A MOLA-CONTROLLED RAND-USGS CONTROL NETWORK FOR MARS.
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Introduction: Since the early 1970's a series of solutions for Mars control networks (coordinate systems) have been performed by both RAND and USGS personnel and others [1,2,3,4,5]. This series culminated in solutions during the late 1990's which were used to control the USGS Mars Digital Image Mosaic (MDIM) version 2.0 [6]. However, after serving for over 25 years to define fundamental coordinates on Mars, these photogrammetrically derived control networks have been superseded by the much more accurate coordinate systems derived from Mars Global Surveyor (MGS) Mars Orbiter Laser Altimeter (MOLA) measurements. The coordinates of the MGS spacecraft can be determined with meter to tens of meters accuracy relative to a Mars-centered inertial coordinate system, and the MOLA ranges can then be used to determine the location of surface features with accuracies on the order of 100 meters for horizontal positioning and 1 meter for vertical positioning [7]. This compares with the absolute accuracies of ground points of 2 to 6 km or so (in horizontal and often even vertical position) as obtained from the photogrammetric solutions.

However, a need still exists for photogrammetric solutions and their associated control network of points with known coordinates. The most important use of these networks is still to refine camera pointing information for Viking Orbiter (VO) images of Mars. The *a priori* pointing information from the Viking mission is notoriously unreliable, in the sense that often the area covered by a particular image has no overlap at all with the area one would predict to be covered from the *a priori* data. Therefore solutions for these camera angles are needed, not only to assist with determining the location of individual images on the Martian surface but also to determine the locations of a large number of images providing global coverage so that global and regional image mosaics (maps) can be derived. Global image mosaics can also now be derived from the MOLA data itself, but only at a resolution comparable to the track spacing of the MOLA data (~1-2 km at the equator).

USGS is currently preparing a new version (to be called MDIM 2.1) of its global Mars digital image mosaic [8], and as part of this process we are planning to make a new photogrammetric solution based on MOLA-derived coordinates, thus resulting in more accurate camera pointing information, as well as more accurate final control point positions. In the remainder of this abstract, we discuss the improvements that have been undertaken or planned as part of this new control solution adjustment.

MOLA Derived Radii: A first and important step, already completed, is to use MOLA-derived planetary radii for all of the control points in the photogrammetric solution. This has been accomplished by searching for the nearest MOLA range to each existing control point, and then fixing the radius of that point to the MOLA-determined value. The MOLA range data are filtered before use, eliminating obvious spurious observations. A correction is also made to the photogrammetrically derived longitude, to correct between the two longitude definitions in use (released MOLA data has so far been based on the IAU 1991 [4] value of W_0 = 176.868º (where W_0 defines the origin for longitude), while the most recent RAND-USGS photogrammetric solutions have used a value of W_0 = 176.753º). The overall procedure here has been iterated, both to take advantage of new or corrected MOLA data as they have been made available, and to account for changes in control point positions (in latitude and longitude) once new radii are adopted, which requires a new search for the closest MOLA radii. It is planned to iterate through this procedure again when further improvements as described below are made to the photogrammetric solution process. We will also investigate whether there is any improvement if radii are interpolated from a MOLA digital elevation (or in this case, radius) model, rather than being obtained directly from the nearest MOLA range. In any case, the adoption of MOLA radii for the photogrammetric solution control points does decrease the *a posteriori* solution uncertainty (RMS) and obviously provides control point radii (or elevations) that are in good agreement with the far more accurate MOLA-derived values.

Additional Images: The most current RAND-USGS photogrammetric control solution contains 88325 measurements of 36396 control points on 6320 VO images. It is based on the solution used to control MDIM 2.0. During the process of creating the MDIM itself, it was found that a number of small areas ("seams") between the initially chosen set of images either had poor coverage or were missing coverage completely. To remedy this problem, portions of 52 additional "add-on" images were added to the mosaic. This was accomplished by first making 406 measurements of 203 control points on 102 images that were either common to the existing control point set or new. A photogrammetric adjustment of this new data and the image camera angles was then performed using the ISIS [9] "Jigsaw" software. However, this was in effect a local adjustment to fixed control point positions from the final RAND global adjustment for MDIM 2.0. Although this method of controlling these "add-on" images seemed sufficient for use in MDIM 2.0, we now plan to take these new measurements and add them directly to the global adjustment. We believe this will result in more consistent camera angle determinations for these "add-on" images, both for use in creating MDIM 2.1 and for other users who will be able to model more precisely the areas of Mars covered by these images.

New Reseau and Orbit Information: Two changes have also been implemented that should result in improved data (i.e. with less systematic errors) being input into the adjustment. This includes the use of a new procedure to derive the position of reseau marks in the VO images, and the use of improved VO spacecraft orbit information.

As part of a series of general improvements to the ISIS software, a new procedure (program "findrx") was developed to automatically find and measure the positions of reseau marks in the VO images. In particular this procedure uses a set of template images of each of the reseau marks, which is automatically matched with the reseau marks on any given VO image in order to determine the reseau positions for that image. This should be an improvement over past methods where a generic image of a single good reseau mark was used for such a purpose. As in the past, these reseau measurements are used to correct pixel measurements from the VO images to mm measurements in the image plane. It is these mm measurements, now corrected for camera distortion, that are used in the global photogrammetric adjustment.

In addition, the NAIF facility [10] has provided improved VO orbit determination parameters, which have resulted from a new adjustment of VO tracking data and the use of an up-to-date Mars gravity field. These orbit determination parameters (for the time of each VO image used) are also input to the global photogrammetric solution, with the spacecraft position information held fixed, and the spacecraft (camera) pointing information adjusted in the solution. We expect that this improved information, especially for spacecraft position, which we cannot adjust, should also result in an improved global solution, due the elimination or at least reduction of previous systematic orbit errors.

IAU/IAG 2000 Recommendations: In a step that will not necessarily improve our solutions but will provide increased compatibility and comparability with other Mars coordinate systems, we plan to adopt the new constants recommended by the IAU/IAG WG on Cartographic Coordinates and Rotational Elements of the Planets and Satellites [11]. In the past photogrammetric control solutions have been used to determine the value of W_0, by fixing the longitude of the crater Airy-0 to 0º. However, an improved value for W_0 has been determined by a combination of methods, using MOLA data, and MOC and VO images [12], and the IAU/IAG WG has adopted that new value of W_0 =176.630º. We will use the same value, as well as the currently specified values for the pole position of Mars and Mars' rotation rate. As other providers and users of Mars coordinate system data provide results in this new system, it will be possible to make direct comparisons of coordinates obtained from our photogrammetric solutions.

MOLA DIM Control: Aside from using MOLA data to determine the elevation of our control points, by far the greatest change in our solutions will be to also use MOLA data to constrain the horizontal positions of some of our control points and to provide new horizontal control points. Small area digital image mosaics (DIM) are being prepared for a number of points on Mars by one of us (TD), using MOLA data to derive the topography and with appropriate illumination of these models added. In turn we are using these DIMs in direct comparison to (projected) VO images in order to measure the positions of existing and new RAND-USGS control points. These points are usually defined by crater centers, and ISIS ("qmatch") software has been modified to make this type of point match, including the determination of crater size radii (actually annulus) determination of the MOLA planetary radius, averaged among the available MOLA radii in the measured crater annulus. The end result is the availability for a select set of existing and new RAND-USGS control points of a MOLA derived latitude and longitude (i.e. in the MOLA inertially derived coordinate system). These positions should be good to nominally 250 m on the surface of Mars. Also available will be a MOLA derived elevation (accurate to the 10s of meters level, depending on the topography of e.g. the crater rim) for the control point (or crater rim). This compares to our previous solutions, where repeated solutions with new image and control point sets show that although relative horizontal accuracies between images are likely on the order of the VO image resolution (e.g. 1 km or less), absolute planetary coordinate accuracies were much lower, e.g. 2 to 6 km or more, due to systematic shifts in blocks of VO images.

Summary: Primarily in support of the creation of MDIM 2.1, but also to provide the best possible image based coordinate system for Mars, we have undertaken and plan to undertake a number of improvements in the RAND-USGS photogrammetric control network for Mars. These primarily will involve the use of MOLA-derived radii to improve control point absolute radii (e.g. elevation) information to the meter or at least tens of meter level, and using a MOLA derived DIM to improve absolute control point horizontal positions to the few hundred meter level. Other improvements are also being undertaken, i.e. using additional images, measurements, improved reseau information, improved orbit information, and IAU/IAG 2000 recommendations in the solution for the network. We expect the horizontal accuracy of the resulting MDIM 2.1 mosaic to be similar to those of the network, resulting in an order of magnitude improvement over the positional accuracy of MDIM 2.0.

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