EARLY ASSESSMENT OF SPACECRAFT JITTER IN LROC-NAC.

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Introduction: The Lunar Reconnaissance Orbiter Camera Narrow Angle Camera (LROC-NAC) currently flying onboard the Lunar Reconnaissance Orbiter (LRO) is comprised of two identical pushbroom cameras with a pixel scale of up to 0.5 m [1]. High resolution pushbroom cameras are susceptible to spacecraft motions (i.e. jitter) because they build an image line by line at line times corresponding to the ground-track velocity and the IFOV of the detector. The rapid line time (typically 337 to 1200 micorseconds) and high resolution combine to capture jitter in the form of (usually) small undulating geometric distortions aligned parallel to image lines. Understanding the frequency and magnitude of jitter is critical to guide mission operations to mitigate the sources of jitter and for post-processing removal of noise from derived Digital Terrain Models (DTMs). This abstract presents results of jitter analysis using NAC images acquired during Commissioning and early Primary Mapping Phases. Characterizing and correcting jitter distortions may be needed for future missions such as the Jupiter Europa and Ganymede Orbiters (JEO and JGO) [2].

LROC is mounted in a fixed position on the spacecraft, but its stability can be affected by several mechanisms on LRO: gimbals on the Diviner instrument, solar panels, or high-gain antenna; reaction wheels and thrusters. Off-nadir imaging for geometric stereo is accomplished by rolling the spacecraft perpendicular to the orbital track. Commissioning Phase tests were conducted to operate motion-inducing instruments and mechanisms on LRO one at a time during NAC imaging.

Measuring Jitter from NAC Images: Magnitude and frequency of jitter is measured from offsets in a small region of overlap between the NAC-L and NAC-R cameras. Since the overlapping area should be imaging the exact same locations on the ground, but at slightly different times, we can measure the distance from the expected position of the corresponding pixels to that of the same ground object in the other image using the Integrated Software for Imagers and Spectrometers Version 3 (ISIS3) [3] program coreg.

The output from coreg consists of sub-pixel offsets in the sample and line directions. Coregistration points are sampled every 50 lines in the images to provide a dense sampling. Outlier points are filtered out before spline-interpolating to a uniform time sampling. These time series are then used with the image line time and average line (along-track) separation for that image to derive the jitter function for the image separately in the sample and line directions. Fourier analysis is used to derive an absolute function describing the spacecraft motion during imaging. The analysis for LROC-NAC jitter is adapted from the algorithm developed for the HiRISE camera on board the Mars Reconnaissance Orbiter [4,5]. One important difference between the two cameras is that unlike HiRISE, LROC-NAC has only one pair of CCDs, which means there will be a range of jitter frequencies that the algorithm cannot detect. These frequencies would have a period close to the along-track separation between the two NAC camera boresights.

Jitter patterns were also analyzed using the 'Lunar Orbiter Mapper' software [6], which matches thousands of points along a NAC pair. Analysis showed jitter patterns consistent with the results based on *coreg* output.

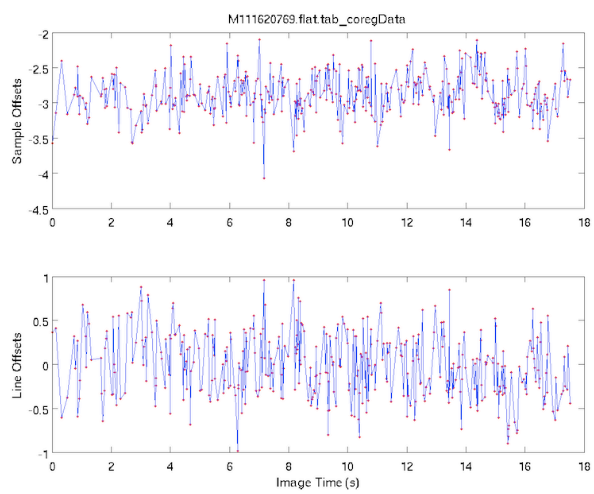

Figure 1 Coreg data from a typical NAC image, acquired during the Primary Mapping Phase. The y-axis is in units of pixels. Line offsets are normalized to the average line offset for that image.

Early Results: Figure 1 shows a typical plot of the coreg output. Almost all of the NAC images analyzed show a pattern similar to Figure 1, which we call "typical," perhaps mostly noise or other effects but not necessarily jitter-free. A typical plot shows an average sample offset of about ±2 pixels and a magnitude (peak-to-trough) of about 1-1.5 pixels. In the line direction, the magnitude is typically somewhat smaller, but the plots can also describe topography and changes in orbital altitude (such as the elliptical orbit during Commissioning Phase). These kinds of motions are not considered jitter. Motions of a greater amplitude are considered anomalous, and are investigated for possible causes. We find that less than ten percent of all NAC images processed through this algorithm show atypical motions. Many of these instances have been associated with known spacecraft events at or near the time of imaging. This information is fed back to the LRO project and LROC uplink and targeting to provide improved commanding.

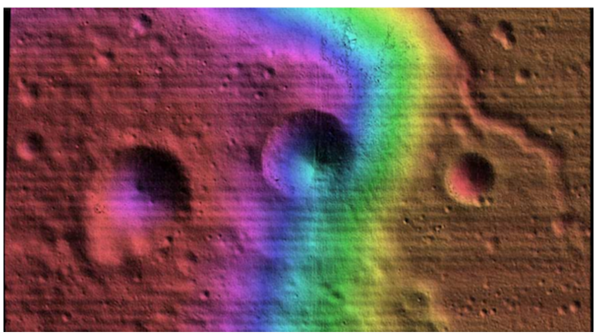

Figure 2 Detail of Gruithuisen Domes DTM [7] showing ripples attributed to jitter in one or both of the images.

Effects of Jitter in DTMs: One of the concerns for LROC planning is to acquire high resolution stereo imagery to construct DTMs. For the most part, the distortions in the NAC imagery due to jitter are invisible to the human eye. However, even small distortions can result in poor correlations by automated stereo matchers, producing artifacts in DTMs. One of the earliest DTMs produced [7] showed a very regular pattern of approximately 10 m high ripples parallel to the cross-track direction (Fig. 2). Low-amplitude jitter could be even more problematic for photometric stereo, which requires three or more images and can produce higher-resolution DTMs if not limited by factors such as jitter distortions.

The ripple pattern seen in the terrain shaded relief (Fig. 2) is apparent in the offsets from the stereo images used to produce the Gruithuisen Domes DTM (Fig. 3). Figure 3 shows a plot from one of the pairs of NAC images used to derive the terrain. The other image showed similar jitter, but of a slightly smaller magnitude. Of the DTMs produced so far some of them have shown these ripples, while others have not [7,8]. Further analysis is required to characterize what case is detrimental to terrain extraction, and what will produce acceptable results.

Discussion and future work: Efforts to date have focused on gathering the data from the images in order to understand the types and magnitudes of motions

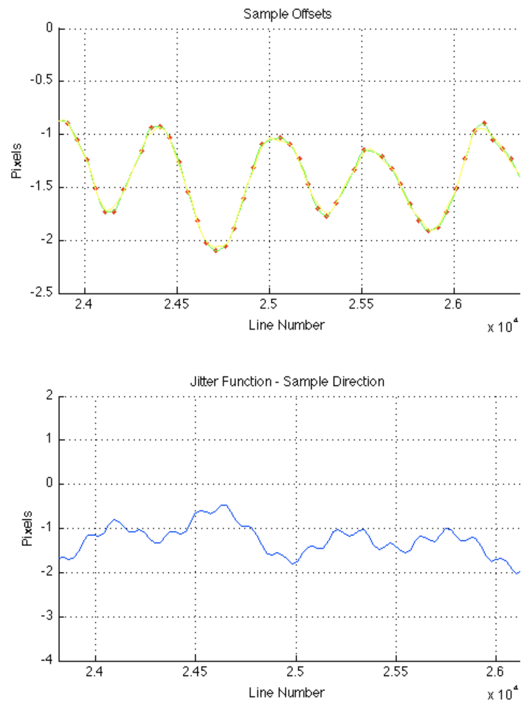

Figure 3 Plot zoomed in on the sample offset data (top) and the derived jitter function (bottom) for image lines 24,000-26,000 of one of the Gruithuisen Domes images.

seen in NAC images. The Commissioning Phase tests to assess operational causes of jitter were very useful for ongoing planning. Analysis of all Commissioning Phase images as well as Primary Mapping Phase images is ongoing to discover unexpected cases of jitter.

At this stage in our analysis, we have not separated out the known pointing information from the jittery motions in a systematic way. Future work to correct the jitter in NAC images will take that into account, as is done in [4]. An important difference to take into consideration is that the NAC L and R have unique camera models, which may complicate the application of one solution to both images. This will be crucial to correcting images to get improved DTM results. Based on the success correcting jitter in HiRISE, it is expected that a similar correction for LROC-NAC will be achievable.

References: [1] G. Chin, et al. (2007) Space Science Reviews 129:391. [2] http://opfm.jpl.nasa.gov/europajupitersystemmissionejsm/ [3] J. A. Anderson, et al. (2004) *LPSC XXXV* [4] S. Mattson, et al. (2009) *EPSC Abstracts*, vol. 4. [5] McEwen et al., 2010, *Icarus, in press*. [6] R. Li, et al. (2008) *Int. Arch. of Photogram., Rem. Sens. and Spatial Info. Sci.*, v 37, no. B4-Comm. IV, pp. 987-992. [7] T. Tran, et al. (2009) *LPSC XLI, This Conference*. [8] R. A. Beyer, et al. (2009) *LPSC XLI, This Conference.*