ANALYSIS OF LIGHT TIME AND STELLAR ABERRATION CORRECTIONS IN ISIS USING LUNAR RECONNAISSANCE ORBITER NARROW ANGLE CAMERA IMAGES.

J.A. Anderson[1], K.J. Becker[1], E.J. Speyerer[2], R.V. Wagner[2], D.A. Cook[1], R.L. Kirk[1], and B. A. Archinal[1], [1]Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, Arizona 86001 (janderson@usgs.gov), [2]School of Earth and Space Exploration, Arizona State University, Tempe, Arizona, 85287.

Introduction: The Integrated Software for Imagers and Spectrometers (ISIS) system [1] can be used for orthorectification of digital images collected by nearly 40 instruments flown on NASA missions over the last 50 years. The orthorectification process makes use of ISIS camera models and the Navigation and Ancillary Information Facility (NAIF) SPICE toolkit [2-3]. An important part of this process is properly characterizing the location of both the spacecraft (observer) and planetary body (target). The apparent position of the target relative to the observer should be corrected for light time and stellar aberration in order to produce the most accurate orthoimages. The SPICE toolkit provides a variety of capabilities for these corrections. We describe how ISIS currently makes use of the toolkit and provide an analysis of various options using well-characterized lunar control points.

Current ISIS Implementation: In ISIS3.4.2 and all previous versions including ISIS2, the apparent position of the observer is computed relative to the target body at a fixed moment in time. That is, the ISIS software is technically using opposite of what is desired; the observer position should be fixed at moment in time and the target position should be corrected for light time and stellar aberration. In addition, the application of the light time correction is relative to the center of the target body and not the surface. We have been aware of these inaccuracies; however, for most instruments the resulting errors in ground coordinate computations have been 1) less than sub-pixel, 2) are smaller than the pointing accuracy of the spacecraft, and/or 3) have been compensated for by incorporating the error into the instrument mounting angles. This is not the case for the Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC), which provides the capability to characterize the accuracy of ISIS software using ground control from three Apollo and two Lunokhod-era retroreflector arrays [4,5].

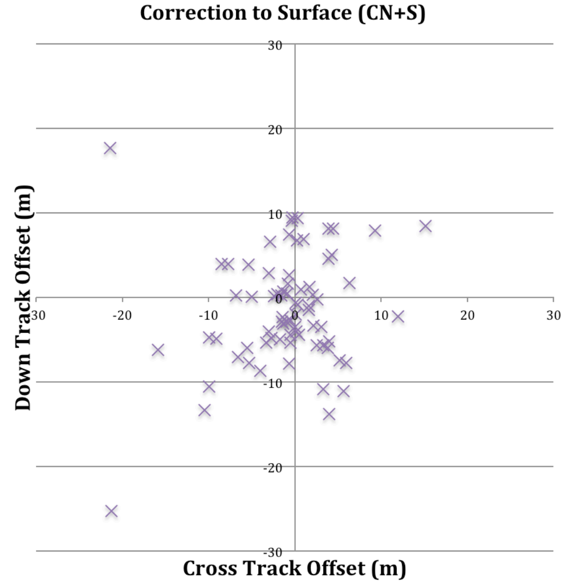
Methodology: Ground Control Points (GCPs) comprised of image sample/line coordinates of the Apollo and Lunokhod retroreflectors were identified in 77 NAC images. A modified, unreleased version of ISIS 3.4.2 was run in a variety of operational modes (Table 1) to compute the observed latitude/longitude at each GCP. This allows for a direct comparison of the observed latitudes/longitudes versus the measured latitudes/longitudes of the retroreflector arrays. Mode "CN+S" provides converged Newtonian light time and stellar aberration corrections to the target surface using the SPICE toolkit "sincpt_c" routine developed in 2009 [6]. Note this is the only mode that corrects for light time to the target surface, but it also involves an iterative solution that is slower than the other modes by a large factor.

Mode	Target or Observer Position Fixed in Time	Light Time Correction	Stellar Aberration Correction
CN+S	Observer	To surface	Yes
LT+S	Observer	To center	Yes
NONE	Both	No	No
LT+S TARGET	Target	To center	Yes

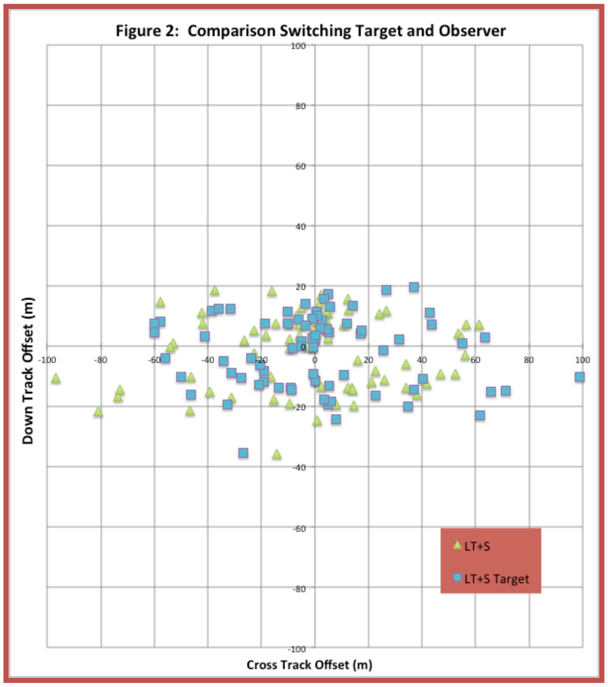
Table 1 – Operational Modes

In Figure 1, the plot shows the deviation of the "CN+S" observed GCPs from the retroreflector array locations [4,5]. The average 2D error is less than 7.2 meters, which is well within the accuracy of the LRO spacecraft attitude control systems [7].

Figure 1: Light Time & Stellar Aberration Correction to Surface (CN+S)



Analysis: First we compare mode "LT+S" versus "LT+S Target." That is, we will examine the differences between holding the observer position fixed (what should be done) and holding the target position fixed (what is being done in the current public release of ISIS 3.4.2). Note that both of the modes apply light time correction to the target center. Figure



2 shows the comparison of the observed GCPs with these two modes. In the plot, we can see the symmetry about the Y-axis, which is due to the change in the position that is held fixed. The overall 2D error is the same for both modes and on average is ~28 meters; however, most of the error is in the cross track direction when compared to the baseline (Figure 1). This is due to overcorrecting for light time and stellar aberration to the center of the target instead of the surface.

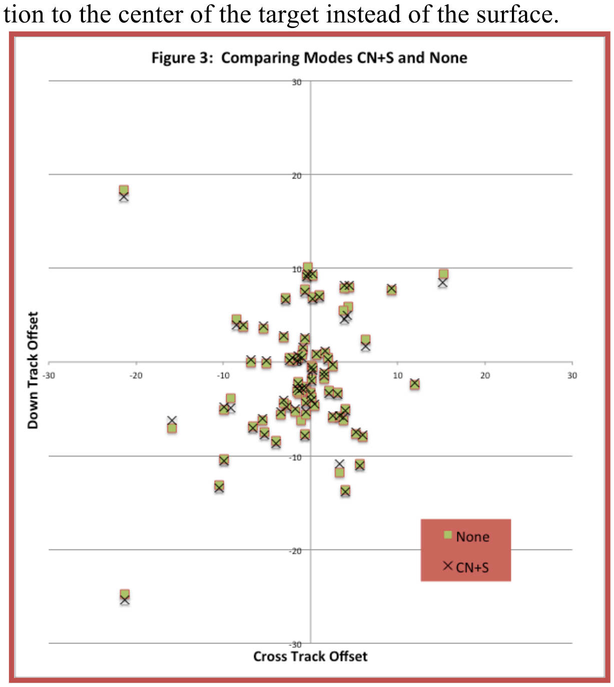


Figure 3 shows the comparison between the baseline "CN+S" mode and "NONE" which eliminates all light time and stellar aberration corrections. Here we see the GCPs align much more closely. Because the LRO spacecraft orbits at a low altitude range of 30km to 200km, the results of the two corrections are so small that it is preferable to omit them than to compute them incorrectly.

Conclusion: For images collected by low altitude instruments such as the LROC NAC, turning off light time and stellar aberration corrections can produce results similar to the "CN+S"/sincpt_c mode. However, this is not general for all instruments such those on spacecraft performing flybys or in highly elliptical orbits, such as the Mariners, Viking, Voyager, Galileo, Cassini, and MESSENGER. Currently, ISIS 3.4.2 does not offer the ability to turn off the corrections. This function will be provided in a future release.

Further analysis must be made to examine other target bodies and instruments. For instance, the Mars Reconnaissance Orbiter HiRISE instrument coupled with GCPs from Martian landers can provide data for further study. In addition, rotational (sometimes called diurnal) aberration of the target should be understood for fast rotating bodies (e.g., asteroids).

Finally, long-term improvements to ISIS must be made to apply corrections based on distance to the target surface with both accuracy and speed-of-execution as primary factors in the design. We cannot use the SPICE sincpt_c routine because it does not support multi-threaded programming and is very slow.

When making these improvements, careful analysis must be completed for each instrument supported by ISIS. The results from inherently low-resolution instruments may not be affected at all. For wide field instruments the target range may vary dramatically across the field and the effect may do so as well. For some instruments, adjustments for light time and stellar aberration errors may have been applied to the SPICE instrument and/or frame kernels and therefore re-solving for the mounting angles may be required. After funding for this work is obtained, we expect this analysis may take several years.

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