CONTINUING ANALYSIS OF SPACECRAFT JITTER IN LROC-NAC. Sarah S. Mattson[1], A. Bartels[2], A. Boyd[3], P. Calhoun[2], O. Hsu[2], A. McEwen[1], M. Robinson[3], J. Siskind[4], T. Tran[3], and the LROC Team. [1]University of Arizona (1541 E. University Blvd., Tucson, AZ 85721, smattson@pirl.lpl.arizona.edu), [2]Goddard Space Flight Center, [3]Arizona State University, [4]NYCB Real-Time Computing, Inc.

Introduction: The Lunar Reconnaissance Orbiter (LRO) has been flying in its nominal, or mapping, orbit of ~50 km above the surface of the Moon since September 15, 2009 [1]. The Lunar Reconnaissance Orbiter Camera Narrow Angle Camera (LROC-NAC) takes high resolution images using two identical line scan cameras (NACL and NACR) with pointing offset from each other by ~2.79º cross-track and ~0.082º along-track. This results in a measured average along-track offset of ~67-127 lines, depending on summing mode and scanning rate, and an overlap of the L-R footprints of 68 or 136 pixels in summed or non-summed mode, respectively. The along-track offset was planned to provide a measure of pointing jitter at a higher frequency than is provided by the spacecraft Attitude Control System (ACS). The high spatial resolution (10 μrad IFOV, or up to 0.5 m pixel scale) [2] makes NAC images susceptible to spacecraft jitter that results in geometric distortions in line scan images. This was shown to occur and to have negative effects on Digital Terrain Model (DTM) quality during the Commissioning Phase of LRO [3,4].

Here we present the ongoing study of mapping orbit jitter, its effects on DTMs, and potential mitigation strategies. LRO is currently operating in the Science Phase of the mission and plans are to return to an orbit similar to that of the Commissioning Phase (fixed 27x216 km elliptical orbit) in the latter part of 2011.

Measuring Jitter in LROC-NAC Images: The method for measuring jitter from non map-projected images remains much the same as in [3]. The overlapping portion of each NACL and NACR images is cropped out. The Integrated Software for Imagers and Spectrometers Version 3 (ISIS3) application *coreg* [5] is used to measure pixel offsets in the line (along-track) and sample (cross-track) directions in the overlapping area. Improved radiometric calibration for LROC-NAC incorporated into ISIS results in measurements of high confidence at the sub-pixel level. Pixel offsets are measured in images without any a priori pointing information (fig. 1).

Mapping Phase vs. Commissioning Phase Jitter: Spacecraft jitter was lessened when the spacecraft went from the Commissioning orbit to the 50-km circular Primary Phase orbit. This reduction was demonstrable by the improved quality of DTMs using mapping orbit stereo images. The suspected cause of the improvement is the range of solar array disturbance frequencies during the Commissioning Phase included dominant solar array resonance modes that affect NAC stereo images, whereas in the mapping orbit the dominant resonance modes were outside of the range of disturbance frequencies. The solar arrays are stowed in the beta=90º position during beta>53º, which improves stability during optimal NAC stereo imaging conditions. However, jitter does still occur in the mapping orbit, causing noise and artifacts in DTMs (fig. 2), although for the most part these effects are typically 10x less than those seen in the Commissioning Phase orbit.

Jitter effects in DTMs: In almost all cases, spacecraft jitter causes no obvious distortions in LROC-NAC images. However, even imperceptible geometric distortions degrade the results of stereo matching software used in DTM production. These effects have been observed in some DTMs produced from NAC stereo images by all groups making DTMs, regardless of the method or software [4,6]. A significant number of stereo images acquired in the Commissioning Phase had a level of jitter that caused a distinctive ripple pattern in the DTM [3,4] (fig. 2, left). This pattern is parallel to the cross-track direction, indicating that the distortions responsible are predominantly in the sample, or spacecraft roll, direction [7]. Distortions in the line direction, or spacecraft pitch, cause y-parallax during stereo

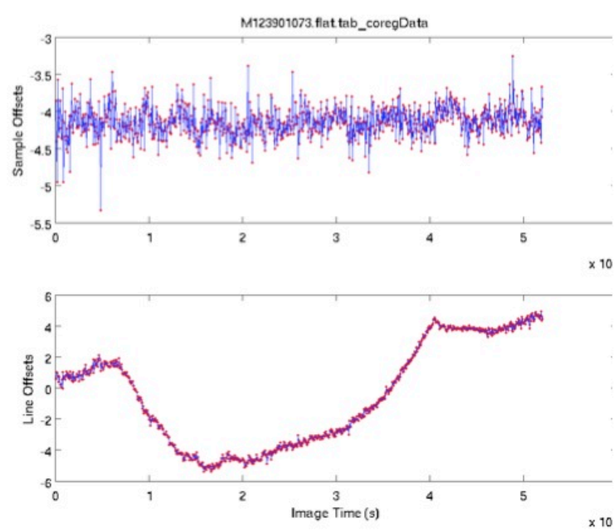

Figure 1. Typical jitter plot from ISIS coreg data, NAC frame M123901073. Sample (top) and line (bottom) offsets are in pixels, and are plotted vs. image time in seconds. The topographic signal is obvious in the line offset plot. This NAC frame was part of a DTM that had jitter artifacts (like the ripples in fig. 2, left).

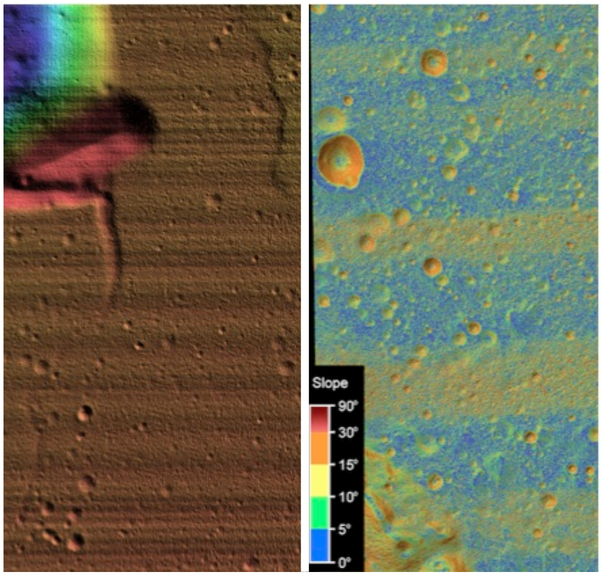

Figure 2. Colorized shaded relief image of a Commissioning Phase DTM (left) showing the ripple pattern of 10s of m in elevation. Science Phase DTM (right) slope map showing noisy bands, but no ripples, from jitter. The bands are not elevation changes. Jitter effects are most apparent in flat topography.

matching, which generally introduces noise into the DTM (fig. 2, right).

Observed Jitter Characteristics: Typical jitter amplitudes range from 0.2-2 pixels. Problematic jitter seems to correlate with amplitudes >1.5 pixels, particularly in the sample direction. Frequencies in the coreg data are seen to cause problems at ~6 Hz. However, the frequency in the measured pixel offsets is not the same as the absolute motion frequency, which is derived by deconvolving the signal with the along-track time offset using Fourier analysis [8]. Because the NACs are pointed slightly differently, the resulting jitter plots are sensitive to lunar topography, particularly in the along-track direction, as it is a line scan camera. We do not consider the topographic signature as jitter, but is can be useful for understanding when jitter is significant.

Correlations with Engineering Data: The CKs (pointing kernels) do not describe the spacecraft jitter. This is apparent in the DTMs, which are produced from images with pointing information applied, but which still contain jitter distortions. The ACS uses 10 Hz gyro angular rate measurements, as well as 5 Hz attitude data from two star trackers, to provide telemetry used for estimating the current pointing. Both the gyro and star tracker data are fed through a 6 state Kalman Filter which generates the pointing telemetry. The gyro rates are averaged over measurement intervals which span 200 milliseconds, and the conclusions of both the gyro and star tracker measurement intervals precede the nominal time at which the telemetry is valid by ~60 milliseconds. The star tracker attitude data is propagated, but only by assuming a constant angular rate derived from the previous 5 Hz rate estimate. Therefore, the data associated with the CK files contain time offsets between the time stamp and the attitude solution.

This situation makes it somewhat difficult to accurately correlate estimated attitude with high frequency, small magnitude jitter detected in NAC images. It also implies that jitter correction may be best approached by the current method of measuring it in the image data. The ACS telemetry is detailed enough though, that some causes of jitter may be discernable and preventable, preferably without having to modify flight software.

Discussion: Mission operations are interested in employing mitigation strategies noted above to reduce the problem of jitter in NAC stereo images, but have to balance the needs of spacecraft and other science instrument requirements. Current and future study will focus primarily on stereo imaging and DTM quality. NAC DTMs are high value products for science and for future exploration planning, so jitter effects are considered a serious problem.

Removing the topographic signature from the along-track signal using the concurrent Lunar Orbiter Laser Altimeter (LOLA) [1] data is being investigated as a possible enhancement to this analysis. The ultimate goal is to correct for jitter in the images, not for topography.

If image correction is possible (i.e. if the absolute jitter function is derived correctly using methods described in [3,8]), two possible approaches should be considered. One would be to transform the image pixels using the ISIS application *slither*. The other approach could incorporate the pointing information, combining it with the derived jitter function appropriately, and using an updated pointing kernel to correct for jitter as in [7], before import into stereo processing software [e.g. 4,6,7].

References: [1] R. Vondrak, et al. (2010) *Space Sci Rev*, vol. 150, 7-22. [2] M.S. Robinson, et al. (2010) *Space Science Reviews* 150:81-124. [3] S. Mattson, et al. (2010) *LPSC XLI*, #1871. [4] T. Tran, et al. (2010) *LPSC XLI*, #2515. [5] J. A. Anderson, et al. (2004) *LPSC XXXV*. [6] R. Beyer, et al. (2010) *LPSC XLI*, #2678. [7] R. Kirk, et al. (2008) *JGR-Planets*, vol. 113, E00A24. [8] S. Mattson, et al. (2009) *EPSC Abstracts*, vol. 4.