

**USGS MAPPING OF THE MARS PATHFINDER LANDING SITE: PROGRESS AND PLANS.** R. L. Kirk, E. Howington-Kraus, T. Hare, J. Barrett, K. Becker, D. Cook, T. Sucharski, K. Thompson, J. Blue, D. Galuszka, B. Redding, C. Isbell, E. Lee, T. Rosanova, L. Gaddis, J. Johnson, L. Soderblom, W. Ward<sup>1</sup>, T. Parker<sup>2</sup>, E. Dorrer, A. Holzapfel<sup>3</sup>. <sup>1</sup>U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, Arizona, 86001 USA, [rkirk@flagmail.wr.usgs.gov](mailto:rkirk@flagmail.wr.usgs.gov), <sup>2</sup>4800 Oak Grove Dr., Pasadena, CA 91109, <sup>3</sup>Univ. der Bundeswehr, München, D-85577 Neubiberg, Germany.

**Summary:** This abstract describes progress in cartographic processing of data from the Imager for Mars Pathfinder (IMP) [1, 2] by the U. S. Geological Survey in the past year, and plans for advanced cartographic production.

**Progress Report:** USGS plans for cartographic processing of the IMP images were first described a year ago [3]. The planned set of products to be archived has been refined in the interim but has not changed significantly [4]. Briefly described, this archive will contain the following products.

- 1) Three multispectral "image cubes" for each azimuth and elevation in the Super Pan, containing respectively the left-camera images shifted so they register to one another, the right-camera images registered by shifting, and all 15 images from both cameras rectified to a common viewpoint and coregistered pixel-by-pixel based on a topographic model of the site.
- 2) A series of multispectral mosaics in panoramic projections, tied to a three-dimensional control network of the site [5]. Separate left- and right-camera mosaics will be produced for all panoramic/cartographic image sets obtained by IMP (First Look, Insurance, Monster, Gallery, and Super Pans), and a 15-band mosaic will be constructed from the rectified/coregistered Super Pan cubes.
- 3) Planimetric (top-view) mosaicked image maps of the 3-color Gallery Pan at multiple scales and extents.
- 4) Digital topographic data coregistered to the above products. Three-dimensional (X,Y,Z) coordinates and the surface normal will be provided at each pixel of the cubes and panoramas. The planimetric dataset will be a digital elevation model (DEM), giving Z on an XY grid.
- 5) Quasi-natural-color panoramic mosaics of the Super Pan with resolution enhanced by interactive "superresolution" processing of the spectral bands for each image [6] with gaps filled by other image sequences and a left-eye green image created from the red and blue filter data.

Generation of these products involves both the USGS in-house digital cartographic/image-processing software ISIS and our commercial digital photogrammetric workstation from LH Systems, with its SOCET Set software. ISIS is used for 2D processing and for mission specific tasks such as image ingestion, calibration, and calculation of the control network and revised camera pointing. SOCET Set provides automatic and interactive capability for measurement of control points and extraction of digital terrain models (DTMs) with a 3D display and input device. We have used the SOCET Developer's Toolkit to write software for exchanging data between the two systems and for geometric transformation of the data.

Significant challenges were encountered because the

IMP images are so different from the vertical aerial photography for which SOCET Set was designed. The system does not handle oblique images reliably, and it represents topographic surfaces as single-valued functions  $Z(X,Y)$  rather than as fully 3D objects. We have overcome most of these challenges by exploiting multiple coordinate systems and making synergistic use of ISIS, SOCET Set, and new software written at the interface between the two.

The 3D control network for the landing site is the cornerstone of cartographic processing and was completed in 1998. In final form this network contains 1322 points measured on 242 image pairs. Both ISIS and SOCET Set were used to obtain the measurements, which were refined to subpixel accuracy by automatic image correlation. Images from the Super and Insurance Pans, with lossless or very slight data compression, were used where possible; gaps were filled with a smaller number of Monster and Gallery Pan images. Other images can be tied to these control images in a separate procedure as needed. The ISIS bundle-block adjustment program IMPJIG was used to simultaneously calculate the ground coordinates of the points and improved estimates of the azimuth and elevation pointing of each stereopair. The resulting control net has a redundancy (ratio of measurements to unknowns) of 3.5 and has strong geometric convergence from 360-degree azimuthal closure, inclusion of pre- and post-deploy images, and measurement of every point in at least one instantaneous stereo pair. The root-mean-square (RMS) residual error in the measured image coordinates is  $\sim 0.5$  pixel, giving subpixel mismatches at the edges of mosaicked images. This is a significant improvement over the mismatches of tens of pixels ubiquitous in uncontrolled mosaics. As a check on the reliability of the calculation with IMPJIG, we have used the commercial bundle-adjustment package CAP (modified to incorporate the constraints on the motion of the IMP camera head and the coordinated motion of left and right cameras) to generate an independent control solution from the same point measurements. The sensitivity of the results to the weighting of various parameters is still under investigation, but the ground coordinates and image pointing are fully consistent with the ISIS solution.

A large fraction of our effort in 1998 was spent completing a detailed digital terrain model (DTM) of the landing site. Points on the ground were located approximately every 3 to 5 image pixels, for a total of  $\sim 3 \times 10^5$  points between the edge of the lander and  $\sim 160$  m distant. Because of a variety of contractual issues that prevented us from getting assistance in "tuning" the SOCET Set automatic stereomatching software to work with IMP data, all points

were collected interactively. Filter 5 (red) stereopairs from the Super Pan were used because of their lossless compression; gaps were filled with Monster Pan pairs. Because of the limitations of SOCET Set, each pair was imported in a "local" coordinate system centered on and aligned with the camera head. Data for the majority of stereopairs were collected as a DEM, with measurements of local-Z (toward the camera) on a regular grid in local X and Y. The surface is steeply inclined in these local coordinates and it was necessary in some cases to break the image into sections with different grid spacings. Late in processing, SOCET Set was upgraded to handle topographic data in Triangulated Irregular Network (TIN) as well as gridded format. Data for the horizon images were collected as TINs, which allowed us to concentrate points on features of interest (rocks and ridgelines) and speeded the work greatly. We wrote our own software to transform the DTM data from the local coordinates in which they were measured to global (Landing Site Cartographic or LSC, with X East, Y North, Z up [4]) coordinates for assembly into a sitewide model. The transformation could not be done with SOCET Set because its topographic formats (including TINs) do not allow surfaces with multiple Z values at the same X and Y (e.g., rocks with top and bottom surfaces mapped). We transformed each datapoint separately, rotating and translating it from local to global coordinates according to the camera pointing angles and camera head position. Lists of the global coordinate points were then concatenated and gridded in ISIS. Points on the undersides of rocks (visible to IMP but not from above) were interactively edited out of the gridded arrays, which were then interpolated by an iterative relaxation technique to produce global DEMs at the desired scales. These could then be re-imported into SOCET Set, but unfortunately they did not yield usable orthorectified planimetric mosaics. Production of orthomosaics will be addressed as described below; in the interim, unrectified planimetric mosaics [2 foldout] will be archived.

The spacing of topographic model points increases systematically with distance from the camera, as do positional errors. The detail and resolution of the final DEM everywhere exceed by a large factor those of the preliminary topographic map to 60 m from the lander, which was based on ~700 manually measured points [2 foldout, 3, 5]. Near the lander (within about 10 m radius), the topographic data are of such high quality that they open up new possibilities for quantitative research. The spacing of points near the lander is 1–2 cm, allowing individual rocks to be resolved; larger rocks can readily be recognized by their distinctive shapes in perspective views of the elevation data. Raytracing synthetic images of the terrain model can be used to produce useful simulations of the site as it would be seen by the Descent Imager on upcoming Mars Surveyor Landers. Quantitative photometric analyses based on the resolved shapes of rocks will be useful to correct spectral measurements for the effects of varying direct and diffuse illumination on surfaces of different orientation. Ideally, it may prove possible to simultaneously

refine the topographic models from several-pixel to individual-pixel resolution by shape-from-shading (photoclinometry). These studies are just beginning.

**Advanced Cartographic Plans:** Although the package outlined above includes the highest priority cartographic products and will support a wide variety of scientific studies, it does not exhaust the potential of the Pathfinder datasets. We have therefore begun the following set of eight interrelated tasks to produce additional, advanced cartographic products. Examples will be shown at the Workshop as space and progress permit.

- 1) Interactive superresolution processing of the Insurance Pan, which has different illumination and viewing geometry from the Super Pan.
- 2) Generation of vertical stereopairs from Insurance and Super Pan images by reprojecting the images so they are much easier to view. Images from 1) may be used.
- 3) More detailed mapping of the far field of the site (beyond 10 m), including collecting more topographic points, using vertical stereo from 1) and 2), and collecting features such as ridges and rock-free areas in GIS format.
- 4) Photogrammetric analysis of Sojourner stereopairs, both to improve resolution of parts of the dataset and to fill in gaps not visible from the lander.
- 5) Generation of a fully 3D shape/image model of the site in VRML format will be essential to make full use of the rover data 4) and will also allow production of orthophotomosaics through the use of commercial software.
- 6) Production of selected hardcopy maps from digital data.
- 7) Photogrammetric analysis of test pans obtained in the Univ. of Arizona "Mars Garden" for evaluation of errors relative to conventional survey data and for outreach.
- 8) Geometric control of remaining, non-panorama images to the net and panoramas, to facilitate change detection, comparison of spectral spot data, and so on.

**References:** [1] Smith, P., et al., 1997, The Imager for Mars Pathfinder Experiment, *JGR—Planets*, 102, 4003–4025; [2] Smith, P., et al., 1997, Results from the Mars Pathfinder Camera, *Science*, 278, 1758–1765; [3] Kirk, R. L., et al., 1998, USGS Experiences Mapping the Mars Pathfinder Landing Site, ISPRS Working Group IV/5 workshop "Mapping of Mars", University College London, 16-17 April 1999, abstract online at <http://www/ps.ucl.ac.uk/isprs-etm/abstracts/kirk.html>; Kirk, R. L., et al., 1998, Mapping the Sagan Memorial Station Site with the Imager for Mars Pathfinder Camera, In *Lunar Planet Sci. XXIX*, abstract #1752 (CD-ROM); Gaddis, L., et al., 1998, The Mars Pathfinder "Super Pan": A U.S.G.S. Cartographic Product, In *Lunar Planet. Sci. XXIX*, abstract #1831 (CD-ROM); [4] Gaddis, L., et al., 1999, Digital Mapping of the Mars Pathfinder Landing Site: Design, Acquisition, and Compilation of a Cartographic Product for Science Applications, *J. Geophys. Res.*, 104 (E4), 8853–8868. [5] Kirk, R. L., et al., 1999, Digital Photogrammetric Analysis of the IMP Camera Images: Mapping the Pathfinder Landing Site in Three Dimensions, *J. Geophys. Res.*, 104 (E4), 8869–8888. [6] Parker, T. J., 1998, "Super Resolution" of the Mars Pathfinder Landing Site by Manual Techniques, In *Lunar Planet. Sci. XXIX*, abstract #1965 (CD-ROM).