GENERATING DIGITAL TERRAIN MODELS FROM LROC STEREO IMAGES WITH SOCET SET. T. Tran[1], E. Howington-Kraus[2], B. Archinal[2], M. Rosiek[2], S. J. Lawrence[1], H. Gengl[1], D. Nelson[1], M. S. Robinson[1], R. Beyer[3], R. Li[4], J. Oberst[5], S. Mattson[6], and the LROC Science Team, [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, 85281, [2]U.S. Geological Survey, Astrogeology Science Center, Flagstaff, AZ 86001, [3]NASA Ames Research Center, Mail Stop 245-3 (Bldg. N245), Moffett Field, CA, USA, [4]Ohio State University, Columbus Ohio, [5]German Aerospace Center (DLR), Institute of Planetary Research, Rutherfordstr. 2, D-12489 Berlin, Germany, [6]University of Arizona, Tucson AZ.

Introduction: The Lunar Reconnaissance Orbiter Camera (LROC) [1] consists of one Wide Angle Camera (WAC) for synoptic multispectral imaging, and two Narrow Angle Cameras (NAC) to provide high resolution images (0.5 to 2.0 m/pixel) of key targets. LROC was not designed as a stereo system, but can obtain stereo pairs through images acquired from two orbits (with at least one off-nadir slew). Typically the two observations that form a stereo pair have different slew angles ranging from zero to twenty degrees [2]. To obtain the most accurate digital terrain model (DTM), the expected precision should be low (less than 1 meter) by making sure that the convergence angle between the two images be ideally more than 12˚ [3]. Off-nadir rolls interfere with the data collection of the other instruments, so LROC slew opportunities are limited to three per day.

The objective of this abstract is to (i) describe a methodology of DTM generation from LROC stereo pairs and (ii) discuss preliminary error analysis of those results. DTMs are important data products which can be used to analyze the terrain and surface of the Moon. Examples include deriving quantitative morphometric measurements (including calculations of slopes and the extraction of elevation profiles) of landforms in the Marius Hills region [4] and the Gruithuisen Domes (Fig. 1) [5]. As of December 10th 2009, we have processed 7 NAC stereo pairs to DTMs: Gruithuisen Domes, Proclus Crater, Hortensius Domes, Lee-Lincoln Scarp, Marius Hills, Reiner Gamma, and Compton-Belkovich.

Methodology: To generate the DTMs, we use the USGS Integrated Software for Imagers and Spectrometers (ISIS) and SOCET SET® [6] from BAE Systems. ISIS routines ingest the image files, perform a radiometric correction, and export to a format SOCET SET accepts. The data imported into SOCET SET are Level 1 radiometrically corrected images and relevant support parameters, such as spacecraft coordinates, altitude, sensor orientation, and lunar ephemeris.

SOCET SET uses a generic pushbroom sensor model to relate the image space to ground coordinates. Often times, there is a bias error in the camera pointing and which is corrected with SOCET SET's multi-sensor triangulation (MST) algorithm, more commonly known as bundle adjustment, to update the parameters (position, velocity, pointing angles, etc.) to improve the registration between overlapping images and between images and ground truth. MST performs an aero-triangulation using sensor position, sensor pointing, ground control points, and image tie points. Ground control points tie identifiable objects in the image with a known longitude, latitude, and (optionally) altitude, and tie points tie a point in the overlap regions of two or more images together. Selected parameters, such as the position, velocity, and pointing angles of the cameras are adjusted so that the RMS error for all ground and tie points is minimized. When working with LROC stereo images, typically RMS errors are ~0.25 pixels, and are rarely larger than 0.4 pixels.

After MST, we perform a pair-wise rectification. This process rotates the images so that the epipolar lines are horizontal and scales the images to a common resolution. The rectified images make stereo vision easier for human eyes and is also required for generation of the DTM with NGATE (SOCET SET's Next Generation Automatic Terrain Extraction algorithm) [7]. NGATE performs image correlation and edge matching for every single pixel in each image to create a dense model. The result is then re-sampled to the desired DTM resolution (meters/post) that can be anywhere between 3 to 10 times the ground scale of the original images to minimize noise. For images with high Sun, results from NGATE require very little editing. However, images with areas of instrument saturation or low Sun (large shadowed regions) require intensive editing to interpolate across areas of no ground data.

Standard products can be generated from the resulting terrain model, including DTMs in ISIS cube and GeoTIFF formats, and orthorectified images. In addition, color shaded relief and perspective views can be generated using the original image and the DTM (Fig. 2). The LROC Team will make these products available to the science community when error analysis and documentation is complete.

Error Analysis: The quality of a DTM is not one quantity but a combination of many absolute and relative accuracies and precisions. As LOLA data becomes broadly available, absolute accuracy of LROC DTMs will be addressed in detail [8]. This section will focus on the relative accuracy analysis of the DTMs (relief and slopes internal to a model).

Initially, the stereo model only contains tie points and no ground control points. The position and orientation of the DTM are tied only to the approximate spacecraft position and orientation information provided with the images. Because there is nothing that ties the images to the ground, artificial tilts can occur. For example, the DTM of Gruithuisen Domes shows a 6° regional slope in the mare and previous knowledge of lunar surface indicates that the slope is not likely to be more than 1°. A first order slope correction to the DTM was derived by placing two Z-control points in the mare as far apart as possible and setting their elevation to be the same. Other solutions require knowing the absolute latitude, longitude, and elevation. Applying the same type of correction but using LOLA elevations as control points will allow us to completely remove regional tilts inherent in stereo datasets.

Spacecraft induced jitter during stereo image acquisition results in artificial topographic ripples in some NAC DTMs [9]. We see these artifacts in about 10% of stereo models taken during the commissioning phase. The LROC Team and the LRO project are working to determine the cause of the jitter and mitigate the problem in the mapping phase [9]. The artificial ripples are readily apparent in derived shaded relief products with illumination along the down track direction. For the Giordano Bruno DTM (Fig. 3) the jitter is seen as consistent banding in the cross-track direction, with higher frequency bands that occur every ~200 meters and lower frequency bands that occur every ~800 meters.

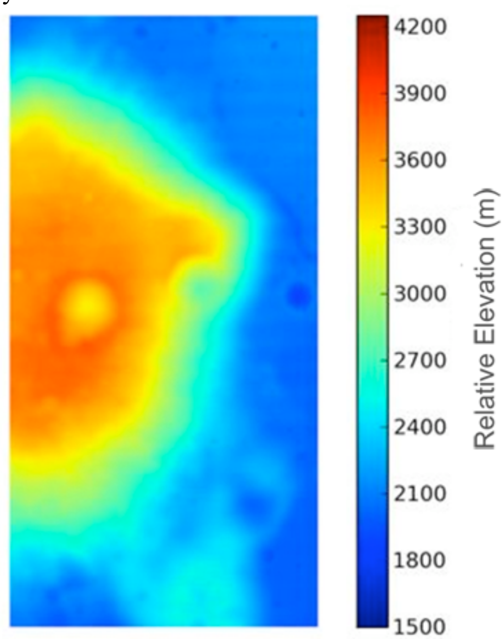

Fig. 1. Color shaded relief map of Gruithuisen Gamma

Future Work: NAC derived DTMs are an important data product for science analysis. Therefore, it is important that the DTMs portray terrain as detailed and accurate as possible. Coordination amongst the LROC team and the Lunar Mapping and Modeling Program (LMMP) will result in a detailed error analysis [8,10-11] that will allow us to fully understand the capabilities of the DTMs made from LROC datasets.

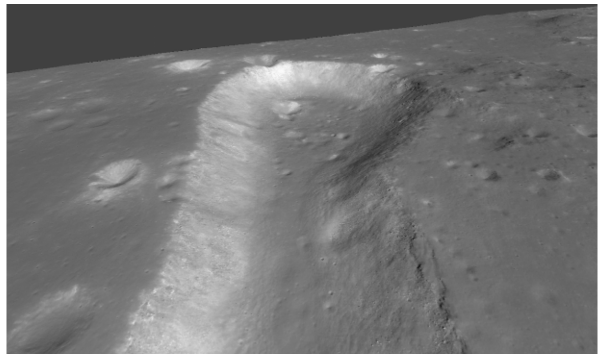

Fig. 2. Reconstructed perspective view of Sinuous Rille A in the Marius Hills region.

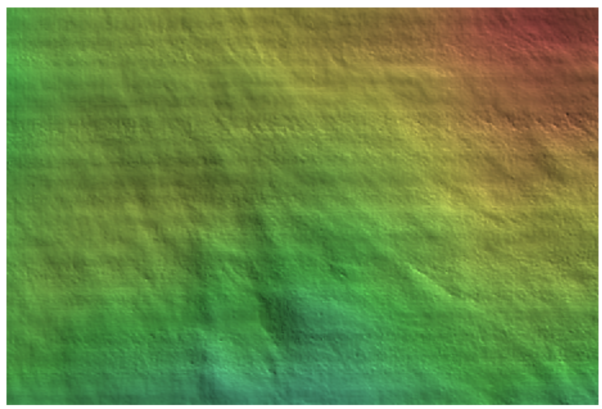

Fig. 3. Jitter patterns in the Giordano Bruno DTM.

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