Jigsaw: The ISIS3 Bundle Adjustment for Extraterrestrial Photogrammetry

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The Integrated Software for Imagers and Spectrometers (ISIS) package (see http://isis.astrogeology.usgs.gov/) was developed by the Astrogeology Science Center of the U.S. Geological Survey in the late 1980s for the cartographic and scientific processing of planetary image data. Initially supporting the Galileo NIMS instrument, ISIS eventually added support for numerous missions including the Viking orbiters; Mariner 9/10; Clementine; Voyager I/II; Galileo SSI; Pathfinder IMP; Mars Global Surveyor MOC, TES, and MOLA; 2001 Mars Odyssey THEMIS; Lunar Orbiter; Cassini ISS, VIMS, and RADAR; Mars Express HRSC; Mars Exploration Rover (MER) Pancam, Navcam, and Micro-Imager; and Mars Reconnaissance Orbiter (MRO) HiRISE and CTX. Ever evolving, the current software version is ISIS3. Recently, support has been added for the Lunar Reconnaissance Orbiter (LRO) NAC, WAC, Mini-RF, and LOLA; MESSENGER; and Dawn missions; and for the Metric Cameras flown onboard Apollo 15, 16, and 17. To meet the requirements of extraterrestrial photogrammetry, the ISIS3 bundle adjustment module, Jigsaw, is evolving as well.

The bundle adjustment is well known as a key element in the typical photogrammetric workflow. Given a set of two-dimensional measurements from multiple images, this least-squares process, in its most general form, simultaneously solves for parameters of image position and orientation, in addition to triangulated ground point coordinates. The challenges posed by extraterrestrial photogrammetry, some of which are listed below, serve to increase the complexity of the bundle adjustment.

In general, the surface of most extraterrestrial bodies lacks adequate and accurate photogrammetric control. Processing a combination of images acquired from a wide variety of sensors is often necessary. These sensors range from the relatively simple frame camera to more complex line scan and push frame sensors, and radar. Images scanned from film cameras on missions long past may be adjusted together with more recent digital images. Sensors may be mounted on orbiting spacecraft or at the surface on stationary platforms or roving vehicles. Images may have vastly different characteristics of illumination, resolution and geometry. Spacecraft navigation and attitude data, particularly from older missions, may have high levels of uncertainty. Unmodeled high frequency spacecraft motions, or jitter, complicate the accurate determination of image position and orientation for line scan, push frame, and radar sensors. A further complication is the large number of images and tie points that often need to be processed, stretching computing resources required by the bundle adjustment to the limit. This in turn necessitates the application of advanced techniques for the storage, formation, manipulation, and solution of the bundle adjustment normal equations.

In this paper, we report on the current state of Jigsaw including the implementation of sparse matrix methods, parameter weighting, and error propagation. We also describe the use of polynomials and splines to address the issue of spacecraft jitter when solving for the position and/or orientation of line scan and radar sensors. Details from the recent processing of Metric Camera images from Apollo 15, 16, and 17 and from recent missions such as LRO and

MESSENGER are given.
Finally we summarize our vision for Jigsaw and in particular its role in the automation of the photogrammetric process. Efficient processing of the ever larger data sets generated by planetary missions today requires automating many of the tasks traditionally performed by a human operator. For the bundle adjustment this can be accomplished in part through the implementation of techniques such as robust outlier detection and sequential estimation. Sequential estimation facilitates both the update of an existing data set with new measurements as they become available and also the removal of outliers. We also touch upon the topics of free network adjustment; augmentation of the functional model of the bundle adjustment to solve for camera interior orientation parameters and target body parameters of shape, spin axis position, and pole position; and the combined adjustment of images from orbiting and surface-based platforms.

Keywords: Bundle, Adjustment, Estimation, Extraterrestrial, Planetary, Space