The Ames Stereo Pipeline: Automated 3D Surface Reconstruction from Orbital Imagery. M. J. Broxton[1,2] and L. J. Edwards[2]. [1]Carnegie Mellon University, [2]Intelligent Robotics Group, NASA Ames Research Center.

Introduction: The Mars Orbital Laser Altimeter (MOLA) has significantly advanced the study of the Martian surface by providing geologists with a highly accurate elevation map of the entire planet [1]. However, its limited resolution (463m/pixel at the equator) and localized interpolation artifacts have rendered it insufficient for detailed studies of specific sites; e.g. geologic stratification and deposition analysis, or in the case of mission planning, landing site selection. The most common technique for obtaining higher-resolution digital terrain models (DTMs) is to employ stereogrammetric techniques, however the substantial number of man-hours and resources required for this aproach has meant that relatively few of these data products have reached the scientific community. To address this problem, the Intelligent Robotics Group (IRG) at NASA Ames Research Center has developed an automated stereo processing software system, the Ames Stereo Pipeline (ASP), that is capable of generating high quality DTMs from orbital imagery using a fully automated process [2].

Approach: The image processing pipeline for the ASP can be broken down as follows. First, images are pre-processed by applying the "Sign of the Laplacian of the Gaussian" (SLOG) filter introduced by Nishihara [3]. This filter is a composition of Laplacian and Gaussian filters followed by the application of a threshold step, which results in increased robustness to lighting variation in the stereo pair.

For dense stereo correlation, the ASP implements a fast area based sum of absolute difference (SOAD) correlation algorithm. The resulting disparity map encodes the offsets between matching pixels in the stereo pair. Several versions of this correlator are available including a multi-scale implementation which first computes a low resolution stereo disparity map that is then refined at successively higher levels of detail until the native resolution of the source images has been reached. Further performance is gained by adaptively partitioning the stereo images into tiles to minimize the disparity search range for any given tile.

A final 3D point cloud is calculated from the disparity map by computing the closest point of intersection of two rays emanating from the cameras through the matched pixels. The ASP includes several camera models that describe the geometry of various imagers including an adaptation of the linear push-broom model [4] of line-scan imagers; a geometry that is found in many modern orbiting camera platforms.

Several final data products can be generated from the 3D point cloud including 3D triangle meshes (e.g. VRML models) and ortho-rectified, map projected DTMs and camera imagery.

Results: Typical processing times are on the order of minutes to tens of minutes depending on the resolution of the images. A level of quality assessment and control that is useful for many applications can be achieved with minimal human involvement. The ASP is being used in existing collaborations with Malin Space Science Systems (MSSS) and the US Geological Survey (USGS) to generate DTMs from the Narrow Angle Mars Orbital Camera (MOC-NA) (Figures 1 and 2), the MRO Context Camera (CTX), the High Resolution Stereo Camera (HRSC), and the Apollo Panoramic & Metric Cameras (Figure 3).

Current and Future Activities: As work on the Ames Stereo Pipeline continues, our focus will be on integration, validation, and scalability. In particular, we have begun work in the following areas:

Integration with widely adopted cartographic software: The USGS Integrated Software for Imagers and Spectrometers (ISIS) package is widely used in the planetary science community for processing raw spacecraft imagery into high level data products of scientific interest such as map projected and mosaicked imagery [5,6]. We are enabling the ASP to read ISIS image files and to utilize ISIS camera models, thereby allowing scientists to prepare data for stereo processing using a familiar tool-chain and peer reviewed camera photometric and geometric calibration.

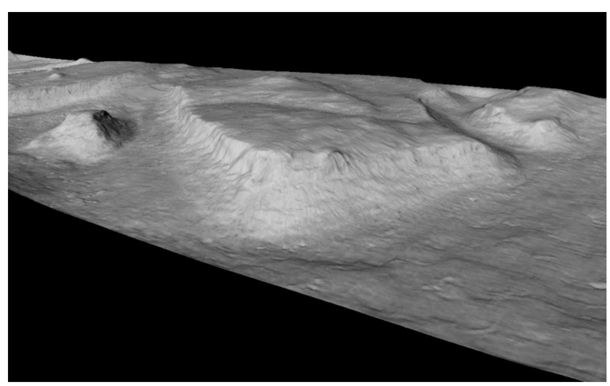

Figure 1: This DTM was generated from MOC image pair M01-00115 and E02-01461 (34.66N, 141.29E). The complete stereo reconstruction process takes approximately five minutes on a 3.0GHz workstation for input images of this size (1024x8064 pixels). This model, shown here without vertical elevation exaggeration, is roughly 2-km wide in the cross-track dimension.

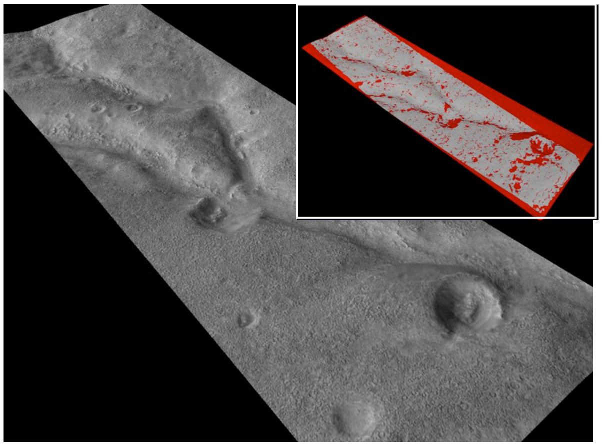

Figure 2: This 3D model of the Warrego Vallis System was generated from MOC-NA images E01-02032 and M07-02071 (42.66°S, 93.55°E). *Upper Right:* Ortho-image overlay. Areas of interpolated data are colored red.

DTM Comparison & Validation: We will continue to work with our colleagues at the USGS to ensure that ASP data products are well documented as well as geodetically and quality controlled so that they meet scientists' and mission planners' needs for high resolution, accurate data products. In particular, we will compare HiRISE DTMs produced by the ASP with those produced using the human-guided process on the SOCET SET[7] system at the USGS.

Mission Support: Our team continues to provide DTM generation support to the CTX instrument team, and we will also be providing DTMs to the HiRISE team in the near future. With the time-saving benefits of our automated approach, science team members will be able to request DTMs that they would not otherwise have the resources to process, thereby increasing the DTM generation "bandwidth" of the mission and greatly increasing science return.

Technology Development: We will seek to address three outstanding technical issues prior to final deployment of the ASP in a mission support capacity. These are 1) "wash-boarding" artifacts that appear in some DTMs as a result of high frequency oscillation of the spacecraft platform, 2) consistent geodetic control of the DTMs to MOLA and LOLA, and 3) software refactoring required to work with extremely large images (e.g. HiRISE and Apollo Metric Camera scans).

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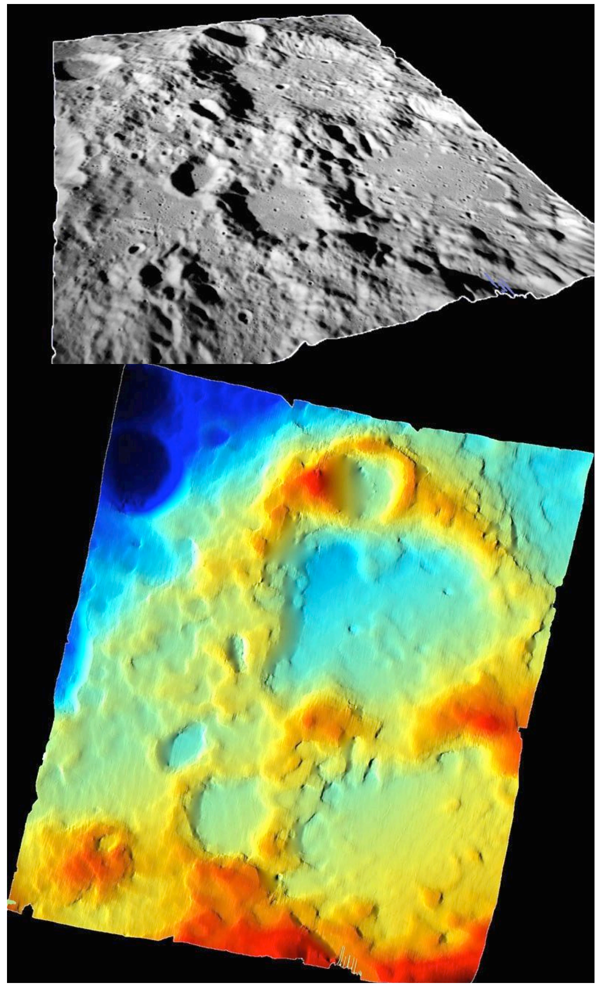

Figure 3: This stereo model depicting the area east of Paracelsus crater was built using high resolution scans of Apollo Metric Camera frames AS15-M-0081 and AS15-M-0082. *Top*: VRML Model. *Bottom:* Colorized DTM with shaded relief.

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