BUILD YOUR OWN TOPOGRAPHIC MODEL: A PHOTOGRAMMETRY GUEST FACILITY FOR PLANETARY RESEARCHERS. R.L. Kirk, E. Howington-Kraus, and M.R. Rosiek, U.S. Geological Survey, Astrogeology Program, Flagstaff, AZ 86001 (rkirk@usgs.gov).

Summary: The United States Geological Survey (USGS) and NASA have jointly established a guest facility in Flagstaff, Arizona, at which NASA-supported planetary scientists will be able to collect high resolution digital topographic data from a wide variety of stereo images in support of their research objectives. The facility has been established with funding from the NASA Planetary Major Equipment (PME) Program. Training and assistance of guest users by the photogrammetrists of the USGS is supported by the NASA Planetary Geology and Geophysics (PG&G) Planetary Cartography Program. Travel expenses for attending training and making use of the facility will be the responsibility of the individual guest users. Researchers wishing to make use of the stereo mapping guest facility should contact the first author with a brief summary of their research goals, measurement needs, and schedule as described below.

Background: Topographic information is a requisite for nearly every phase of research on planetary surfaces, as well as an essential tool for planning and operating spacecraft missions. Where available, laser altimetry provides the gold standard for global topographic information because of its unexcelled absolute accuracy. Mars Orbiter Laser Altimeter measurements [1] of the 1990s revolutionized both the geodesy/cartography of Mars and the study of martian geologic features, and the Lunar Orbiter Laser Altimeter is poised to make a similar impact on lunar science [2], but the applicability of these data sets to the study of small surface features is limited by their cross-track spacing, which can be several km. Stereo provides height estimates every few pixels, so images of modest resolution (e.g., tens to hundreds of m) can fill the gaps left by laser altimetry. High resolution images (e.g., MRO HiRISE, with 0.25–0.3 m pixel scale [3]) yield topographic data with vertical precision on the order of a meter or better, comparable to the altimeter measurements. Altimetric data for bodies other than the Moon and Mars are much more limited or nonexistent, so stereo imaging is usually the best available source of topographic information.

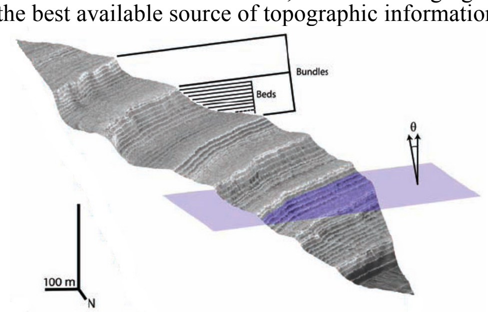

Figure 1. Perspective view of sedimentary layers in Becquerel crater, Mars, based on a topographic model with 1 m spacing derived from 0.3 m/pixel HiRISE stereo images. The orientation and true thickness of beds and bundles of beds were measured from the model [5].

A few examples taken from our own recent experience serve to illustrate the breadth of applications of stereo topographic mapping (Figure 1). Our ability to produce digital topographic models (DTMs) with 1 m grid spacing from HiRISE images [4] has been exploited to study the stratigraphy [5,6] and structural geology [7] of Mars as well as the evolution of polar [8] and circumpolar [9] deposits and to perform quantitative simulations of the emplacement of recently active slope streaks [10]. Stereogrammetric analysis of Cassini RADAR images of Titan [11] provides constraints on the thickness of liquid and solid organic deposits, can be used to quantify the rheology of cryovolcanic features, and provides insight into the nature of features such as Ganesa Macula, hypothesized to be a cryovolcanic dome [12].

Softcopy Photogrammetry: The availability since the 1990s of "softcopy" photogrammetric systems [13] based on digital image processing software running on standard computer workstations offers the prospect of wider access to stereo mapping capabilities than in the past, when specialized and expensive analog plotters were needed. Unfortunately, none of the software packages available in the public domain yet provide a complete set of stereo mapping tools that can be used with a variety of planetary image data sets.

The first step in topomapping is automated identification (i.e., *matching*) of corresponding features between images, from which round coordinates are then calculated. In order to achieve full accuracy it is necessary to calculate the exact geometric relation between pixels in the given type of image and ground coordinates. The software needed to do this is known as a *sensor model*, and it, rather than image matching, is the true heart of a digital photogrammetric system. Sensor models are also used in *bundle adjustment*, the refinement of camera position and pointing parameters in order to improve both the internal consistency between the images and the agreement of the stereo results with a priori information such as altimetry.

The main public-domain software packages for planetary mapping, ISIS [14,15] and VICAR [16], provide some of these tools, including sensor models for many cameras and basic image-matching. Software to make DTMs from the matching results is available for only a restricted set of cameras in VICAR and not at all in ISIS, though it can be added for specific sensors by a sufficiently knowledgeable user [17]. Efforts are now underway to implement and distribute user-friendly, ISIS-compatible software for image matching and DTM production from a wider range of images [18,19], and we support these developments as one means of making stereo DTMs more available to the planetary community.

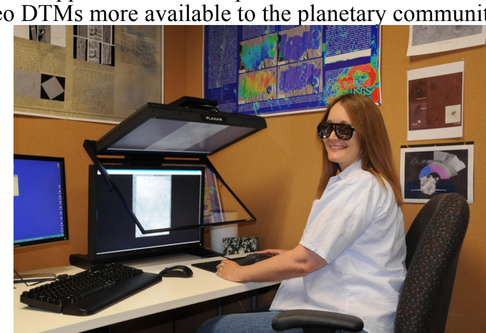

Figure 2. Coauthor Howington-Kraus, using the interactive stereo display of a digital photogrammetric workstation. By wearing lightweight polarizing glasses, she can see topographic data overlaid on the stereo images. She holds an input device that can be used to select and edit erroneous regions of a digital topographic model.

A final, essential component of a full softcopy photogrammetric system that is not addressed by such developments, however, is the ability to view and interact with image pairs and topographic data on a stereoscopic display system (Figure 2). Such a capability is needed because, despite decades of research on the algorithms, automated matching is never entirely reliable. It has been estimated that 5% to 30% of points matched by current techniques are in error and must be first detected, then edited by a human operator [13].

Planetary Photogrammetry with SOCET SET: An increasing number of commercial, off-the-shelf digital photogrammetric workstations with all of the capabilities just described have become available in the past two decades. In 1996 the USGS solicited competitive bids for such a system to be adapted for use with planetary data, and selected the SOCET SET® system [20], which was licensed at the time by Leica but is now sold by BAE Systems. A single workstation and set of software licenses were initially purchased with PG&G funding and have been used to produce DTMs and topographic maps for the PG&G Cartography Program. Additional workstations have since been acquired with other funding and are being used to support several missions, the Mars Critical Data Products Initiative, and the Lunar Mapping and Modeling Project.

As delivered, SOCET SET is useful for mapping the Earth with a variety of airborne and satellite sensors. The main steps of adapting the system for use with planetary data are 1) entering cartographic constants for each planetary body into the SOCET database of reference surfaces; 2) providing images and all the metadata necessary to define their geometry in forms that the system can recognize; and 3) providing a suitable sensor model for each instrument. We use the standard ISIS programs to ingest, decompress, and radiometrically calibrate images, and to obtain a priori geometric information from SPICE kernels. The image is then exported as a raw binary file and an ISIS-to-SOCET translation program is used to write the geometric metadata in a format recognized by SOCET SET. A similar process is used to translate DTMs and image maps produced in SOCET SET back into the ISIS format, after which they can be exported for use in geographical information systems.

BAE provides "generic" sensor models for framing cameras, pushbroom scanners, and panoramic cameras. The majority of planetary images can be processed with one of these generic models by supplying the appropriate values of various parameters such as detector size, focal length, and optical distortion coefficients. A few cameras are too complex to fit the generic models, but can be handled by resampling the images in ISIS to simplify the image geometry. Optical distortions and distortions caused by vibration of the spacecraft are also removed during this process. SOCET SET does not include a generic sensor model for synthetic aperture radar (SAR) images, so we have used the SOCET Developers' Toolkit (DevKit) to produce our own sensor models for instruments of this type [11]. In addition to developing ISIS-SOCET translation software and, in some cases, sensor models, we have also had to determine appropriate procedures for working with each type of data, for example, how to "tune" the automated image matching algorithms to obtain the best results with each type of image.

Table 1 lists the planetary sensors for which we have developed photogrammetric software and techniques. Many of these data sets are extremely large, so that they cannot be exploited fully, even by a vigorous centralized mapping program. For example, HiRISE has obtained nearly 1000 stereo pairs to date, but only a few tens of DTMs can be made per year. (It should be noted that each HiRISE DTM, produced digitally in 1-2 weeks, contains as many elevation points as the entire pre-MOLA DTM of Mars [21], which took ~50 work-years to complete!) This shortfall has led an increasing number of research groups to purchase their own SOCET workstations and obtain training from us in their use, but the systems remain out of reach for most scientists unless the costs (roughly $70,000 per workstation) can be shared.

A Guest Facility: In 2008 we obtained funding from the PME to purchase an additional SOCET SET workstation as an *Investigator Facility Instrument,* defined as "an instrument acquired…to support the PI's research where an identified portion of its time is to be reserved for use by the PI, but where an additional specified portion of its time will be made available to other knowledgeable NASA-supported planetary program investigators," and for which "all details or access, method of use, charging, and data rights are determined by the PI in negotiation with potential users." The cost of maintaining this system is being borne by the PG&G Program, and it will be reserved 50% of the time to increase the productivity of our PG&G-funded mapping projects. PG&G is also providing support for USGS staff to train and assist guest researchers, to whom the system will be made available up to 50% of the time. The level of funding is sufficient to train four guests or groups of guests per year.

The USGS will not charge researchers for training or the use of the guest facility, but they must find their own funding to cover all costs of travel to use the system. While guest users are present at USGS, they will have priority of access to the system; USGS use will be restricted to off hours and periods when guest researchers are not present. Data products generated by guest users (with or without USGS assistance) will remain proprietary to them for a period of 6 months, after which they will be made available online. All images for mapping with the guest facility must be released and in the public domain at the time of use.

How to Apply: Our criteria for selecting guest researchers will be feasibility of the proposed work (availability of images, existence of software to handle the given data set at the USGS, and suitability of the resolution, etc. for answering the desired research questions) and reasonableness of the desired quantity of work (sufficient to justify the effort needed for training and support but fitting into the time the facility is available). Preference will be given to users with flexible schedules who can be trained as part of a larger group, or who are returning to the facility to collect additional data and do not require re-training. Selection will otherwise be on a first-come-first-served basis. NASA-funded planetary researchers who wish to use the guest facility should therefore contact the first author by mail or email with a brief description of their proposed use. Proposals should be 1 page in length and should summarize how the desired topographic data will be used and indicate the type(s) of images to be used, types of products to be made (DTMs, slope maps or other derived products, feature measurements, etc.), and the number and size of areas or features to be mapped. Applicants should also indicate their availability and preferred schedule for training and data collection. USGS staff will contact applicants by email to notify them of selection and establish a schedule for use of the facility.

References: [1] Smith, D.E. et al. (2001) *JGR*, *107*, 23,689. [2] Smith, D.E. et al. (2006) *Eos Trans. AGU*, *87*(52), U41C-0826. [3] McEwen, A.S. et al. (2007) *JGR*, *112*, E05S02. [4] Kirk, R.L. et al. (2008) *JGR*, *113*, E00A24. [5] Lewis, K.W. et al. (2008) *Science, 322*, 1532. [6] Wray, J.J. et al. (2008) *GRL*, *35*(12), L12202. [7] Okubo, C.H. et al. (2008) *JGR*, *113*, E12002. [8] Fishbaugh, K.E. et al. (2009) *Icarus*, submitted. [9] Lefort, A. et al. (2009) *JGR*, submitted. [10] Pelletier, J.D. et al. (2008) *Geology*, *36*, 211. [11] Kirk, R.L. et al. (2008) *IAPRSSIS*, *XXXVII*(4), 973. [12] Kirk, R.L. et al. (2009) *LPS XD*, this conference. [13] Agouris, P. et al. (2004) *Manual of Photogrammetry*, ASPRS Press, 949. [14] Eliason, E. (1997) *LPS XXVIII*, 331; Gaddis, L.R. et al. (1997) *LPS XXVIII*, 387; Torson, J., and K. Becker, (1997) *LPS XXVIII*, 1443. [15] Anderson, J.A. (2004) *LPS XXV*, 2039. [16] NASA (2005) http://www-mipl.jpl.nasa.gov/external/vicar.html, accessed 1/4/09. [17] Schenk, P.M. (2008) *IAPRSSIS, XXXVII*(4), 976. [18] Broxton, M.J. and L.J.Edwards (2008) *LPS*, *XXXIX*, 2419. [19] André, S.L. et al. (2008) *JGR*, *113*, E11006. [20] Miller, S.B., and A.S. Walker (1993) *ACSM/ASPRS Annual Conv.*, *3*, 256; — (1995) *Z. Phot. Fern. 63*, 4. [21] Batson, R.M. and E.M. Eliason (1991) *PE&RS, 61*, 1499.

Table 1—Planetary Image Data Sets Used with SOCET SET

Framing Cameras (Digital)	**Framing Cameras (Film)**	**Panoramic Cameras**
Viking Orbiter VIS	Lunar Orbiter	Apollo Panoramic
Voyager ISS	Apollo Metric Camera	**Synthetic Aperture Radars**
Clementine UVVIS	**Pushbroom Scanners**	Magellan SAR
Galileo SSI	MGS MOC (Narrow and Wide Angle)	Cassini RADAR
Mars Pathfinder IMP	Mars Express HRSC	Chandrayaan-1/LRO Mini-RF
MER Pancam	Mars Recon Orbiter HiRISE	
MER Microscopic Imager	Mars Recon Orbiter CTX	
Phoenix SSI	Lunar Recon Orbiter Camera (Narrow Angle)	