LROC NAC FEATURE MOSAICS: A POWERFUL TOOL FOR LUNAR LANDING MISSIONS.

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Introduction: Lunar Reconnaissance Orbiter camera (LROC) Narrow Angle Cameras (NACs) capture high spatial resolution (0.5-2 m/pixel) images for Feature Mosaics (FMs) production [1]. FMs consist of two or more NAC pairs that have been taken on sequential orbits and controlled to produce accurate, high resolution maps with consistent lighting geometry and pixel scales for areas of interest larger than a single NAC pair. LROC NAC FMs can be used for a multitude of scientific and exploration tasks, including planning for human and robotic missions. Here we present a summary of FM production and availability, their scientific and engineering applications, and ways users can access these products.

NAC Feature Mosaic Production: Since entering lunar orbit in June of 2009, 1,359 FM image sets consisting of 2 to 10 NAC pairs have been acquired, with an average of 3 pairs per set. Of these image sets, 309 have been processed into controlled FMs that have been released to the LROC Planetary Data System (PDS) node. The LROC NAC system consists of a NAC-Left and a NAC-Right camera with a combined 5.7° field-of-view with an average 135-pixel intersection between the left and right images [1]. A FM consisting of three NAC pairs covers an approximate ~35 km x ~70 km area at a median pixel scale of 1.3 m, resulting in an average of 2.7x more coverage than in a single NAC image pair.

Processing: A FM is produced using the USGS Integrated Software for Imagers and Spectrometers (ISIS3) [2]. NAC images are first radiometrically corrected; noise is removed through image calibration, images are sharpened by echo correct, and a priori spacecraft position and pointing information is integrated using the Navigation and Ancillary Information Facility (NAIF) SPICE system [2,3].

A control network is made by automatically adding tie points in the region where two or more images overlap. The control network is then examined and edited to manually add ground control points and supplementary tie points (in lieu of the misplacement of automatic points) [Fig. 1]. Tie points control an image to another image. Ground points control the images to an orthophoto derived from a NAC digital terrain model (DTM)[4]. If a NAC orthophoto is unavailable, a nadir-looking NAC pair projected onto the Wide Angle Camera (WAC) GLD100 DTM (a 100 m/pixel global DTM merged with Lunar Orbiter Laser Altimeter (LOLA)), is used [Fig. 1] [4,5].

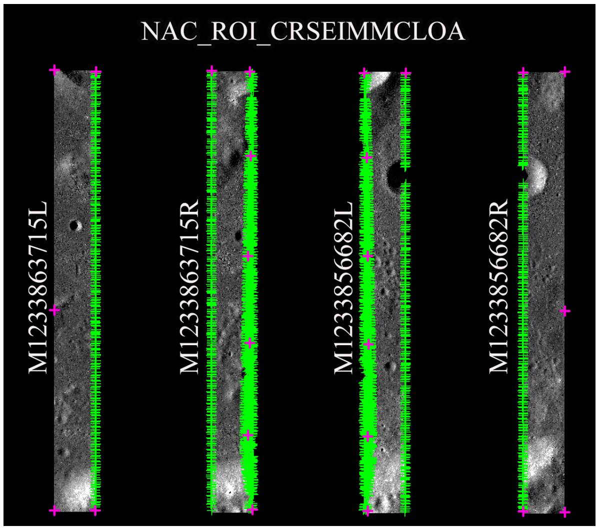

Figure 1: Example of a 2 pair control network. Magenta points represent ground points, green are tie points.

After all the points are added, a bundle adjustment optimizes the C-Kernel (spacecraft orientation) minimizing cartographic offsets between images [6]. *Jigsaw*, the ISIS3 bundle-adjustment tool, provides residual projection errors for all tie points. Tie points are corrected or removed until the maximum point residual is <5 pixels and the overall residual value, *Sigma0*, is <1.0 pixel [6]. Images are photometrically corrected and the corrected cubes are then map-projected in Equirectangular (65°S to 65°N) or Polar Stereographic (±65° latitude to the poles) projection, and mosaicked [7]. The controlled products are released to the LROC PDS node as Reduced Data Records (RDRs) [8].

Landing Site Applications: FMs are useful for both assessing potential science targets of a proposed landing site, as well as assessing that region for landing and traverse hazards. These mosaics allow for detailed landform studies of features >5 m and accurate coordinate derivation (±20 m) [9].

High resolution images, along with knowledge of topography and illumination conditions are required to confidently plan for landing site safety and traversability [10]. Landforms such as craters and rocks can prove detrimental for a lander or rover, and FMs enable estimation blocks at meter scales. We have FM at both high and low Sun for some areas, the high resolution and variability of lighting conditions in NAC observations allows for measurement of surface properties that can be used to calculate rock abundance, or the cumulative area covered by rocky material [11]. NAC FMs are frequently acquired at large incidences angles (mean of 74°), making them ideal sources for hazard analysis.

Seamless maps of a landing area with large coverage, varied lighting conditions, and relative accuracy are effective tools for exploring the potential in landing sites [12]. Variations in lighting conditions between FMs allow for features that are otherwise shadowed to be revealed. Low incidence FMs emphasize albedo variations allowing for composition and maturity analysis. In Fig. 2, two FMs of the same Larmor Q crater show vastly different results. One was made with a 62° incidence angle and eastern solar azimuth shadowing part of the crater wall, but highlighting small topographic variations. The second was acquired with a 38° incidence angle and western azimuth revealing the full extent of the crater and ejecta and emphasizing albedo variations. [Fig. 2].

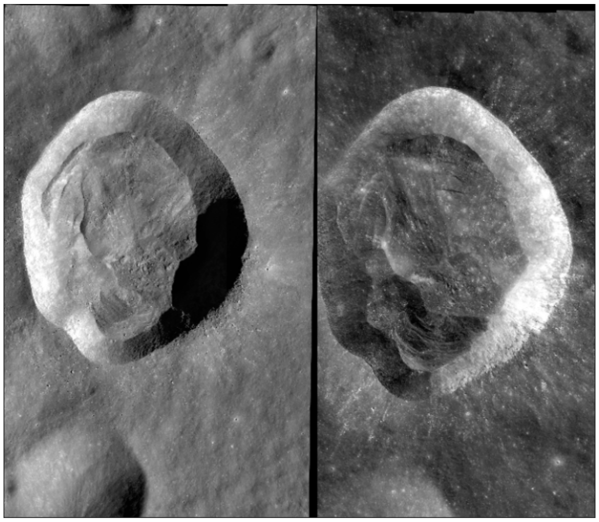

Figure 1: (left) Larmor Q (NAC_ROI_LARMORQ_LOA) with illumination from the east at 62° incidence (right) Larmor Q (NAC_ROI_LARMORQ_HIA) with illumination from the west at 38° incidence. The change in Sun direction and angle allow for features like ejecta and floor morphology to become visible, thus, permitting a detailed hazard analysis.

Finding Products: FMs and NAC images targeted for FMs can be viewed and downloaded through the LROC website and PDS node [Table 1] [8]. Users can search for controlled FMs by feature name or coordinates, browse all existing FMs, and download shapefiles with FM locations. FMs can also be found on Quickmap and Lunaserv, an open-source Web Map Service (WMS) application specifically designed to support planetary bodies [Table 1] [13,14]. Users can access Lunaserv with any WMS-capable GIS software or online with Lunaserv Global Explorer (LGE) [15]. Lunaserv and Quickmap contain regularly updated layers for many lunar data sources including shapefiles of controlled and targeted FMs [Table 1]. Access to these and additional resources can be found in the archive section of the LROC website [16]

Interface	*Product*
LROC RDR interface PDS node	*SHAPEFILE_CONTROLLED_MOSAIC (completed FMs)*
	SHAPEFILE_FEATURED_MOSAICS (targeted images for FMs)
ACT-REACT Quickmap	*LROC NAC -> NAC ROI mosaics*
	LROC NAC -> Feat. Mosaics Observations
Lunaserv (WMS)	*luna_nac_controlled_mosaics*
	luna_nac_featured_mosaics

Table 1: FM product locations and downloadable information/ layers.

Summary: FMs provide accurate and virtually seamless high-resolution products with consistent lighting over large regions without discontinuities, useful for mission planning, science investigations and resource analysis. FMs cover past landing sites, potential landing sites, and a host of key science targets. Due to the LRO orbital inclination increasing over time (drifting away from the poles) we can no longer acquire images located 86.9° N and 86.3°S to the poles without slewing. An average of 15 new FMs are released to the PDS every 3 months and work is on-going to continue to improve the controlled mosaic production process.

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[15] http://lunaserv.lroc.asu.edu/
[16] https://www.lroc.asu.edu/archive.