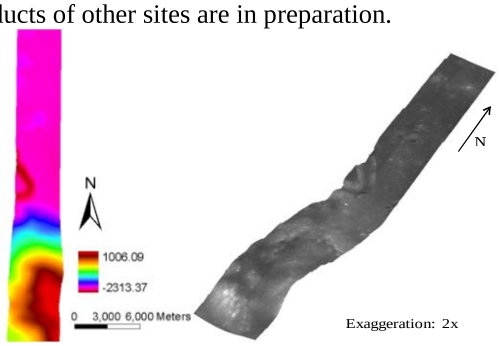

Figure 2. DEM (left) and perspective view (right) covering Apollo 15 landing site.

A new version of a previously generated DEM at the Apollo 15 landing site has been generated based on the LOLA-integrated BA and compared with preliminary LOLA data to verify its improvement. LOLA data obtained on 15 orbits were truncated within the range of the DEM. By applying a correlation coefficient between the LOLA profile and corresponding DEM vertical profile, we found that average offsets in the north-south and east-west directions were 108.6 m to the south and 51.4 m to the east. Then after these offsets were removed a comparison between LOLA profiles and two DEMs elevation profiles (before and after LOLA-integrated BA) were made for four LOLA tracks (Table 1). The BA has reduced the mean elevation difference between DEM and LOLA from a half-hundred meter level to less than five meters. Figure 3 shows the comparison on Orbit 1577 as an example.

Table 1. Vertical difference between DEM and preliminary LOLA profiles

Orbit No	LOLA vs BAed DEM Min (m)	Max (m)	Mean (m)	Std. dev(m)	LOLA vs SPICE based DEM Min (m)	Max (m)	Mean (m)	Std. dev(m)
1229	-23.69	26.68	-4.14	6.71	29.03	107.03	69.44	10.90
1577	-29.21	20.24	-2.94	8.46	-6.63	94.20	56.65	21.14
1924	-24.44	18.97	-3.90	7.92	6.45	106.15	61.10	19.64
2445	-32.75	36.81	-3.15	10.93	16.42	137.33	68.94	23.57

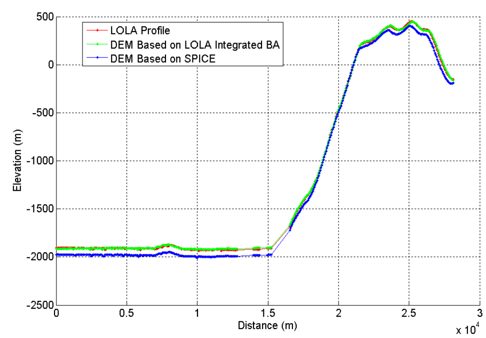

Figure 3. Lunar surface elevation profiles: preliminary LOLA versus DEM (LOLA track on LRO Orbit 1577).

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References: [1] M.S. Robinson et al. (2005) *LPSC XXXVI*, Abstract #1576. [2] G. Chin et al (2007) *Space Sci. Rev.*, *129:391-419, doi 10.1007/s11214-007-9153-y*. [3] R. Li et al. (2009) *AGU Fall Meeting*, Abstract #U31A-0008. [4] B.A. Archinal et al. (2010) *41st LPSC*, Abstract # 2609. [5] R. Li et al. (2010) LEAG, Abstract # 3038. [6] J.W. Hwangbo et al. (2010) *Proc of the ASPRS 2010 Annual Conference*. [7] J. Yoon et al. (2005) *Photogrammetric Engineering and Remote Sensing*, *71*(10), 1179–1186. [8] R. Beyer et al. (2010) *41st LPSC*, Abstract # 2678.