OPERATIONAL DETERMINATION OF TIE POINTS AND BUNDLE ADJUSTMENT OF HRSC IMAGES OF THE MARS EXPRESS MISSION

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ABSTRACT:

Since January 2004 the HRSC (High Resolution Stereo Camera) onboard Mars Express is imaging the planet Mars stereoscopically, in colour and at high resolution and has returned more than 1800 image strips to earth. The pushbroom scanner is equipped with 9 CCD line detectors with 5176 pixels each mounted in parallel on the focal plane and is able to obtain panchromatic stereo data at three or five angles and colour data simultaneously in one image strip. With an average flying height of about 270 km at pericenter a resolution of up to 12 m per pixel is achieved. The orbital elements have been designed to obtain overlapping image strips after 11 orbits respectively 3 days which allows for processing larger areas in a block structure. Because of a low data transmission bandwidth between Mars and Earth the image data is compressed by a DCT (Discrete Cosine Transform) known from the JPEG algorithm. Additionally, only the nadir channel is transmitted at full resolution while the others are reduced by pixel binning. The three-dimensional position of the orbiter with respect to the body-fixed coordinate system of Mars is permanently observed by Doppler measurements of the FDT (Flight Dynamics Team) of ESOC (European Space Operations Centre). The pose of the camera is adjusted with star trackers to the viewing direction from mission planning. The two elements position and pose form the exterior orientation of the HRSC with six values for each image line. An absolute accuracy of about 200 m is achieved in practice, but along flight direction the deviation can amount up to some hundred meters. These values are not accurate enough for precise photogrammetric point determination, therefore a bundle adjustment is carried out to improve the relative accuracy of the ray intersections and the absolute position of the spacecraft. For absolute positioning the MOLA (Mars Orbiter Laser Altimeter) DTM is used, which features high global accuracy and currently marks the best available reference system on Mars. With the improved exterior orientation high quality products such as high resolution DTMs or mosaics can be produced.

The improvement of the exterior orientation of the orbiter can be divided into two separate steps: At first a large number of tie points have to be determined automatically which will be used as input in the subsequent bundle adjustment. The automatic extraction of tie points is carried out at Institute of Photogrammetry and GeoInformation (IPI) of Leibniz Universität Hannover and the result is transferred to Photogrammetry and Remote Sensing (FPF) of Technische Universität München respectively Planetary Sciences and Remote Sensing of Freie Universität Berlin. For every HRSC strip the image quality is visually inspected prior to processing because sometimes they are unusable due to dust storms or other unfavourable conditions. In various cases image quality is degraded by low contrast, noise and compression artefacts which hampers finding corresponding points. For this reason the images are being restored by robust anisotropic diffusion which is a self-adapting edge preserving filtering process. After that the images of the strip are prerectified to a common cartographic system using the MOLA DTM as height information though in absence of an applicable DTM it would be possible to rectify on an ellipsoid, sphere or plane. The prerectification eliminates all scale and other geometric differences of the images which is necessary to yield a dense and correct point cloud for the bundle adjustment. Pairwise image correlation is carried out in a pyramidal approach to handle imprecise approximation values using the normalised cross correlation coefficient (NCC) as similarity measure which compensates for radiometric differences. As the images are prerectified big correlation windows can be used which are often vital in areas with low texture. Normally, the points are matched in a regular grid separated by a couple of pixels since the bundle adjustment needs a dense and equally distributed point cloud. Nevertheless, it is also possible to extract dedicated points by an interest operator (Förstner operator in this case). The corresponding points are refined in a Multi-Image Least Squares Matching (MI LSM) and the inverse of the prerectification is calculated for the image coordinates. For a stable bundle adjustment on average 25 000 points have to be extracted per image strip. When processing overlapping image strips of adjacent orbits the geometric and in particular the radiometric differences pose a critical problem for image matching which sometimes even prevents manual finding of corresponding points in strips with heterogeneous quality.

The mathematical model for bundle adjustment is based on the well known collinearity equations. Generally, the collinearity equations are formulated for each pair of image coordinates. Therefore, it is necessary to improve the exterior parameters for each image line in which observed image coordinates are available. But, due to geometric reasons this is not possible. In case of Mars Express (satellite orbit) the trajectory is assumed to stable and the parameters of the exterior orientation are improved only at few

selected positions. Because the exterior orientation parameters are needed for all image lines the positions in-between the orientation points are formulated with Lagrange polynomials of grade three. Also, with this approach the parameters of the interior orientation can be improved. Because of problems of the Doppler shift measurements there are systematic effects in the observed exterior orientation. To model these effects in bundle adjustment it is possible to improve bias (offset) and drift parameters. For this, it is necessary to expand the approach with additional observation equations. Additionally, the MOLA DTM is used as control information to fit the object points from the matching into the existing reference system on Mars. As a result the height differences between HRSC object points and MOLA DTM is reduced for all investigated orbits.

So far 1396 image strips are suitable for photogrammetric evaluation and 82% of them have been successfully adjusted and improved exterior orientations are provided. The adjustment of neighbouring single strips computed as block yields even better results compared to the adjustment of single strips alone. Finally, a high consistency between HRSC object points and MOLA DTM can be reached.