AUTOMATED DIGITAL ELEVATION MODEL GENERATION FROM ORBITAL IMAGERY. L. J. Edwards[1] and M. J. Broxton[2], [1]NASA Ames Research Center, MS 269-3, Moffett Field, CA, 94035 (Laurence.J.Edwards@nasa.gov), [2]Carnegie Mellon University, West Campus at NASA Ames Research Center, MS 269-3, Moffett Field, CA, 94035 (Michael.J.Broxton@nasa.gov).

Introduction: The Intelligent Robotics Group (IRG) at the NASA Ames Research Center (ARC) has been developing 3D surface reconstruction and visualization capabilities for planetary exploration for more than a decade. A critical component technology enabling this work is the Ames Stereo Pipeline (ASP). The ASP generates high quality, densely sampled terrain models from stereo image pairs.

Although initially developed for processing images acquired by stereo camera pairs onboard rovers and landers, the IRG has adapted its surface reconstruction tools to generate Digital Elevation Models (DEMs) from orbital imagery. This adaptation required supporting linear sensor "push-broom" image acquisition modes as typically employed by orbiters (versus the area scan image acquisition typically utilized by rover and lander cameras[1]).

DEMs are important for mission planning (e.g., landing site selection) and operations, and are a valuable tool for scientific analysis (e.g., large scale geomorphology). Initial work was done in collaboration with Malin Space Science Systems (MSSS) on a Mars Critical Data Products (CDP) funded project to produce high resolution DEMs from Mars Global Surveyor (MGS) Mars Orbiter Camera Narrow Angle (MOC-NA).

For the Mars Reconnaissance Orbiter (MRO) mission this work has been extended to accommodate images from the MRO Context Camera (CTX). In addition, proof of concept adaptations have been developed for other orbital imagers including Mars Express High Resolution Stereo Camera (HRSC), and Apollo Panoramic and Metric cameras.

The high volume of data returned by current and future orbiters will be difficult to manage with traditional photogrammetric DEM generation methods that depend on intensive human input. The automated DEM generation capability developed by the IRG provides an important tool to address the problem of processing the large quantities of stereo image data that will be available and relevant to planetary exploration.

DEM Generation: The ASP implements a fast area based stereo-correlation algorithm that determines correspondences between points in two images. Parallax between corresponding points is then used to determine 3D location. A surface generation step interpolates the calculated 3D points, and resamples the surface on a regular grid to produce the output DEM and corresponding co-registered image. A schematic of the processing flow is shown in Figure 1.

Although various parameters must be adjusted for specific cameras and acquisition modes, model generation is essentially automatic.

As a first step in the processing, images are re-projected and aligned to speed the stereo correlation process, improve correlation, and reduce the chances of miscorrelation. Alignment is accomplished by an algorithm that identifies a sparse set of robust features or "interest points" in each image, and determines an affine image transformation that optimally aligns matching features.

The images are then optionally filtered, typically with a Sign of Laplacian of Gaussian (SloG) operator. This filter provides some insensitivity to overall differences in brightness and contrast between the two images.

The stereo correlator identifies corresponding points in two images based on image similarities in a small region surrounding the given points. Similarity is calculated as the sum of absolute differences in pixel intensities over the regions. To reduce the chance of miscorrelation (i.e., incorrect correspondences or matches) it is desirable to have knowledge of the range of disparities that will be encountered in the correspondence search. However, in an automated DEM generation scenario this information is generally not known. To overcome this, a coarse to fine search is done to quickly determine the approximate range of disparities that will be encountered in a given image pair. In addition, consistency checks are implemented to ensure that the same result is obtained irrespective of which image is considered the reference image.

Although the correlator is typically successful in determining a dense set of correspondences between images, there usually will be points or regions where no correspondence is found. An optional "hole filling" step can be invoked to fill such voids with a 2D spline interpolant. In addition, an optional outlier removal step can be invoked for noise reduction.

The differences in position between corresponding points, "disparities", is used to determine 3D location based on the geometry of image formation and camera location. As noted, orbiter imagers typically incorporate 1D linear, or "line-scan," sensors where the motion of the spacecraft provides the second dimension for the image acquisition process. As such, orbiter state information is required to determine the geometry of image formation. This information is read from spacecraft ephemeris files produced by NASA's Navigation and Ancillary Information Facility.

Once the 3D locations of image points have been determined, the 3D points are interpolated using a triangle mesh interpolant. This mesh is then sampled at regular intervals in latitude and longitude. Finally a planetary datum is optionally subtracted from the calculated locations to generate the final elevation values.

The size of images produced by modern orbital imagers (.e.g, 5k x 50k pixels for MRO CTX) can be problematic when processed on current computer workstations. To address in-core memory usage and processing speed issues a tiled image and multi-threaded correlator implementation was developed that can handle very large images.

Results: We have generated 3D terrain models for a number of MGS MOC NA image pairs (see example in Figure 2). Our current work with MRO CTX is in its initial phases but we have generated a number of terrain models used to support proposals for potential Mars Science Laboratory (MSL) landing sites (see example in Figure 3).

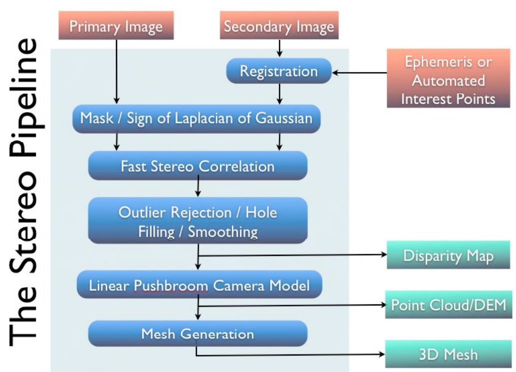

Figure 1. ASP processing flow diagram.

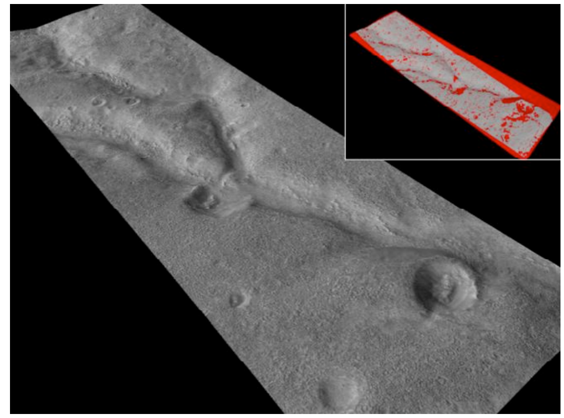

Figure 2. This 3D terrain model was generated from MOC-NA images. The inset in the upper right shows areas of interpolated data where the stereo correlation failed to find a match.

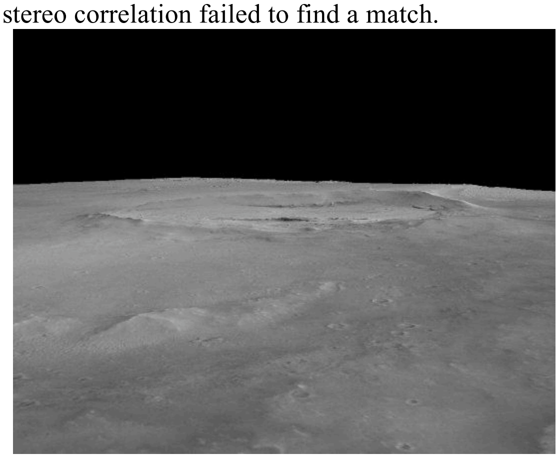

Figure 3. Terrain model generated from MRO CTX image pair used to support MSL landing site proposal.

References: [1] Edwards, L., Bowman, J., Kunz, C., Lees, D., Sims, M., "Photo-realistic Terrain Modeling and Visualization for Mars Exploration Rover Science Operations," Proceedings of IEEE SMC 2005, Hawaii, USA October 2005.

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