CONTROLLING LROC NAC PHOTOMETRIC IMAGES. A.C. Martin, A.K. Boyd, M.S. Robinson and the LROC Team, [1]Arizona State University, School of Earth and Space Exploration, PO Box 873603, Tempe AZ, 85287-3603 acmart19@asu.edu

Introduction: Analysis and interpretation of mosaics, photometric sequences, temporal pairs, and other observations all benefit from geometric control. Science output from the high-resolution Lunar Reconnaissance Orbiter (LRO) Camera (LROC) Narrow Angle Camera (NAC) images is increased through accurate and precise geometrical control to a common ground.

LROC is one of seven instruments on LRO. LROC is composed of three camera subsystems: two Narrow Angle Cameras (NAC) and one Wide Angle Camera as controlled through the Sequence and Compressor System [1].

A NAC image is a series (typically 52,224) of individual, 1x5064-pixel integrations. From an altitude of 50 km, the image spans 2.5 km in width and 26 km in length with a pixel scale of 50 cm. Left and Right NAC images are taken simultaneously, where NAC-Left is pointed away from the NAC-Right at ~2.85 degrees, producing a 135-pixel overlap (from 50 km altitude) between the pair. The square pixel integration time at this altitude is 0.000337 seconds per line requiring 18 seconds to capture a full NAC image. From an altitude of 100 km, the nominal square pixel integration time would double [1].

Photometric Sites: Images acquired of the same feature across different incidence, emission and phase angles make up a photometric site. To extract accurate photometric information from a sequence each image is tied to a NAC Digital Terrain Model (DTM) [2] derived orthophoto (ground truth), facilitating precise photometric angle calculations using the NAC DTM. [3]. Up to 100 overlapping images are acquired at each site of interest as incidence and emission angles vary. LROC observing constraints allow for phase angles ranging up to 115°.

For control, the images are sorted by incidence angle according to the following classification scheme: 0°-30° are low, 35°-60° are medium, and 65° and greater are classified as high incidence angle enabling images that look alike to be controlled at the same time, avoiding eye strain.

Images in photometric sites are tied to the ground source only, making the process different than controlled mosaics [2] which are also tied to areas of overlap within each image in the mosaic.

Processing: Running a series of USGS Integrated Software for Imagers and Spectrometers (ISIS) programs [Table 1], some specific to LROC, transforms the NAC Experiment Data Records into radiometrically precise ISIS cubes with spacecraft position and orientation information attached. Controlled images then have the spacecraft orientation updated, and as a requirement of LROC NAC photometric efforts, the images are projected onto high resolution local area NAC DTMs [5].

Calibration	Description
lronac2isis	imports LROC NAC images to ISIS cubes
lronaccal	radiometrically calibrates LROC NAC images
lronacecho	removes echo from LRO NAC images
spiceinit	update the SPICE kernels
camstats	generates camera statistics
footprintinit	allows the user to view the polygons in qmos
qmos	*ISIS program that analyzes cube footprints*
qnet	*ISIS program that creates and edits control networks*
Bundle Adjustment	
jigsaw	performs a bundle adjustment on the overlapping level 1 cubes and defines control point coordinates and reduces boundary mismatches
Map Projection	
camstats	generates camera statistics
phocube	calculate the angles
cam2map	converts the images to be map projected to three dimensional coordinates
qview	*ISIS program that displays and analyzes cubes*

Table 1: ISIS commands needed to process Level 1 Cubes, Bundle Adjustment, and Level 2 Cubes with a description of how they work.

The bundle adjustment process is started as images are opened in the ISIS program *qnet* to create a control network with tie points that contain information on the spatial orientation and relation between images and the ground [4]. All images are tied to only the ground source, which is a NAC DTM-derived orthophoto, while the radius source is the NAC DTM. A typical control grid for a photometric site (7.5 km x 40 km) is

Jigsaw Application	
observations=yes	allows the images to be treated as single observations
radius=no	radii of the points will not change
outlier_rejection=no	does not allow outliers to be rejected
camera_angles_sigma=0.01	uncertainty for camera angles
imagescsv=no	flags output of image data
output_csv=no	flags output of point and image data
point_latitude_sigma=0 point_longitude_sigma=0 point_radius_sigma=0	Set to zero for little to no movement in the points

Table 2: Significant parameters in jigsaw. Points are considered truth and the bundle adjustment prohibits warping of the images.

comprised of 60 unique geographic locations spaced apart across the orthophoto totaling ~1000 tie points amongst all images. The number of unique locations and tie points increases with greater DTM coverage. Each image is tied to the ground well enough that there are minimal offsets between the orthophoto and images after the *jigsaw* bundle adjustment [4].

Jigsaw bundle adjustment: Parameters for photometric sites allow the images to be treated as single observations, do not use outlier rejection, and do not allow ground points to move [Table 2].

Checking for large offsets before submitting the cubes to level 2 processing involves examining the jigsaw output. Jigsaw produces an overall summary of the bundle adjustment and an in-depth table of tie point residuals [4]. The residuals provide specific information about each point in each image.

The magnitude values are sorted from highest to lowest to get a better understanding of what images or what location are causing errors in the bundle adjustment. The most important parameters to determine unacceptable errors in the bundle adjustment are the X and Y residuals, total residual magnitude, ground location, and image name.

To fix large residual values, the control network and the DTM-derived orthophoto are opened in *qnet*. The points with largest residuals are selected, and the error image is consulted for offsets in the tie point. If the image is too noisy or the slew angle is too large, the point will not match properly resulting in high magnitude errors. The tie points are then either fixed or ignored if a match cannot be made. Figure 1 shows sample and line residuals from the final *jigsaw* bundle adjustment for the Reiner Gamma photometric site. The larger residuals in the sample direction are likely caused from images with large slew angles where small roll or vertical position errors in the spacecraft result in large motions in the sample direction.

*Map Projection***:** Once the error analysis is completed and *jigsaw* has updated the pointing information, the images can be processed to level 2 data products. *Phocube* calculates the phase, emission, and incidence angles using the NAC DTM, and *cam2map* map projects the images by wrapping them to the three-dimensional NAC DTM, seen in Table 1.

The final products are opened in *qview*, where they are visually inspected by comparing them to each other and the DTM. If there is minimal to no offsets between the map projected images, then the level 2 cubes are ready for release.

Summary: Photometric sites offer unique information about planetary surface properties with many different viewing geometries and lighting conditions paired with the specificity of illumination and viewing angles computed from NAC DTMs.

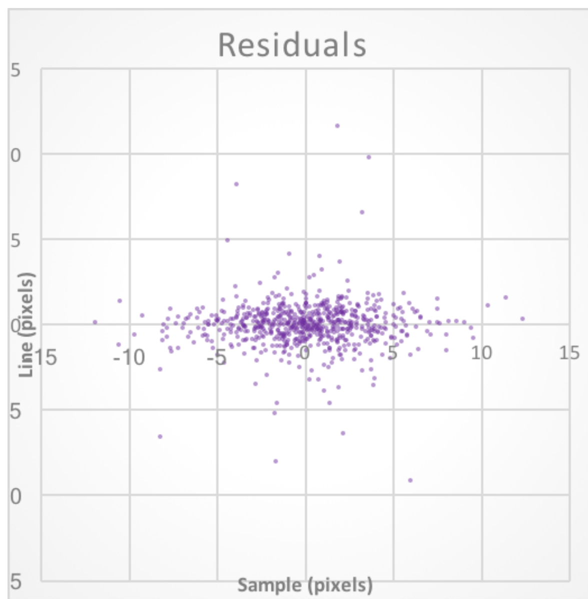

Figure 1: Residuals from the Reiner Gamma photometric site. The line direction is in the line of flight of the spacecraft, and the sample direction is perpendicular to the direction of flight and parallel to most slew directions.

References: [1] Robinson, M.S. et al. (2010) Space Sci Rev, 150:81-124. [2] Klem, S.M. et al. (2014) *LPS XLV Abstract #2885* [3] Woodham, R. J. (1980) *Optical Engineering*19. [4] J.A. Anderson et al. (2004) *LPSC XXXV, Abstract #2039.* [5] M.R. Henriksen et al. (2015) *Second Planetary Data Workshop. Abstract #7033.*