POINTING CORRECTIONS FOR THE LUNAR RECONNAISSANCE ORBITER NARROW ANGLE CAMERAS. R. V. Wagner, E. J. Speyerer, P. Mahanti, J. Danton, and M. S. Robinson. Lunar Reconnaissance Orbiter Camera, School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-3603 (rvwagner@asu.edu).

Introduction: The Lunar Reconnaissance Orbiter Narrow Angle Camera (NAC) consists of two identical line scan cameras, each with a field-of-view (FOV) of 2.85°. Each NAC is mounted off nadir in opposite directions, providing a 5.7° combined FOV (10,000 pixels across track). The instantaneous FOV for each NAC pixel is 10 µradians, providing 50 cm pixels at an altitude of 50km, which was common during the first two years of the mission. Accurate placement of NAC images in a cartographic framework requires precise knowledge of the camera orientations relative to the spacecraft coordinates. To that end, inflight observations were compared to improve preflight camera orientation estimates. The absolute accuracy of the camera pointing can be determined by getting the derived location of one of the five retroreflectors on the Moon (three flown on Apollo missions, two on Soviet Lunokhod rovers), the true locations of which are known to sub-meter accuracy [1].

Relative translational offset: The temperature-dependent component of the offset between the left (NACL) and right (NACR) cameras. This is actually a rotation about the spacecraft X and Y axes, but is represented by a translational offset in a map-projected image.

Absolute translational offset: Offset of a given map-projected pixel from its true coordinates. Like the relative offset, this is actually a rotation of the cameras.

Twist offset: Amount that each sensor is rotated about the boresight, with 0° and 180° being perpendicular to the flight direction.

The previous absolute pointing was good to within ±833 µradians cross-track and ±612 µradians down-track (42 m and 31 m, respectively, from a 50km altitude), and the relative offset was 50-250 µradians (5-25 pixels) between the two cameras. After corrections described in this abstract for these factors are applied, the absolute pointing error is ±639 µradians cross-track and ±635 µradians down-track (33 m and 32 m from a 50km altitude), and the relative offset is reduced to ±5 µradians (0.5 pixels).

Relative Translational Offset: The relative offset between the NACL and NACR cameras was determined by coregistering the overlapped regions of several thousand map-projected left/right pairs. When analyzing this dataset it was discovered that the offset between the two cameras was not constant over time. Many time variable parameters (i.e. spacecraft orientation, subspacecraft latitude, incidence angle, temperature) were investigated for correlation with the pointing errors; temperature had the best correlation. Each NAC is mounted to the spacecraft at three locations at the base of the telescope, so a plausible mechanism for the relative offset is differential expansion of the mounting brackets or the optical bench, as the spacecraft thermal environment changes. Thermisters mounted on the camera system and spacecraft were checked, all available temperatures were strongly correlated with each other. Ultimately the SCS temperature was chosen as the correction parameter since it is included in the PDS header of each NAC image. The SCS is mounted on the outside of the spacecraft optical bench, on the –Z (non-Moon-facing side), and is not covered by any thermal blankets, so it may provide a good analog for the temperature of the optical bench.

Temperature dependent pointing offsets were derived for images with solar incidence angle <70°, and spacecraft slew angle <40°. These restrictions were selected to allow the automatic coregistration function to easily find matching features between the images.

At SCS temperatures below 2°C, the correlation with pointing offset vanishes. For these images (usually at incidence angles above 80°), a constant correction factor of the average offset between the cameras is used instead. A possible cause for this is that only 200 images within the above restrictions had SCS temperatures below 2°. Additional tests with looser restrictions have not shown any correlation, but also had a >50% failure rate of the coregistration function. See Figures 1 and 2 for the results of the relative offset correction.

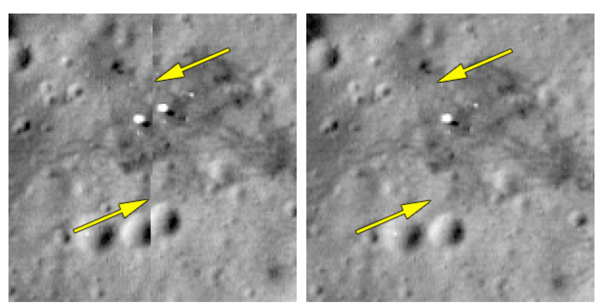

Figure 1: The boundary between the frames of a mosaicked NAC pair showing the Apollo 15 ALSEP before (left) and after (right) the relative correction. Arrows indicate the frame boundary.

Absolute Translational Offset: The absolute pointing error for each camera was determined by locating the five retroreflectors in 62 NAC frames (43 of which are from after the spacecraft commissioning phase and have LOLA cross-over controlled SPKs). For each image, the exact pointing required for the retroreflector to be at that location was iteratively derived, assuming the spacecraft ephemeris was correct. These absolute pointing values did not converge on a single solution, so they were then correlated with image metadata to find an empirical relation with some other factor. Two possible correlating factors were uncovered for the cross-track pointing (no correlations were found with the down-track pointing):

1) Spacecraft slew angle, where the sign indicates whether the camera is pointing to the east or west, regardless of spacecraft flight direction.

2) SCS temperature. The correlation with slew gets less pronounced as temperature increases.

As a result, a 2-dimensional 2nd-order polynomial fit was calculated based on the factors above, and was applied to both cameras. Figure 3 shows an example of projected object locations before and after correction.

Twist Offset: A rotational offset was found between NACL and NACR cameras when several Apollo landing site images were projected with corrected pointing based on retroreflector positions. The absolute values for the twists of the NACL and NACR were determined by generating a control network of over 3000 overlapping polar images, and back-calculating the spacecraft pointing required for each image. This analysis showed twists of -0.24° for the NACL and +0.13° for the NACR, with no temperature dependence.

Order of Derivation: The exact values of these correction factors are interdependent, so to derive them correctly, each needed to be applied in the correct order. The twist correction was applied first, as neither of the translational offsets produce a twist component, and the absolute translational offset could be off by up to 20 pixels due to twist, depending on which column of the image the reference point was in. Finally, the coregistration to obtain the relative offset was run on images that had the absolute correction applied, as the absolute pointing correction resulted in a 20 pixel constant offset in addition to the temperature-dependent component. This offset was likely due to uncertainty in the orbital position of the spacecraft [2].

Conclusion: These correction factors are incorporated into a new SPICE kernel that defines the pointing of the NACs over time relative to the spacecraft frame of LRO. This kernel contains a constant correction offset from spacecraft frame for each NAC image instead of the current single fixed offset for all images.

The absolute correction does not improve pointing errors in the down-track direction, but as cross-track and down-track errors are similar post-correction, both may be due to errors in the spacecraft ephemeris.

References: [1] Murphy T. W. et al. (2010) *Icarus, 211*, 1103-1108. [2] Mazarico E. et al. (2011) *J Geodesy,* DOI: 10.1007/s00190-011-0509-4. [3] Davies M. E. and Colvin T. R. (2000) *JGR, 105,* 20,277-20,280.

Object	Latitude	Longitude	Delta (°)	Delta (m)
A11 LM	0.6739	23.4732	0.0002	7.4
A12 LM	-3.0121	336.5783	0.0003	10.3
A14 LM	-3.6455	342.5282	0.0004	13.3
A15 LM	26.1322	3.6341	0.0008	24.2
A16 LM	-8.9738	15.5007	0.0010	28.9
A17 LM	20.1906	30.7726	0.0010	29.3
A11 EASEP	0.6730	23.4732	0.0002	6.8
A12 ALSEP	-3.0093	336.5754	0.0001	3.4
A14 ALSEP	-3.6439	342.5224	0.0003	8.9
A15 ALSEP	26.1339	3.6308	0.0009	26.5
A16 ALSEP	-8.9762	15.4982	0.0008	25.7
A17 ALSEP	20.1917	30.7661	0.0012	36.1

Table 1: New positions of Apollo hardware based on averages of multiple images with corrected pointing. Delta columns are the change from previous location estimates [3].

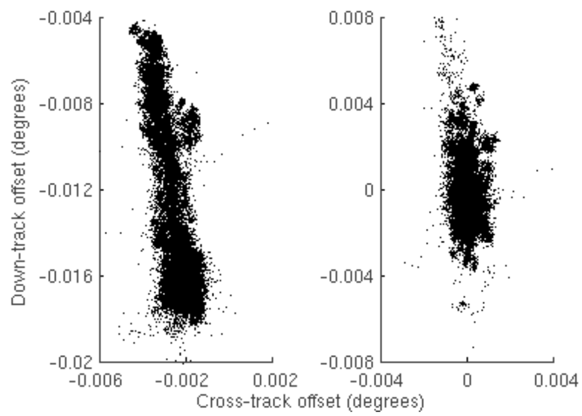

Figure 2: Cross-track and down-track components of the relative offset, before (left) and after (right) correction. All axes are on the same scale.

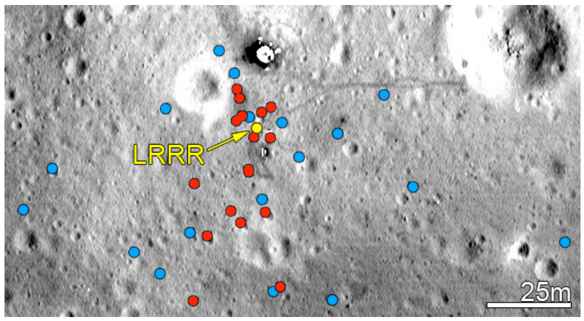

Figure 3: Projected Apollo 11 LRRR locations before (blue dots) and after (red dots) applying the corrections, compared to the actual location (yellow dot).