In-Flight Geometric Calibration of the Lunar Reconnaissance Orbiter Camera

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The Lunar Reconnaissance Orbiter Camera (LROC) consists of two imaging systems that provide synoptic and high resolution imaging of the lunar surface. The Wide Angle Camera (WAC) is a seven color (315, 360, 415, 566, 604, 643, 689nm) push frame imager with a 90° field of view in monochrome mode and 60° field of view in color mode. From the nominal 50 km polar orbit, the WAC acquires images with 100 meter pixel scale for the visible filters. Since signal is low in the UV bands, the data is acquired by summing a 4x4 set of pixels thus providing 400 meter pixel scale UV images. The WAC consists of two sets of optics (UV and VIS) that project onto a single CCD. Geometric calibration was performed before launch using a collimated light source (pinhole) and rotating the instrument on a rotary stage to build up a dense set of pinhole observations.
The Narrow Angle Camera (NAC) consists of two cameras that provide images at a pixel scale of 0.5 to 2.0 meters. Each NAC consists of a 5064 pixel wide line scan CCD with a field of view of 2.86°. Combined, the NACs have a field of view of 5.7° and have a total ground track swath width of 5 km from the 50 km orbit. The NACs were calibrated using a rotary stage and a bar pattern. The results of the pre-launch calibration were then used to define the proper focal length, boresight, and distortion coefficients to provided a baseline for initial observations and further in-flight calibration.
Since the launch of the Lunar Reconnaissance Orbiter, LROC has acquired over 600,000 observations. Using this in-flight dataset, and known targets on the lunar surface, we have re-calibrated both camera systems. For the in-flight calibration of the NAC, we map projected several thousand NAC image pairs and coregistered surface features found in both images to analyze the relative angular offsets between the two cameras. In addition, using the known locations of the laser ranging retroreflectors found at three Apollo sites (AP11, AP14, and AP15) and Lunokhod 2 the absolute camera pointing was improved. The result of the NAC in-flight calibration is a new C-kernel (CK), which defines the pointing of the two NACs with respect to the spacecraft as a function of slew angle and instrument temperature.
In addition, we have also recalibrated the WAC using NAC images. The NAC optics are very well characterized geometrically, and the improved pointing enables accurate placement of NAC images to within fifteen meters, which is a less than a fifth of a WAC pixel. With the baseline correction calculated from pre-flight experiments, we identified residual geometric errors of one to two WAC pixels in the original camera model. Since the NAC field of view is always in the same cross-track location in the WAC frame, NAC and WAC images acquired of the same regions at different times and under similar lighting conditions were map projected. Hundreds of NAC (truth image) and WAC images were then coregistered using an automatic registration algorithm. The

registration offsets were then converted into focal plane coordinates for the distorted (original) and undistorted (corrected location derived from the truth image) pixel. With this dataset, offsets in the WAC distortion model were identified and accounted for with a new camera model. This technique improves the accurate placement of each WAC pixel across the sensor in target space to the sub-pixel level. These corrections for both the NAC and WAC will be included in new frames kernel (FK), C-kernels (CK), and instrument kernels (IK) in an upcoming release through NAIF and USGS.