Ames Stereo Pipeline, NASA's Open Source Automated Stereogrammetry Software

Zachary M. Moratto[1], Michael J. Broxton[1], Ross A. Beyer[2,1], Mike Lundy[1], and Kyle Husmann[3], [1]NASA Ames Research Center, MS 269-3, Moffett Field, CA, USA, [2]Carl Sagan Center at the SETI Institute, and [3]California Polytechnic State University

Introduction There is a large demand for the creation of digital elevation models (DEMs) from stereogrammetry methods. Traditional methods are unfortunately slow and expensive. For example, at the time of this writing there are 1,346 stereo pairs[1] from the High Resolution Imaging Science Experiment (HiRISE), only tens of which have been processed into DEMs. The Ames Stereo Pipeline [2] (ASP) aims to correct this problem by providing an open source suite of fully automated geodesy and stereogrammetry tools designed to process planetary imagery captured from robotic explorers. In particular the ASP has been tuned for processing HiRISE and LROC stereo pairs. The ASP was recently released to the public in October 2009 and is available at `http://ti.arc.nasa.gov/project/ngt/stereo/`.

Background The Intelligent Robotics Group (IRG) at the NASA Ames Research Center has been developing 3D surface reconstruction and visualization capabilities for planetary exploration for more than a decade. First demonstrated during the Mars Pathfinder Mission where the Stereo Pipeline provided topography for exploration in a project called MarsMap [3]. Since then, IRG has been using the ASP to provide data products to the science operations teams of the Mars Polar Lander mission, the Mars Exploration Rover mission, the Mars Reconnaissance Orbiter (MRO) mission, the restortion of Apollo Metric Camera data [4, 5], and most recently the Lunar Reconnaissance Orbiter (LRO) mission[6].

The ASP has focused recently to address orbital stereogrammetry and cartographic applications. In particular, long-range mission planning requires detailed knowledge of planetary topography, and high resolution topography is often derived from stereo pairs captured from orbit. However, NASA's current orbital mapping satellites such as MRO and LRO now return orders of magnitude more data than previous missions and measure in the tens of terabytes. Existing processing techniques are still human intensive, and on their own cannot keep pace with the creation of stereographic data from planetary spacecraft. It is clear that an automated process is required.

The ASP was designed to address this issue. By applying recent advances in robotics and computer vision, we have created an automated process that is capable of generating high quality DEMs with minimal human intervention. With the release of this software, we hope to encourage the adoption of this tool chain at institutions that run and support remote sensing missions. Over time, we hope to see this tool incorporated into ground data processing systems alongside existing automated image processing pipelines. As this tool continues to mature, we believe that it will be capable of producing DEMs of exceptional quality without any human intervention.

The ASP is built on top of the United States Geology Survey (USGS) Integrated Software for Imagers and Spectrometers (ISIS, `http://isis.astrogeology.usgs.gov`). ISIS is widely used in the planetary science community for processing raw spacecraft imagery into high level data products of scientific interest. The ASP leverages this advantage by using internally the large database of camera models provided by ISIS. This means relatively new missions like MESSENGER that already have camera models available in ISIS are ready for stereo reconstruction with the ASP.

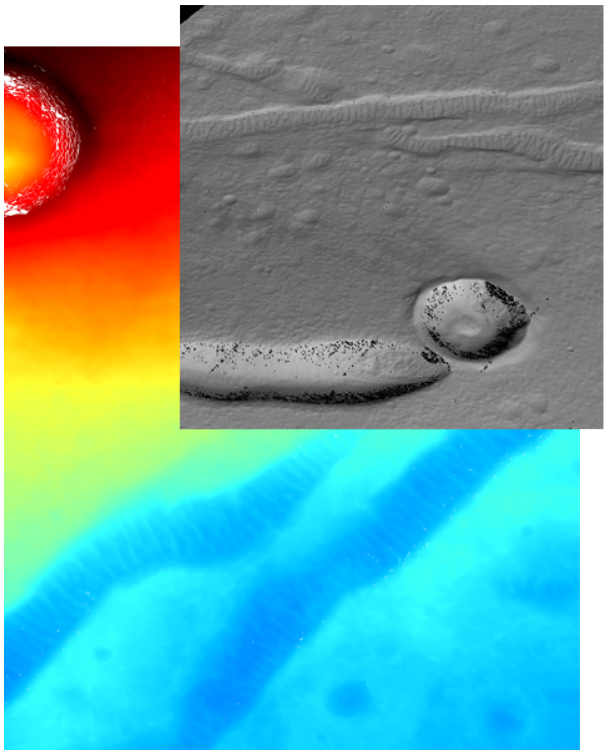

Figure 1: Colorized height map and 3D render of East Mareotis Tholus.

ISIS also provides a larger number of camera models for past missions such as Galileo, Clementine, and Voyager which can be used with the ASP to extract new information from old data sets.

Human vs Computer: When to Choose Automation When is it appropriate to choose automated stereo mapping over the use of a conventional, human-operated stereogrammetric workstation? This is a philosophical question with an answer that is likely to evolve over the coming years as automated data processing technologies become more robust and widely adopted. For now, our opinion is that you should always rely on human-guided, manual data processing techniques for producing mission critical data products for missions where human lives or considerable capital resources are at risk. In particular, maps for landing site analysis absolutely require the benefit of an expert human operator to eliminate obvious errors in the DEM; and also to guarantee that the proper procedures have been followed to correct satellite telemetry errors so that the data has the best possible geodetic control.

When it comes to using DEMs for scientific analysis, both techniques have their merits. Human-guided stereo reconstruction produces DEMs of unparalleled quality that benefit from the intuition and experience of an expert. The process of building and validating these DEMs is well established and accepted in the scientific community. However, only a limited number of DEMs can be processed to this level of quality. For the rest, automated stereo processing can be used to produce DEMs at reduced cost. The results are not necessarily less accurate than those produced by the human operator. Yet, they do not benefit from the same level of scrutiny and quality control. As such, users of these DEMs must be able to identify potential issues, and be on the lookout for errors that may result from the improper use of automated tools.

Results Figure 1 shows a crop of finished product of East Mareotis Tholus that was created by the ASP using the HiRISE images PSP_001760_2160 and PSP_001364_2160. Those images were prepared from their original experimental data records (EDR) format using ISIS. For convenience, the ASP supplies a script that will call ISIS and mosaick the multiple CCD that constitute HiRISE. Afterwards the stereo pair was processed for stereo reconstruction on a 3.0 Ghz 8-core system in 8 hours. The finished DEM was 12000 by 17500 pixels in size and covers and area of about 6 km by 9 km in size. The figure focuses on two wind swept channels that are south of an extinct volcano. The channels are 250 m wide and the DEM resolves the bedforms in the bottom of the channels.

Using the Ames Stereo Pipeline The ASP software is available at our website [7]. The binary installations provided are for OSX (prior to 10.6.0), and Linux 32/64 bit. Documentation is available and most importantly we provide example outlines of processes to perform stereo reconstruction on HiRISE, CTX, MOC-NA, Cassini ISS NAC, and several others.

The current release of the ASP is an alpha release. While we are confident that the algorithms used by the ASP are robust, they have not been systematically tested or rigorously compared to other methods in the peer-reviewed literature. We have a number of efforts underway to carefully compare ASP-generated data products to those produced using established processes, and we will publish those results as they become available.

References

[1] HiRISE — Stereo Pairs. World Wide Web electronic publication, Dec 2009. URL `http://hirise.lpl.arizona.edu/stereo_pairs.php`.

[2] M. J. Broxton and L. J. Edwards. The Ames Stereo Pipeline: Automated 3D Surface Reconstruction from Orbital Imagery. In *Lunar and Planetary Science Conference 39, #2419*, 2008.

[3] C. R. Stoker, T. Blackmon, J. Hagen, B. Kanefsky, D. Rasmussen, K. Schwehr, M. Sims, and E. Zbinden. Marsmap: an Interactive Virtual Reality Model of the Pathfinder Landing Site. In *Lunar and Planetary Science Conference 29, #1018*, 1998.

[4] M. J. Broxton, Z. M. Moratto, A. Nefian, M. Bunte, and M. S. Robinson. Preliminary Stereo Reconstruction from Apollo 15 Metric Camera Imagery. In *Lunar and Planetary Science Conference 40, #2282*, 2009.

[5] M. J. Broxton, A. V. Nefian, Z. M. Moratto, T. Kim, M. Lundy, and A. V. Segal. 3d lunar terrain reconstruction from apollo images. In *ISVC*, pages 710–719, 2009.

[6] R. A. Beyer, B. Archinal, Y. Chen, K. Edmundson, D. Harbour, E. Howington-Kraus, R. Li, A. McEwen, S. Mattson, Z. Moratto, J. Oberst, M. Rosiek, F. Scholten, T. Tran, M. Robinson, and LROC Team. LROC stereo data – results of initial analysis. In *Lunar and Planetary Science Conference 41, this meeting*, 2010.

[7] Intelligent System Division — Projects. World Wide Web electronic publication, Dec 2009. URL `http://ti.arc.nasa.gov/project/ngt/stereo/`.

Acknowledgements This work has been funded by the NASA Advanced Information Systems Research (AISR) Program grant #06-AISRP06-0142, the Luar Advanced Science and Exploration Research (LASER) program grant #07-LASER07-0148, and the ESMD Lunar Mapping and Modeling Program (LMMP).