AUTOMATIC TIE POINT GENERATION FOR THE PROCESSING OF HRSC IMAGERY OF THE MARS EXPRESS MISSION. R. Schmidt[1], M. Spiegel[2], C. Heipke[1], J. Oberst[3], G. Neukum[4] and the HRSC Co-Investigator Team, [1]Institute of Photogrammetry and GeoInformation, Universität Hannover, Nienburger Str. 1, 30167 Hannover, Germany, schmidt@ipi.uni-hannover.de, [2]Photogrammetry and Remote Sensing, Technische Universität München, Arcisstr. 21, 80333 München, Germany, photo@michaelspiegel.de, [3]Institute of Planetary Research, German Aerospace Center (DLR), Rutherfordstr. 2, 12489 Berlin, Germany, [4]Institute of Geological Sciences/Planetology, Malteserstr. 74-100, Freie Universität Berlin, Malteserstr. 74-100, 12249 Berlin, Germany.

Introduction: With Mars Express being in orbit for one year now, the spacecraft has returned more than 250 image strips to earth taken by the multiple line scanner camera HRSC (High Resolution Stereo Camera).

The three-dimensional position of the spacecraft is determined by combining ranging and Doppler shift measurements. An onboard star tracker is used to control the spacecraft's attitude (and thus the pointing of the body-fixed camera). These values result in a three-dimensional position and attitude of the spacecraft over time (termed "exterior orientation" (EO) in classical photogrammetry). Unfortunately, these parameters are sometimes poorly contrained. However, the HRSC experiment with its multiple stereo lines is designed with the goal in mind to improve these nominal values of exterior orientation by means of photogrammetric techniques. This is accomplished in two steps. First, a large number of tie points between the multiple stereo strips are extracted via digital image matching (DIM). Then, a bundle adjustment (BA) is performed to correct the EO, using the collected tie points as observations for the unknown EO parameters.

The automatic determination of tie points is carried out at the Institute of Photogrammetry and GeoInformation (IPI) of Universität Hannover and is presented in this abstract. The subsequent BA is carried out at Department Photogrammetry and Remote Sensing (FPF) of Technische Universität München [2]. The remaining processing like digital terrain model (DTM) and ortho photo generation is done at Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) in Berlin Adlershof [7].

Matching approach: Our matching approach follows a coarse to fine strategy, which means that the matching result is refined step by step through image pyramids. The HRSC imagery, the observed EO, and the calibration data of the interior orientation (IO) are needed as input.

At first, point features are extracted using the Förstner operator; the images are matched pairwise in all combinations using the cross correlation coefficient as similarity measure. Each image is divided into subareas to ensure an even distribution of the tie points over the whole area. To reduce ambiguities and computing time the matching location and a search space for the corresponding feature is computed when transferring a feature from one image to the other. Since no epipolar geometry exists for linescanner imagery, a feature in one image is transferred to the next image via equation (1) [1]:

$$\begin{pmatrix} x - x_0 \\ y - y_0 \\ -c \end{pmatrix} = \lambda M^T \left(\Delta\varphi, \Delta\omega, \Delta\kappa\right) D^T \left(\varphi, \omega, \kappa\right) \left[\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} - \begin{pmatrix} X_0 + \Delta X_0 \\ Y_0 + \Delta Y_0 \\ Z_0 + \Delta Z_0 \end{pmatrix} \right] \quad (1)$$

For the transformation from object space to image space as a function of the image line (readout cycle) n an additional condition (2) has to be introduced where x points in flight direction:

$$\mathrm{x(n)} = \mathrm{x}\left(\mathrm{n},\, \mathrm{X}_0(n), Y_0(n), Z_0(n), \varphi(n), \omega(n), \kappa(n)\right) = 0 \quad (2)$$

This problem can be solved using the Newton-method for the above zero-crossing detection where the derivative $x'(n_i)$ is replaced by the pixelsize of the image (3):

$$\begin{aligned} & n_0 = \textit{initial value for the image line} \\ & n_{i+1} = n_i - x\left(n_i\right) / \textit{ pixelsize} \qquad i = 0,1,\ldots \end{aligned} \quad (3)$$

After matching all overlapping images pairwise in all combinations, the point tuples are generated by applying a Random Sample Consensus (RANSAC) procedure [3]. From the start pyramid level (lowest resolution) to the so-called intermediate level (medium resolution), feature based matching is carried out on the entire images. Going down the image pyramid the image size and the number of extracted features increase. Besides the heavily increasing computational time, the matching of the complete images would result in an exceedingly large number of tie points. Therefore, the matching procedure is carried out only for selected "image chips", starting from the intermediate pyramid level. Tie points are searched for only in those areas where points have been found before.

To further refine the positional measurements of the tie points, Multi Image Least Squares Matching (MILSM) is carried out. In our approach the tie points are matched simultaneously in all images (see [4] for details).

Finally, model points are derived via a forward intersection of the image coordinates of the tie points. They serve as an approximation for the reduction of the search space on the next lower pyramid level. In our implementation of the matching software, we can also use a DTM to find the approximate search area for points. On Mars a high resolution DTM of excellent quality derived by the MOLA experiment is available [5] which is used during matching. A more detailed description of the application flow can be found in [6].

Results: The matching was evaluated with selected imagery from the orbits 266, 279, and 292. Also a block composed of these three strips has been analyzed. The strips were obtained in April 2004 from an orbit height between 265 and 297 km (note that the ground pixel size from an orbit height of 250 km is approx. 10 m). While the nadir channel was operated at full resolution, the stereo channels were operated with 2x2 pixel binning, i.e. at a reduced resolution of 20 m.

Figure 1 shows the results of matching for the three overlapping orbits 266, 272, 292 and the distribution of the tie points. It can be seen that the tie points are evenly distributed over the whole block with a good connection between the strips. But there are also some areas with a lower density of tie points due to low texture or image data gaps.

In a first evaluation the ray forward intersections of the tie points are computed from the nominal values of the EO. Next, the BA is carried out and the obtained results are compared to the prior values. Note that for single strips only constant offsets (biases) of two out of three pointing angles, φ (pitch) and κ (yaw), can be determined. The translations and the pointing angle ω (roll) cannot be determined from tie points alone. Within the block the three translations have been estimated for the two outer strips as well.

orbit	σX [m]	σY [m]	σZ [m]
266	11.7 / 4.5	18.7 / 5.1	39.2 / 11.0
279	17.0 / 5.3	10.5 / 4.4	35.3 / 11.2
292	10.6 / 4.9	16.5 / 6.2	35.3 / 13.8
block	10.9 / 5.6	17.3 / 7.0	36.6 / 15.9

Table 1: Theoretical standard deviations of the object coordinates before/after the bundle adjustment.

In Table 1 the accuracies of the computed object coordinates are shown for the selected orbits and the block. The left value is the theoretical standard deviation of the object points using the nominal EO. The right value shows the achieved standard deviations after improving φ and κ (and the mentioned biases for the block). The accuracies lie in a range of about 5 to 7 m in X (flight direction) and Y (across track). Z (height) accuracies of all orbits are about 11 to 16 m. Obviously, the theoretical standard deviations are improved by a factor of 2 to 3. Considering a ground pixel size of 20 m this translates to a final accuracy of about 0.4 pixel in X and Y and 0.8 pixel in Z which is an excellent result considering the low texture of the imagery. While the software described in this paper was specifically written for the HRSC on Mars Express, the algorithms may be useful to image data sets from other planetary space missions alike.

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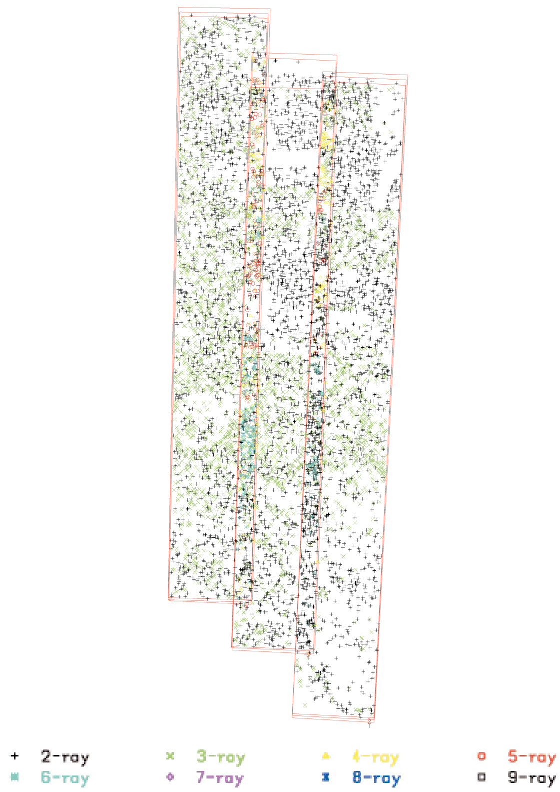

Figure 1: Distribution of tie points in the block of orbits 266, 272 and 292 (north is up).