Utilizing Mars Digital Image Model (MDIM) and Mars Orbiter Laser Altimeter (MOLA) data for photogrammetric control. M. R. Rosiek, R. Kirk, T. Hare and E. Howington-Kraus United States Geological Survey, Astrogeology Team, Flagstaff AZ 86001 (e-mail: mrosiek@usgs.gov).

Introduction: The USGS is producing digital elevation models (DEM) and topographic maps of Mars at scales of 1:250,000 to 1:1,000,000. The initial source material will be Viking Orbiter images [1], with a later transition to Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC) [2] when stereo coverage from that source is available for topographic mapping. The digital terrain models and topographic maps produced by this effort will support geologic mapping and geophysical studies. The maps will be based on the horizontal and vertical control from Mars Orbiter Laser Altimeter (MOLA) [3]. Currently, the maps are based on planetographic coordinates, but eventually planetocentric coordinates will be used.

Background: Topographic information is essential to the understanding of many planetary surface processes. MOLA is producing a global altimetric dataset with phenomenal absolute accuracy and excellent vertical and along-track (north-south) spatial resolution but a larger inter-track separation that limits the overall resolution of gridded products. An analysis, as of April 2001, shows that the current MOLA dataset (~8100 orbits) has an average of one equator crossing every 1.3 km. Even if the orbits were uniformly spaced, gaps larger than 1.3 km would be common, but they are not uniformly spaced; 1/2 to 1/3 of the orbits are clustered on top of previous tracks. Assuming that about 2/3 the total are more uniformly distributed, it is calculated that about 39% of the grid cells (at 1/32 deg or 1.8 km) contain no track and have to be interpolated. Runs of four interpolated grid cells (7.4 km gaps between actual MOLA data) are not rare; they make up several percent of the area near the equator. For geologic mapping purposes, the 7.4-km width of these gaps is a much better measure of the quality of the MOLA DEM than just its 1.8 km grid interval or the average 1.3 km per track. Note also that by the end of the MGS extended mission a 1/64 deg grid will be released and there will be about twice as many orbits in it, so all the resolution figures will be cut in half, but gaps of several kilometers will still be present. Photogrammetric mapping from medium- to high-resolution images remains useful in the post-MOLA era, because it can produce much more finely gridded DEM. These models can now be tied to data from MOLA so that they partake of its absolute elevation accuracy. High resolution DEM produced in this way can be used to study various local geologic processes.

With the loss of the Mars 96 mission, whose High Resolution Stereo Camera (HRSC) would have produced extremely high quality data for photogrammetry, the Viking Orbiter images will remain our best source for local topographic mapping in the near term, but two other image sets may become available later. First, the narrow-angle Mars Orbiter Camera (MOC NA) is now imaging Mars at a minimum of 1.5-m/pixel resolution. Because of the very small footprint of the NA images, repeat coverage from which a stereopair of two such images can be formed will be extremely rare. Overlap between a MOC NA image and high-resolution Viking images with usable stereo convergence will be much more common, and mapping with such mixed stereopairs may become important. Second, the HRSC has been proposed for reflight on the European Mars Express mission to be launched in 2003. Thus, HRSC images will not be available for several years at best. Both MOC and HRSC are pushbroom scanners, and an appropriate sensor model will need to be adapted or created before they can be used for stereomapping. For the latest on mapping with MOC NA images see the paper “High Resolution Digital Elevation Models of Mars from MOC Narrow Angle Stereoimages” that is presented in this workshop [4]

Control: There has been a substantial improvement in geodetic control available for topographic mapping. Past topographic maps were either based on small, local control networks or tied to the USGS global three-dimensional control net [5]. A variety of problems subsequently were identified with this net, including an overall longitude difference of almost a quarter of a degree with respect to more recent and better accepted nets [6, 7], widespread horizontal errors (both random and patterned) of several kilometers, and vertical errors of as much as several kilometers.

Over the past two years, however, we have participated in a joint effort by groups at USGS, RAND, JPL, Goddard, DLR, and elsewhere to produce a new generation Mars global geodetic control net that is substantially improved in accuracy and that is widely supported by all relevant experts. As the first step of this project, which was funded by the Mars Data Analysis Program, we densified the RAND control network by adding images and point measurements from the global image mosaic of Mars (the well-known MDIM, distributed on six CD's in 1991) [8], tripling the number of Viking images [9]. We also contributed substantially improved estimates of the image coordinates of all three U.S. Mars landers used in the net [10]. The RAND net is two-dimensional, that is, it uses near-vertical images and must have the elevations of control points specified as input. In 1999, the majority of control points were given elevations interpolated from MOLA data [11] and a new control net was developed. MDIM 2.0 has been produced [12] based on that control net. A further revision to the geodetic control net will take place with MDIM 2.1. This product will be based on additional horizontal and vertical control from the MOLA data [13]. Thus, excellent data are available currently and in the future for both horizontal and vertical control of special-scale maps. One difficulty is to use data based on different control.

Geodetic Parameters: Another complication is the change and refinement in geodetic parameters for Mars. A reference surface for a planet is defined by the semi-major and semi-minor axis. The origin for longitude on Mars is based on defining a location for the prime meridian located at Airy-0. For MDIM 2.0, MDIM 2.1 and the MOLA data these data are different. The MOLA and MOC data have helped define improved values for Mars. The most recent values are: semi-major axis is 3396.19 km; the semi-minor axis is 3376.2 km; and the prime meridian is based on W_0 = 176.630° [14]. In the future, data will be provided based on these parameters. At present, it is necessary to determine which geodetic parameters were used to produce the data and to determine the appropriate parameters for the product being produced.

Coordinate System: There are two coordinate systems for Mars that were defined and approved by the International Astronomical Union (IAU) [16]. One combines longitude measured positive east with latitude measured from the equatorial plane to a point through the center of the planet, planetocentric latitude. This is a right-handed spherical-polar coordinate system. The other system uses longitude measured in such a direction that the sub-Earth longitude increases with time; for Mars, this means positive west. The second system uses planetographic latitude, which is measured as an angle between the local vertical at a point and the equatorial plane. Because the shape of Mars is flattened relative to a sphere, the planetographic latitude of any point is greater in magnitude than the corresponding planetocentric latitude (except at the equator and poles, where the two types of latitude are equal). The maximum difference between the two types of latitude on Mars is about 0.3 degree or 20 km, at 45 degrees North and South. [15]

Historically, maps produced by the USGS have used the West positive longitude, planetographic latitude systems. To adapt commercial photogrammetric and geographic information software to this system meant negating the longitude values since earth coordinates are positive east longitude and geographic latitudes.

The MOLA team used positive east longitude and planetocentric latitude values for the altimetry data. This system is not directly supported by commercial photogrammetric and geographic information software. The coordinate values are converted to coordinates based on planetographic values. Since the MOLA data are so widely available and many products are based on this data, there is a need to consider which coordinate system to use in the production of map products. The USGS has requested approval from NASA to move to positive east longitude, planetocentric latitude coordinate system for cartographic products.

Photogrammetry: The photogrammetric triangulation and DEM extraction will be carried out on a LH Systems DPW 790 digital photogrammetric workstation (BAE Systems SOCET SET software) [16]. We have augmented the SOCET SET software supplied with this system with interface routines to Integrated Software for Imagers and Spectrometers (ISIS) system [17] for importing and exporting planetary data.When importing images into the photogrammetric workstation the camera positions and angles are converted from the J2000.0 inertial coordinate system into a Mars fixed and centered coordinate system. Input parameters into this conversion process include the geodetic parameters for semi-major and semi-minor axis, $W_{0,}$ W_dot, and the observation time. The final coordinate system is a planetographic latitude with longitude values positive west. The commercial systems are primarily used for earth-based projects and the coordinate system must be compatible with the expected input of the commercial software.

The quality of stereomapping depends on the resolution and geometry of images available and varies widely over Mars; understanding the availability of data is crucial to planning this task. A Viking Orbiter Image Database is available to help select images for topographic mapping [18]. This database contains a subset of geometric metadata from the most up-to-date records at the USGS, Flagstaff. We have written customized software to analyze and display selected aspects of these data. This provides an indication of the stereo quality for a given area and helps in selecting the images to use for topographic mapping.

Photoclinometry: Photoclinometry (PC, or more descriptively, shape-from-shading) is another method that is used for producing high-resolution topographic data. Numerous approaches to PC have been developed; we will use the method of Kirk [19], which constructs a full two-dimensional digital elevation model (DEM) from an image. In essence, a finite-element model of the surface shape is set up and iteratively adjusted until a shaded "image" calculated from it agrees with the real image, in a least-squares sense.

Because PC directly determines slopes and then integrates slopes to get elevations, the accuracy of relative elevations between points varies with separation. PC provides excellent topographic detail at the single-pixel scale, which stereomatching cannot do, but is subject to increasing distortions over larger horizontal distances.

One effective way to use PC is as a form of "smart interpolation", to add pixel-scale detail to a preexisting stereo dataset while retaining the absolute accuracy of the later. If the broad-scale distortions can be tolerated, PC can also produce useful topographic models where stereo coverage is nonexistent or extremely poor.

Methodology: When producing a map product it is necessary to determine the geodetic parameters and coordinate system for the input data (images, elevation data) and the desired geodetic parameters and coordinates system for output map product. The input data will have to projected to a common coordinate system, which might not be the coordinate system of the final map product. This means the final data produced might have to be projected to the final coordinate system.

To use MOLA data in map production the data has to be projected to a common coordinate system. Since the commercial photogrammetry software expects data in geographic coordinates, all base products are projected into this system. The longitude values are projected to have the prime meridian based on $W_0 = 176.630°$. Future releases of MOLA data will use this value, so a check is made of which W_0 was used to produce the MOLA data. This projection is carried out using the ArcView software by ESRI. The values used for the semi-major and semi-minor axis of the planet are dependent upon which MDIM is being used.

MDIM 2.0 is based upon 1991 geodetic parameters (a=3396.0 km, b=3376.8 km). The images used in MDIM 2.0 were projected to fit a reference surface based upon those geodetic parameters. When using MDIM 2.0 as a base image the mapping project will use the 1991 geodetic parameters through out the mapping project. A base image is produced using the Map-A-Planet web site (http://pdsmaps.wr.usgs.gov/maps.html) and an image is produced in simple cylindrical map projection. The MDIM 2.0 image is then registered to the MOLA data that was projected into planetographic coordinate system. The registered image is then brought into the photogrammetric workstation and is used to provide an initial estimate of the horizontal coordinate values.

In the future when MDIM 2.1 is available, the images will already be tied to the MOLA data and will use the most recent geodetic parameters. Those geodetic parameters will be used throughout the mapping project. Both the MDIM 2.1 and MOLA data will need to be projected into a planetographic system since the commercial photogrammetric software expects geographic coordinates as inputs. The digital terrain model and orthographic image mosaics produced by the photogrammetric workstation will then be projected in planetocentric coordinate system.

To obtain vertical control, the MOLA data are used as a surface to interpolate an elevation value for the estimated horizontal coordinates values. These estimated horizontal and vertical coordinates are used in the triangulation solution solved for on the commercial photogrammetric workstation. The triangulation solution is a weighted solution and all parameters are used in the solution. By adjusting the weights, different parameters are solved for and some are held constant. The camera angles are allowed to be adjusted the most, since their estimates are the least reliable. The horizontal coordinate estimates are allowed to adjust somewhat, since they are based on the MDIM and that product is not a true orthoimage the horizontal coordinates need to be adjusted for the difference in elevation. The vertical coordinate estimates are allowed to adjust slightly, since the estimates for the horizontal coordinates can be off and the values are interpolated from an interpolated surface based on the MOLA data. This triangulation solution is iterated, as better estimates, for the horizontal coordinates are obtained new estimates for the vertical coordinates are obtained, this iteration continues until a stable solution is obtained.

The triangulation solution provides better estimates for the camera angles. Based on these angles a digital terrain model can be obtained by extracting terrain values from stereo models. The digital terrain model provides the base data needed to produce contours, orthoimages, and shaded relief images that are used to produce maps used by the geological mappers and scientist.

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