MODEL DEVELOPMENT AND TESTING FOR THEMIS CONTROLLED MARS MOSAICS. B. A. Archinal[1], S. Sides[1], L. Weller[1], G. Cushing[1], T. Titus[1], R. L. Kirk[1], L. A. Soderblom[1], and T. C. Duxbury[2], [1]U. S. Geological Survey (2255 N. Gemini Drive, Flagstaff, AZ 86001, USA, barchinal@usgs.gov), [2]Jet Propulsion Laboratory (4800 Oak Grove Drive, M/S: 264-379, Pasadena, CA 91109, USA, Thomas.C.Duxbury@jpl.nasa.gov).

Introduction: As part of our work [1] to develop techniques and procedures to create regional and eventually global THEMIS mosaics of Mars, we are developing algorithms and software to photogrammetrically control THEMIS IR line scanner camera images. We have found from comparison of a limited number of images to MOLA digital image models (DIMs) [2] that the a priori geometry information (i.e. SPICE [3]) for THEMIS images generally allows their relative positions to be specified at the several pixel level (e.g. ~5 to 13 pixels). However a need for controlled solutions to improve this geometry to the sub-pixel level still exists. Only with such solutions can seamless mosaics be obtained and likely distortion from spacecraft motion during image collection removed at such levels. Past experience has shown clearly that such mosaics are in heavy demand by users for operational and scientific use, and that they are needed over large areas or globally (as opposed to being available only on a limited basis via labor intensive custom mapping projects). Uses include spacecraft navigation, landing site planning and mapping, registration of multiple data types and image sets, registration of multispectral images, registration of images with topographic information, recovery of thermal properties, change detection searches, etc.

Algorithms for Adjustment of THEMIS IR images: Procedures for the photogrammetric adjustment of standard framing camera (e.g. using film or electronic detectors such as vidicons or areal CCDs) have been well developed, initially for terrestrial photogrammetry [4], but also since the 1970's for planetary photogrammetry [5]. Attempts at photogrammetric adjustments using line-scanner camera images however are fairly recent, having first been developed for terrestrial aerial and orbital uses in the 1980's and '90's [6], and for limited mapping with Mars Orbiter Camera (MOC) narrow angle images in the last few years [7]. However, general procedures for handling such images and particularly THEMIS IR images have not yet been developed and are now the focus of our work.

Our adjustment procedure is based primarily on an extension of the techniques and software used for the adjustment of framing camera image measurements, e.g. those developed at RAND and currently used at USGS [8]. The fundamental difference with line scanner images vs. framing camera images is that the camera position and orientation must be determined at the exposure of every line, rather than more simply at the exposure of every image. Obviously a direct extension of solving independently for such information (exterior orientation) at every line of a line scanner camera, even assuming a much larger number of image tie point measurements were available, would result in an underdetermined system of equations. As has been done in terrestrial mapping [6] we therefore propose to reduce the number of parameters required for a solution to a reasonable level, by solving for simple polynomial expressions for the exterior orientation while the line scanner image is being collected, thus [4, pp. 290-291]:

$$\begin{bmatrix} X_s \\ Y_s \\ Z_s \end{bmatrix} = \begin{bmatrix} X_0 + X_1(t-t_R) + X_2(t-t_R)^2 \\ Y_0 + Y_1(t-t_R) + Y_2(t-t_R)^2 \\ Z_0 + Z_1(t-t_R) + Z_2(t-t_R)^2 \end{bmatrix},$$

$$\begin{bmatrix} \hat{\alpha} \\ \hat{\delta} \\ \kappa \end{bmatrix} = \begin{bmatrix} \hat{\alpha}_0 + \hat{\alpha}_1(t-t_R) + \hat{\alpha}_2(t-t_R)^2 \\ \hat{\delta}_0 + \hat{\delta}_1(t-t_R) + \hat{\delta}_2(t-t_R)^2 \\ \kappa_0 + \kappa_1(t-t_R) + \kappa_2(t-t_R)^2 \end{bmatrix},$$

where X_0, Y_0, and Z_0 is the position of the spacecraft at some reference time t_R, e.g. the time of the central line of a particular image. Similarly, the camera orientation at that moment is given by the J2000.0 right ascension and declination $\hat{\alpha}_0$, $\hat{\delta}_0$, and twist angle κ_0. X_s, Y_s, Z_s, $\hat{\alpha}$, $\hat{\delta}$, and κ are the corresponding values at the time t of any line in the image. To allow for unknown variations in the spacecraft position and orientation while the image is being obtained, we will solve for some or all of the additional unknowns shown.

Of course, with such a technique there are still a number of additional issues that must be addressed. For example, this procedure could result in up to 9 additional parameters for positions (3 in position, velocity, and acceleration) and 6 in orientation (3 in both velocity and acceleration, in addition to the 3 orientation angles) per image. If an image is in some way collected discontinuously – e.g. due to data dropouts or sudden spacecraft motion – additional sets of parameters will also need to be determined for each image segment. To solve for such additional parameters, additional tie points will indeed be needed between overlapping images.

Additional effort will also be needed to estimate the a priori values of the polynomial parameters, based on the initial estimates of exterior orientation (derived from the input SPICE data).

The polynomial parameters will also likely be highly correlated. In fact, in our past planetary mapping photogrammetric solutions [5, 8], spacecraft position has always been held fixed and never been solved for along with spacecraft orientation, since for the relatively narrow angle cameras in use, these parameters are highly correlated. It will be necessary to address these correlations – so that a solution can be achieved – by weighting the polynomial parameters based on realistic accuracy estimates for the a priori exterior orientation information (e.g. orbit position and camera pointing accuracy). We will also experiment with various image sets in order to determine the usefulness of solving for the higher order parameters, e.g. spacecraft acceleration and orientation acceleration. It is likely that for many solutions, e.g. with images that do not cover substantial arcs along the planetary surface, the full parameterization will not be needed in order to obtain sub-pixel accuracy.

Current testing. We are currently completing the manual measurement of tie points (using ISIS *qmatch*) [9] for a number of THEMIS IR images covering the two MER landing site ellipses. We also plan to work on one additional area (such as any prime Phoenix landing site ellipse). We are making a dense set of tie point measurements between a few pairs of images in order to ascertain the best initial set of parameters, weights to be used and numbers of tie points needed for image pairs. Tie points are also being measured between the THEMIS images and MOLA DIMs in order to provide absolute control for the images (at least at the ~100 m (~1 THEMIS IR pixel) accuracy of the MOLA data [2]. Once photogrammetric solutions are successfully completed, we will use the updated exterior orientation information (updated SPICE) in ISIS to generate controlled mosaics of these areas, both to assist in the final evaluation of our techniques and as useful products for use in the study of these sites.

Future development. An immediate goal of this work will be to demonstrate the control of THEMIS IR to THEMIS VIS images by adjustment of a limited set of VIS images to the IR mosaics. This will assist in the evaluation of such a line scanner to framing camera image adjustment technique and also provide absolutely controlled VIS mosaics of these areas. Later we also hope to demonstrate the use of this technique to adjust other types of images and combinations of images, such as THEMIS IR band to band, THEMIS IR to other framing camera images (e.g. Viking), Mars Express HSRC images, Mars Reconnaissance orbiter HiRISE images, and MOC NA images. Depending on our results with these other types of images, we may also develop alternate parameterizations, e.g. to address the known high rate oscillatory ("jitter") spacecraft motions that occur during collection of MOC NA and are likely to occur with HiRISE images.

Global Mapping Issues: Some separate issues require consideration for the production of large regional or even global controlled mosaics. A "holy grail" of planetary mapping has been to develop procedures to automatically measure tie points (correlate) overlapping images. Such procedures are essential for the generation of large area or global mosaics as the manual measurement of the needed tie points may be impractical. A rudimentary correlation matching procedure (*coreg)* has been developed in ISIS for such a capability, and we had initially planned to use it to collect measurements for our testing described above. However, we found that this procedure had several problems, including primarily that it is specific to processing of Clementine images, where images were collected in regular grid pattern, and that that it also often fails in bland areas. Rather than try to address these problems in an ad hoc fashion, we are instead planning to develop a comprehensive suite of image matching algorithms and software. The first part of these procedures will assume that SPICE data can be used to find approximate areas of overlap, to locate appropriate "patches" of images that then be automatically matched. The second part will be to do the matching, choosing from a suite of "plug in" algorithms tailored to image geometry, wavelength, expected type of terrain, etc. for matching between any given pair of images. Different matching algorithms might be used, e.g. for different instruments, area matching, point of interest matching, texture matching, feature matching (craters), etc. A third part will be the automatic rejection of outliers to the photogrammetric adjustment software, in order to minimize or even eliminate manual checking of tie point measurements.

In large photogrammetric solutions (e.g. with tens of thousands or more of measures, images, and parameters) the method of conjugate gradients [10] can be used to complete solutions. However a better solution method would be true block adjustment solutions, i.e. solutions where image coverage is broken into regions and correlations between regions (except for image overlap between regions) are ignored. This would reduce the solution round-off error, and allow for nested (blocked) matrix inversion solutions. The latter could provide any desired parameter uncertainties, and possibly provide for faster solutions (vs. conjugate gradient solutions).

So scaling up solutions from using a few images to regional or global datasets is still an area that needs thus, to be addressed. However, the basic adjustment procedures (described here) and the likely necessary block adjustment techniques are tractable. Beyond this, the significant issues that will require future attention are developing reliable automatic tie pointing procedures – to provide the measurement input to the solutions – and to handle the sheer volume of images and measurements involved.

Summary: We are in the process of developing the algorithms and software to make controlled mosaics of THEMIS IR images. Results of this work will be reported in our poster. This work is serving as a pilot study on the feasibility of creating controlled regional or global THEMIS IR mosaics of Mars.

Acknowledgements: We thank P. Christensen of ASU, and J. Torson, D. Cook, and K. Becker of USGS for supplying information and/or participating in many useful discussions. We acknowledge the efforts of Tim Colvin and the late Merton Davies of RAND for their development of basic framing camera algorithms and software used. This work is partially funded through the NASA Mars Critical Data Products Initiative.

References: [1] Archinal, B. A. et al. (2004) *LPS XXXV*, Abstract #1903. [2] Smith, D. E., et al. (2001) *JGR 106(E10)*, 23,689. [3] See http://pds-naif.jpl.nasa.gov/. [4] McGlone, J., ed. (2004) *Manual of Photogrammetry Fifth Edition*, ASPRS, Bethesda. [5] Greely, R., and Batson, R. M. (1990) *Planetary Mapping*, CUP, Cambridge. [6] Kratky, V. (1989). *ISPRS JPRS*, 44, 53-71. Fritsch, D. and Stallmann, D. (2002) *IAPRS Vol. XXXIII, Part B1,* 313-321, [7] Kirk, R. L. et al. (2004) *LPS XXXV*, Abstract #2046. [8] Colvin, T. *R. (1990) Photogrammetric Algorithms and Software for Spacecraft Optical Imaging Systems*, RAND, Santa Monica. Archinal, B. A. et al. (2004) A New Mars Digital Image Model (MDIM 2.1) Control Network, *XX ISPRS*, Istanbul. [9] Eliason, E. (1997) *LPS XXVIII*, 331-332; Gaddis, L. et al. (1997) *LPS XXVIII*, 387-388; Torson, J. and Becker, K. (1997) *LPS XXVIII*, 1443-1444. Also see http://isis.astrogeology.usgs.gov/. [10] Saxena, N. K. (1974) *JGR*, 79, 1147-1152.