REGISTERING HRSC IMAGERY OF THE MARS EXPRESS MISSION TO MARS OBSERVER LASER ALTIMETER DATA. M. Spiegel[1], R. Schmidt[2], U. Stilla[1], A. Baumgartner[1], G. Neukum[3] and HRSC Co-Investigator Team, [1]Photogrammetry and Remote Sensing, Technische Universitaet Muenchen, Arcisstr. 21, 80333 Muenchen, Germany, spiegel@bv.tum.de, [2]Institute of Photogrammetry and GeoInformation, Universitaet Hannover, Nienburger Str. 1, 30167 Hannover, Germany, schmidt@ipi.uni-hannover.de, [3]Institut fuer Geologie, Geophysik und Geoinformatik, Freie Universitaet Berlin, Malteserstr. 74-100, 12249 Berlin, Germany.

Introduction: The High Resolution Stereo Camera (HRSC) on board of ESA Mission Mars Express started imaging the surface of planet Mars in color and stereoscopically in high resolution in January 2004. The Institute of Photogrammetry and GeoInformation (IPI) of the University of Hannover and the Department Photogrammetry and Remote Sensing (FPF) of the Technische Universitaet Muenchen are jointly processing the data of the HRSC. The primary goal is to register the HRSC data to the Mars Observer Laser Altimeter data (MOLA). With the result of the processing chain (especially with the improved exterior orientation), high quality products such as DTMs, ortho images and shaded reliefs can be derived from the imagery. In the following sections HRSC and MOLA-data, the concept, and results of photogrammetric point determination with and without MOLA data as control information in the bundle adjustment is described.

Data Sources: There are two different data sources: The HRSC data and the MOLA data.

HRSC. The ESA and the German Aerospace Center (DLR) delivers images strips of HRSC and observed exterior orientation of Mars Express spacecraft. In general, one strip has a length of about 300 km up to 4000 km. At pericenter one image strip has as swath width of about 60 km and has a ground resolution of 12,5 m. The interior orientation of the camera is known from calibration and it is assumed to be stable. The IPI uses these data as input for the automatic extraction of image coordinates of tie points. The matching software delivers a large number of automatically measured tie points between the multiple stereo strips [1].

MOLA. During the operation time (1997-2001) the MOLA instrument acquired more than 640 million observations by measuring the distances between the orbiter and the surface of Mars. These 640 million observations cover the entire surface of Mars with high and consistent accuracy. In combination with orbit and attitude information these altimeter measurements have been processed to coordinates of points on the ground [2]. In addition to the surface described by the original, irregularly spaced MOLA track points NASA distributed a grid-based global Digital Terrain Model (DTM) which is derived from these MOLA points [3]. MOLA global terrain models have been recommended as reference surface for the planet. The accuracy of the DTM is 200 m in planimetry and 10 m in height.

Concept: In this section the two steps of the bundle adjustment software of FPF are described: In the first step an internally consistent solution is reached. In the second step the matched HRSC points are fitted to the MOLA DTM.

Bundle Adjustment without MOLA DTM. In the bundle adjustment the concept of orientation images proposed by [4] is used. This approach estimates the parameters of the exterior orientation only at a few selected image-lines, at the so-called orientation images. The mathematical model for photogrammtric point determination with a three-line camera is based on the well known collinearity equations. These equations describe the fundamental geometrical condition that the rays through the three corresponding image points and the corresponding perspective centers intersect in the object points. Two collinearity equations are established for each image point. For every object point there are several equations, because corresponding image points are found in images of different sensor lines.

The collinearity equations are not in linear form and must be linearized by a truncated Taylor's expansion. Therefore, approximations for the orientation parameters and the object points are required in bundle adjustment. All observations are used in a simultaneous least squares adjustment to estimate the unknowns. Because of the non-linearity of the problem, several iteration steps are necessary. Result of this first adjustment step is a consistent point cloud and gross errors of the matching are eliminated.

Using MOLA DTM as control information. In general, the classical photogrammetric point determination requires image coordinates of tie points, interior and exterior orientation, and ground control points (GCP). In case of HRSC on Mars Express there are no GCP available and observed parameters of exterior orientation will probably not be precise enough for a consistent photogrammetric point determination on a global level. Nevertheless, the observed parameters can serve as good approximate values.

But additional control information is necessary in order to fit photogrammetrically derived object points into the existing reference system on Mars. Instead of classical GCPs there is a large number of ground points measured by MOLA. The special thing about the laser points is, that they can not be identified in the images in an easy way. I.e., image coordinates of most of these points can not be measured, and therefore, it is not possible to use them as normal GCPs in a bundle adjustment. As a remedy it is proposed to use control surfaces.

At locations where HRSC points are available a local surface is derived from the MOLA data. The constraint is that HRSC points have to lie on this local surface defined by four neighboring DTM grid points, which enclose the HRSC point. The distance of the HRSC point to the surface defined by the four DTM points is minimized. This is ensured by one additional conditions equation for each HRSC point [5]. After this second step the HRSC points are fitted optimally into the MOLA reference and with the HRSC point cloud also the exterior orientation of HRSC imagery is registered to the global reference frame provided by MOLA data.

Results: During the first ten month of orbiting Mars the HRSC acquired images of an area of about 22 million square kilometers. All imagery from orbits with an orbit altitude between 265 and 500 km have been processed. Thus, the ground pixel size is between 12,5 m and 25 m in nadir channel. The first step of the bundle adjustment is able the improve the exterior orientation, especially φ (pitch) and κ (yaw). The accuracies of object points after bundle adjustment are in a range of about 5 to 20 m in X (flight direction) and Y (across track). Z (height) accuracies of all orbits are about 30 to 50 m. In fact, even without MOLA control information the theoretical standard deviations of the object points can be improved by a factor of 2 to 3 by bundle adjustment.

Next, in the second step the HRSC object points are tied to the MOLA DTM. In the orbits investigated the improvement can be determined with high significance. Additionally, the root-mean-square (RMS) differences between HRSC and MOLA DTM is reduced by a factor of 2-3. Hence, there is a high consistency between HRSC points and the MOLA reference system after the bundle adjustment. This is clearly visible by comparing the differences graphically before and after the bundle adjustment (Figure).

Conclusion: The results show the potential of bundle adjustment approaches to achieve an improved exterior orientation. The accuracy of the attitude increases from 28 to 1-2 mgon in the two angles, which can be improved without DTM. The object coordinates of the tie points have a very high internal accuracy. With MOLA DTM as control information the height divergence decreases by a factor of 2-3. Finally, there is a high consistency between HRSC points and MOLA DTM, which constitutes the valid reference system on Mars.

References: [1] Heipke, C. et al. (2004) *IntArchPhRS, Vol. 35 Part B4,* 846–851. [2] Smith, D. et al. (2001) *JGR, 106*, 23689-23722. [3] Neumann, G.A. et al. (2003) LPS XXXIV, Abstract #1978. [4] Hofmann, O. et al. (1982) *IntArchPhRS, Vol. 24 Part B3*, 216-227. [5] Ebner, H. et al. (2004) *IntArchPhRS, Vol. 35 Part B4,* 852–857.

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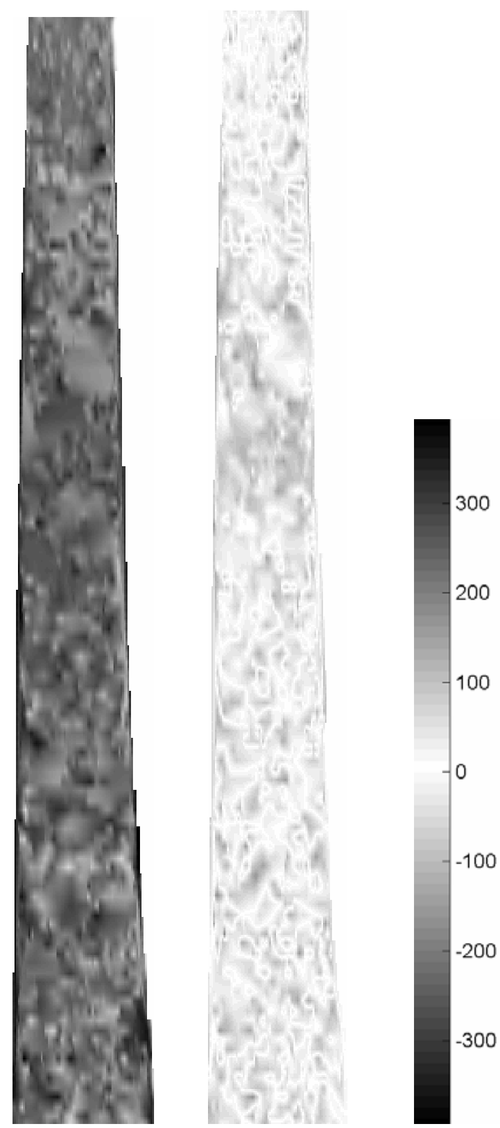

Figure: RMS differences between HRSC points and MOLA DTM in height before (left) and after (right) registering to MOLA DTM.