DETERMINATION OF CONJUGATE POINTS OF STEREOSCOPIC THREE LINE SCANNER DATA OF MARS 96 MISSION

Franz Wewel
Technical University of Berlin, Department for Photogrammetry and Cartography
Sekr.: EB9, Straße. des 17. Juni135, D-10623 Berlin, Germany
Tel.: +49 30 314 23338, Fax.: +49 30 314 21104, E-mail: franz@fpk.tu-berlin.de

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ABSTRACT:

In November 1996 a Russian spacecraft starts to the planet Mars. The spacecraft will carry two German cameras: The High Resolution Stereo Camera (HRSC) and the Wide Angle Optoelectronic Stereo Scanner (WAOSS). Both cameras are three line stereo cameras. Besides other tasks the image data will be applied to obtain digital terrain modells. Due to the camera design an to the proposed orbit the image data will be really complex. Especially the image matching process is affected by varying ground pixel resolutions. Software to handle these problems is under development.

KURZFASSUNG:

Im November 1996 startet eine russisches Raumfahrzeug zum Mars. An Bord sind zwei deutsche Kameras, die Hochauflösende Stereokamera (HRSC) und der Optoelektronische Weitwinkel-Stereoscanner (WAOSS). Beide Kameras sind als Stereokameras konzipiert. Aus den Bilddaten der Kameras sollen unter anderem globale digitale Oberflächenmodelle abgeleitet werden. Aufgrund des Kamerakonzeption und der gewählten Umlaufbahn werden die Bilddaten sehr komplex sein und hohe Ansprüche an die photogrammetrische und kartographische Software stellen. Die Bildzuordnung hat insbesondere das Problem, von sich ständig wechselnde Bodenpixelauflösungen zu bewältigen.

1. INTRODUCTION

1.1 General aspects of the determination of conjugate points for the Mars 96 mission

Scheduled for launch in November 1996 a Russian spacecraft will reach the planet Mars in fall 1997. The main tasks of this mission are obtaining global views of the Martian surface and atmosphere and the systematic examination of morphological feature with high resolution imagery for geoscientific and cartographic purposes. Besides other sensors the spacecraft carries two German cameras: the High Resolution Stereo Camera (HRSC) and the Wide Angle Optoelectronic Stereo Scanner (WAOSS) (Albertz J. et al., 1992). Similar to the MOMS-02 sensor HRSC and WAOSS work with the pushbroom principle and have a nadir, a forward and a backward looking stereo channel. Thus permanent along track stereo data acquisition is provided.

At the Technical University of Berlin a working group develops photogrammetric and cartographic software (Scholten F., 1996) to process the data of the HRSC and WAOSS scanners. Among other products, the data of the stereo cameras will be used to generate a global Martian elevation model as well as terrain models (Uebbing R., 1996) with high spatial resolution of feature of high interest. The generation of these terrain models requires the determination of a great amount of corresponding points.

The special properties of the image data, as a result of camera design and operation, the proposed orbit and the particular conditions of the Martian surface, have a great influence on the data processing and the matching strategy. Especially the highly elliptical orbit leads to unconventionally looking image data and affects the image correlatability and the determination of stereo disparities. Inorder to illustrate this, here the main aspects.

1.2 Stereo cameras and platform system of the Mars 96 mission

The HRSC and WAOSS cameras are single optic instruments working with the pushbroom method. The scanning of both cameras based on an along track triple stereo concept.

parameter	HRSC	WAOSS
focal length	175 mm	21.7 mm
number of CCD's	9	3
active pixel per CCD	5184	5184
field of view (FOV)	11.9°	80.0°
FOV per pixel	8.3"	67.4"
stereo angle	18.9°	25.0°
duration of imaging sequence	3 min	1 h
line scan frequency	< 450 Hz	< 240 Hz
min ground resolution	12 m	96 m
exposure time	2.2-54.5 ms	12.5-15 ms

Table 1: HRSC and WAOSS camera parameter

Due to an inertially fixed spacecraft the cameras are mounted on a manœuvrable platform (ARGUS) which has a three axial suspension (Schwarz G., 1994).
Besides the three stereo CCD's the HRSC camera has four multispectral and two photometry channels. The main technical characteristic of both cameras are listed in Table 1.

1.3 Orbit of Mars 96 Mission

To get a very close sight to the planet Mars the spacecraft orbit is highly eccentric. At periapsis the spacecraft altitude will be approximately 300 km. By the true anomaly of 90 degree the altitude will be 3000 km. The orbit period will be about 12 - 14 h. The proposed orbit does not guarantee constant illumination conditions. The sun elevation will be different at overlapping image strips and will partly be less than 30 degrees during the mapping period.

2. MARS 96 DATA

2.1 The HRSC and WAOSS Image Data

The HRSC and WAOSS image geometry is completely different to data geometry of other CCD sensor like the SPOT or the TM scanner, as well as the MOM-02 three line scanner data.

As a result of the orbit design the image pixels will have a dynamically varying ground pixel size. There will be across and along track effects. Due to the increasing spacecraft altitude ground resolution will differ by the factor of ten. The highest resolution of HRSC nadir channel will be 12 meters at periapsis with an orbit altitude of 300 km. By a true anomaly of 90 degree and an altitude of 3000 km the ground pixel resolution will be 120 meter. The numerical values of the WAOSS image pixels will be 96 and 960 m. Because of the great across track field of view of the WAOSS camera the ground resolution differs considerably among centre and margin pixel of a single sensor line (Fig. 1). Due to the narrow field of view of the HRSC sensor this effect is negligible.

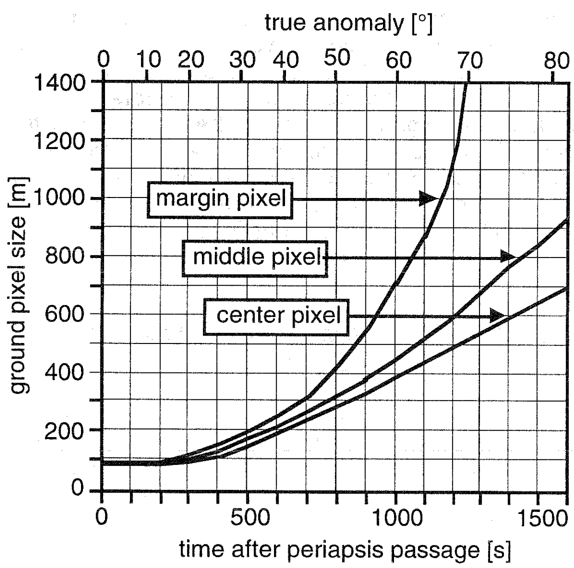

Figure 1: WAOSS image along and across track effects of the pixel ground size. The ground resolution variation of the center, a middle and the margin pixel for the nadir CCD line is plotted.

Apart the intrastrip effects there will be interstrip effects. Corresponding pixels of the three stereo channels will be imaged with different pixel size due to slant range and macro pixel format. The limitation of onboard mass storage and the bottleneck of radio link communication with the ground stations make macro pixel forming essential. Generally the macro pixel formats of the HRSC stereo channels will be 2 by 2 pixel or 4 by 4 pixel. The HRSC macro pixel mode is constant during a single scanning period. The macro pixel formats of the WAOSS camera is more complex. Different macro pixel formats can be joined during a scanning session to simulate locally constant ground resolution. By that the line of intersection between different macro pixel steps are potential matching barriers.

Beside the macro pixel format the HRSC and WAOSS cameras uses DCT compression to reduce the amount of data. At high compression rates blocking structures and artefacts will affect the image data adversely (Schlotzhauer G. 1994, Heipke C., 1995).

Moreover the stereo image data processing will be seriously interferred by a poor texture of large areas of the Martian surface. Gaps, at which the correlation failed, maybe filled by matching with a shape from shading technique (Heipke C., et al, 1994).

Apart poor textured areas on Mars are regions with surface discontinuities and with height differences much larger than known from Earth.

2.2. Additional Data

For the determination of the conjugate points we need auxiliary data in order to calculate approximate values to reduce the search areas in image space and for the controlling of the matching results in the object space. In particular to handle the complicated image geometry additional information will be required for an image data pre-processing step.

The basic apriori information will be the navigation data of the spacecraft: The position and pointing data together with planetary and instrument parameters. These data are components of the SPICE kernels (Spacecraft, Planet, Instrument C-matrix, Event Data). The position and pointing data will be improved by a bundle adjustment (Ohlhof T., 1996). For this purpose an automatic and manual tiepoint measurement will be carried out (Tang L., 1994). These input data for the bundle adjustment becomes also apriori information, with high priority, for the matching process.

Existing Martian elevation models are coarse and their accuracy and reliability are low (Ohlhof T., 1995). So we can estimate an average terrain altitude but we will make no further use of them.

3.1 General

Normally the determination of the conjugate points takes place by matching the three stereo images of a single HRSC/WAOSS mapping period.

The advantage of using only these data are:

- The scanning periods are really short. Differences of the illumination will be very small and do not affect the matching process. On the other hand the image data of adjoining orbits may have completely different illumination conditions.

- There will be merely small rotation angles among the stereo images. The effects of the Martian rotation are negligible.
- The camera position and pointing information has an excellent relative accuracy. Accordingly the valuation of approximate values is more reliable. The area of candidate search will be reduced. The correct estimation of a triple of conjugate points can be valuated in the object space. The collection of conjugate points of images sampled in different orbits makes a previous bundle adjustment essential.
- The search region of stereo candidates can be limited to small areas along the track.

Nevertheless the matching algorithm should also deal with images of overlapping respectively intersecting image sequences. In particular the data of the WAOSS sensor will have great overlapping regions especially at the Martian poles. Using overlapping images puts high constraints on the orbits to choose and high requirements to the bundle adjustment. In addition to use overlapping images the combination of HRSC and WAOSS data and the use of the HRSC photometry channels is conceivable. The redundant information should enforce the accuracy and the reliability especially at the poorly textured Martian regions.

Consequently the matching procedure requires a multi resolution and a multi image matching solution. The chosen matching strategy comprise a feature based and an area based matching approach.

Expected poor texture images with only less features lead to the suggestion to use a fixed raster with chooseable grid size for matching. This approach has especially two advantages. First the relationship among neighbouring rasterpoints is well defined. Thus blunder detection is easy. In the second place regions with poor texture will be covered and there will be enough matched points to compute object points and to achieve a good representation of the terrain. In order to match distinct points we use the feature based matching technique too (Förstner W., 1987). For the feature based matching the approximate values must not be as good as for the area based technique. Thus we use it also to optimise the start points for the area based matching.

The results of the matching process will be conjugate points and not DTM points. As a result of that there is the feasibility to compute always easily new DTM's with actual pointing data of the bundle adjustment process.

3.2 Preprocessing

All matching algorithm are more or less sensitive against scale and rotation differences. Consequently the image resolution and the image rotation differences of the reference image and the stereo partners must be adjusted. In order to keep locally the highest resolution the images will be subdivided and adjusted part by part. The size of the subdivided image parts will be chosen dynamically and guarantee a locally nearly constant resolution. To determine the different ground resolutions and to get a first coarse localisation of corresponding image areas the spacecraft navigation data will be used. The scale adjustment takes place by a resampling procedure with a low pass filter. In order to avoid image distortion binomial filter will be used with the property of shift invariance. The kernel size is variable and has to be adapted to the scale differences. A further preprocessing step is the generation of image pyramids. The image pyramid starts at the level with the highest common ground pixel resolution. The decimation steps are chosen to the power of two.

3.3 Approximate values

An important aspect is the availability of good and reliable approximate values, to assure sufficient convergence of the subpixel matching. Above all for the least square matching method the correct pixel position of the discrete pixel determination has to be better than two pixels. In order to get these good and reliable approximate values a hierarchical coarse to fine strategy by using image pyramids is implemented. At the first pyramid level we get the startpoints either from the conjugate points, used by the bundle adjustment, or from the pointing data of the cameras. For this case a grid of anchor points is defined in the reference image and will be transferred in the object space. For all the grid points we compute the intersection point of their line of sight and the Martian ellipsoid. Next we search in the stereo image the scanning line which defines together with the line of sight of the centre pixel a plane which include the intersection point or is located close to it. The corresponding pixel will be found across the image line.

The approximate values will be used to compute the coefficients of a polynom function to determine corresponding feature of the candidate list of the feature extraction and to detect incorrect matches.

3.4 Subpixel matching

In order to get subpixel accuracy a multiple image least square matching technique is used (Tsingas V., 1991). Analogous to the stereo least square matching a minimising of the grey value differences of all image patches is carried out. The estimation is performed by using the affin transformation. If we have n image patches there will be n*(n-1)/2 possible transformation combination. The transformation parameters of all combination are highly correlated. Therefore one of the patches will be the reference patch. All transformation between two patches can be described by the roundabout way of the transformation to the reference image. With that the number of transformations is reduced to n-1 with 6*(n-1) independent transformation coefficients.

4. SOFTWARE TESTS WITH PLANETARY IMAGE DATA

Up to now, no image data which such a complex image geometry is available. Therefore we test the software with images of diverse planetary missions. In particular the image data from the Clementine misson to the Moon and the Galileo mission to the asteroid Ida are suitable to test the matching software.

The Clementine data serves the main aspects for the software tests:

- multiple images.
- forward, nadir and backward viewing images.
- poorly textured regions and surface discontinuties.
- position and pointing data stored at SPICE-kernels.
- different ground pixel resolution.

To perform the tests only a few software modules had to be adapted. The tests yielded reliable results with high accuracy and only few blunders. Especially in the poorly textured areas a great amount of matching succeed. There are some difficulties particularly if image patches include data of surface discontinuies.

Some of the results are published by Oberst J. et al. (1995). Further details can be found in Scholten F. and Uebbing R. (1996).
Additional tests will be carried out with real three line scanner images of MOMS-02.

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