APPROACHES FOR A COMBINED ADJUSTMENT OF HRSC IMAGE DATA AND MOLA CONTROL INFORMATION

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ABSTRACT

In this paper we focus on a detail concerning the estimation of exterior orientation parameters of the High Resolution Stereo Camera (HRSC) orbiting planet Mars during the European Mars Express mission. One of the challenges for the photogrammetric processing of HRSC images will be the low number of Ground Control Points (GCP's) on Mars which can be identified and measured in the images in the usual way. Therefore, we want to use Mars Observer Laser Altimeter (MOLA)-data as control information in the photogrammetric bundle adjustment of HRSC images. Here, we discuss advantages and disadvantages of alternative approaches to improve exterior orientation parameters employing MOLA-data. The first approach assumes that each MOLA point lies in a plane defined by tree neighboring HRSC points. A similar approach could be applied, if there are less HRSC points than MOLA points. In this case we could take three MOLA points in the neighborhood of each HRSC point. The last approach we want to discuss uses a grid-based Digital Terrain Model (DTM) which has been derived from MOLA-data.

1 INTRODUCTION

The reconstruction of the exterior orientation is a fundamental task in photogrammetry. An established process to determine these orientations parameters is bundle block adjustment, i.e., simultaneous estimation of exterior orientation parameters and coordinates of object points. In general, the classical photogrammetric point determination requires conjugate points, interior orientation, approximations for exterior orientation, and Ground Control Points (GCP's). On earth a reduction of GCP's is possible because highly accurate GPS/INS-data is available. On Mars we do not have GPS and the observed exterior orientation is not accurate enough to use them for bundle adjustment without GCP's.

For Mars Express mission conjugate points will be measured automatically by means of image matching. Interior orientation is supposed to be known from calibration. Observations for the exterior orientation will be derived from Inertial Measurement Unit (IMU) measurements and orbit analysis. However, these observations for the parameters of the exterior orientation will probably not be precise enough for a consistent photogrammetric point determination on a global level. The orbit determination errors at the pericentre is radial 1 – 80 m, along velocity 10 – 2120 m and out of orbit plane 2.5 – 800 m (Hechler and Yáñez, 2000), but they can serve as approximate values. Therefore, we need additional control information in order to fit photogrammetrically derived object points into the existing reference system on Mars.

On Mars there are only few precisely known points which can serve as classical GCP's. But there is a large number of ground points measured by Mars Observer Laser Altimeter (MOLA). Unfortunately, it is hard to automatically identify MOLA points in images, because they are usually not related to image features. In some cases the approach to match MOLA and image data as proposed by (Kim et al., 2000) can be helpful. However, it might be too difficult to embed this approach in the operational photogrammetric processing. Therefore, our intention is to use control surfaces derived from the MOLA points rather than using MOLA points as individual control points.

In Section 2 we describe the MOLA- and High Resolution Stereo Camera (HRSC)-data and their quality. Previous approaches are given in Section 3. Then, in Section 4 we discuss different approaches to integrate MOLA-data in a bundle adjustment of HRSC-data. For each approach the mathematical model is described. In Section 5 a summary and an outlook are given.

2 DATA SOURCES

2.1 Mars Observer Laser Altimeter (MOLA)

In February 1999 the Mars Global Surveyor (MGS) spacecraft entered the mapping orbit at Mars. During the recording time (February 1999 to June 2001) the MOLA instrument acquired more than 640 million measurements by measuring the distances between the orbiter and the surface of Mars. After processing this altimeter measurements with orbit and attitude data object coordinates of points on the ground can be calculated. Each orbit results in one track of MOLA points.

The along track distance resolution is about 330 m with a vertical neighboring precision of 37.5 cm, i.e., from shot to shot. The absolute vertical accuracy is better than 10 m, but it depends on accuracy of reconstruction of radial spacecraft orbit. The surface spot size is about 130 m (Smith et al., 2000), (Smith and Zuber, 2002), (Smith, 2003). The across-track shot to shot spacing depends on the orbit and varies with latitude. The variation between neighboring tracks is up to more than 1 km (Kirk et al., 2002).

In addition to the surface described by the original, irregularly distributed MOLA points there exists a grid-based global Digital Terrain Model (DTM) which is derived from these MOLA points (see Figure 1).

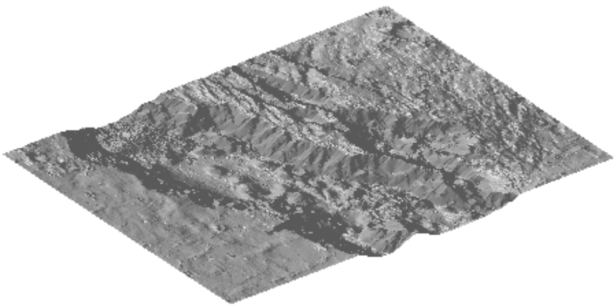

Figure 1: Part of Mars DTM, derived from MOLA-data

As mentioned before, 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, we are not able to treat them as normal GCP's in a bundle adjustment.

Another problem of MOLA data is that the surface points contain scan errors due to referencing errors of spacecraft. The elimination of the scan error is possible with a robust interpolation. However, due to roughness of Mars, points in regions without scan error will be eliminated, too. Better result will be reached by analyzing scan line segments (Briese et al., 2002), (Dorninger et al., 2003).

2.2 High Resolution Stereo Camera (HRSC)

The HRSC-data are not yet available because Mars Express with the HRSC (see Figure 2) on board will be launched in June 2003. In December 2003 the orbiting phase will begin and the first images will be acquired.

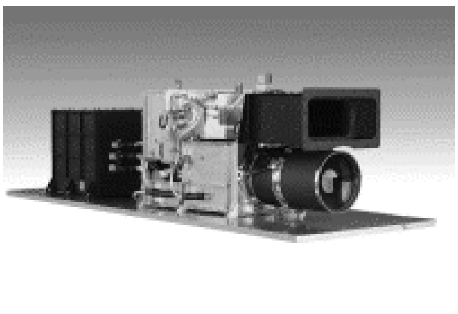

Figure 2: High Resolution Stereo Camera (Source: DLR)

The HRSC is a line sensor with nine CCD-lines. It has one nadir channel, four stereo channels, and four color channels. The images are generated by catenating the lines of each sensor. The result is one image per sensor-line and orbit. The pixel size on ground of 10 – 12 m will be reached at an altitude of 250 km at pericentre and increase to 50 m at an altitude of 1000 km (Neukum and Hoffmann, 2000).

Conjugate points will be measured automatically in the HRSC images by means of image matching. In addition, the delivered data will contain the position- and attitude-data of the orbiter. Interior orientation parameters of HRSC have been calibrated in laboratory and are expected to be stable.

2.3 Comparison of data

The MOLA points are characterized by their relative low point density compared to the point density we expect from HRSC images. With respect to our goal the most important feature is the good global accuracy of the MOLA points. The relative accuracy between neighboring points derived from HRSC-data is supposed to be better than the accuracy between neighboring MOLA points but the global accuracy will be worse. This is because the accuracy of HRSC points is limited by precision of the observed exterior orientation parameters.

Our intention is to improve the estimation of the exterior orientation parameters using the advantages of both data sources. We use the MOLA-data as control information in the bundle adjustment of the HRSC-, position-, and attitude-data.

3 PREVIOUS APPROACHES

Related work on the use of control surfaces for the orientation of aerial images has been presented, e.g., by (Ebner and Strunz, 1988). This approach describes the use of DTM as additional or exclusive control information for aerial triangulation. They investigate the conditions for the datum determination by exclusive use of DTM. Finally, by means of simulations they analyze the accuracy achievable with DTM as control information.

(Jaw, 2000) describes a model in which the surface information is integrated into the aerial triangulation workflow. Here, the surface information is derived from airborne laser range finder and the object points are derived from manual measurements or matching. The object points together with the adjusted surface points provide an improved description of the surface.

An approach to optimize orientation parameters is given in (Oda et al., 2000). They use a method, called Digital Surface Model Based Orientation Technique, for stereo image orientation based on image registration techniques. The concept is to optimize the six orientation parameters of each image in a stereo pair. The approach does not require classical GCP's but uses a digital surface model.

Starting point of our discussion in Section 4 is the approach of (Ebner and Ohlhof, 1994). This approach describes a point determination without classical GCP's. As control information they use terrain points which have not to be identified in the images. In their approach the conjugate points are acquired in such a way, that at least three object points are arranged in the surroundings of each control point. The approach assumes that all these points lie on the terrain surface. The mathematical model for the bundle adjustment includes three observation equations for each GCP (Equation (1))

$$\begin{aligned} \hat{v}_{X_{GCP}} &= \hat{X}_{GCP} - X_{GCP} \\ \hat{v}_{Y_{GCP}} &= \hat{Y}_{GCP} - Y_{GCP} \\ \hat{v}_{Z_{GCP}} &= \hat{Z}_{GCP} - Z_{GCP} \end{aligned} \quad (1)$$

and one condition equation (Equation (2)).

$$\hat{Z}_{GCP} - \hat{Z}_{GCP}(\hat{X}_{GCP}, \hat{Y}_{GCP}, \hat{X}_k, \hat{Y}_k, \hat{Z}_k) = 0 \quad (2)$$

The condition equation postulates that the control point, i.e., the new GCP, is located in an inclined plane, which is defined by the tree surrounding object points.

Computer simulations (Ebner and Ohlhof, 1994) have been carried out with additional or exclusive control information to validate the use of this approach. These simulations were based on 121 aerial images, with an image scale of 1:10000. Four different cases have been investigated. In case A a classical block triangulation was used with 20 conventional 3D-GCP's and 16 height GCP's. In case B the height control points are replaced by 16 new GCP's. four conventional 3D-GCP's and 32 new GCP's were used in case C. In case D the conventional GCP's are completely replaced by 36 new GCP's.

The results of case A and B show that the height control points can be replaced without any loss of accuracy. The results of case C and D show that the height accuracy is quite independent from terrain slope. Whereas, the planimetric accuracy depends on the terrain type and more accurate results can be achieved for rougher terrain.

4 POSSIBLE APPROACHES FOR MARS EXPRESS

If we transfer the approach of (Ebner and Ohlhof, 1994) to our goal, then the HRSC points are the object points defining the inclined plane. The role of the new GCP's corresponds to the role of the MOLA points. (see Figure 3).

The observations in the Least Squares Adjustment are the image coordinates of tie points, the interior orientation, the position- and attitude data, and some of the MOLA points which serve as a new type of GCP's. The unknowns are the exterior orientation, the object coordinates of tie points, and coordinates of new GCP's. In addition to position and attitude the exterior orientation includes parameters for bias and drift. In the following approaches (Section 4.1, 4.2, 4.3) most of observations and unknowns will be the same.

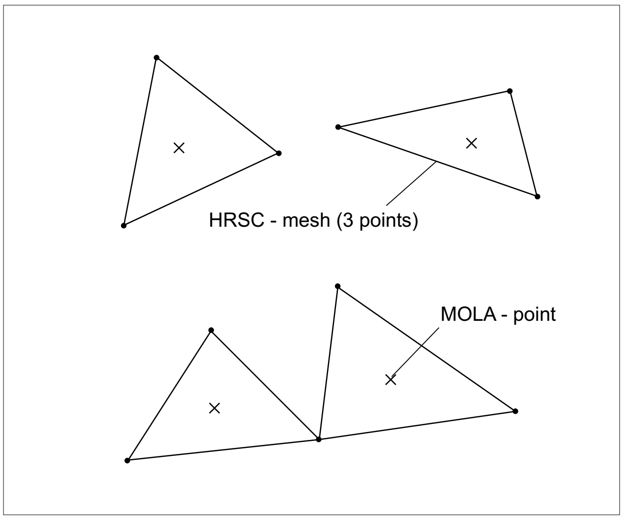

Figure 3: Fitting MOLA points in planes defined by HRSC points

Since HRSC points as well as MOLA points are treated as unknowns in the proposed condition equations, this would result in a Least Squares Adjustment with conditions between unknowns. This imposes some disadvantages and also the number of unknowns will raise approximately about 30%.

4.1 Fitting MOLA points in HRSC surface

A possibility to simplify the approach would be to take the distance d (see Figure 4) from the MOLA point to the plane defined by three neighboring HRSC points as observation and not to treat the coordinates of the MOLA point as unknowns.

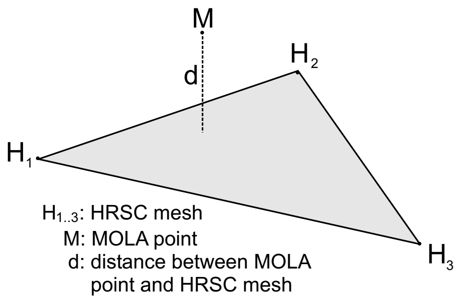

Figure 4: Fitting MOLA point in plane defined by HRSC points

In the mathematical model of the bundle adjustment the condition equation can be reduced to an observation equation (Equation (3)) with nine unknowns ($\hat{X}_{H_i}, \hat{Y}_{H_i}, \hat{Z}_{H_i}$, $i = 1...3$), one observation ($d = 0$) and three constants (X_M, Y_M, Z_M) for each mesh. The standard deviation σ_d will be determined by the standard deviation of the MOLA point.

$$\hat{v}_d + d = f(\hat{X}_{H_i}, \hat{Y}_{H_i}, \hat{Z}_{H_i}, X_M, Y_M, Z_M) \quad (3)$$

Thus, the mathematical formulation is slightly less exact, but the implementation of a Least Squares Adjustment becomes much easier without conditions between the unknowns.

However, as the above mentioned approach also this modified approach is applicable only if there are enough HRSC points to define rather small meshes around MOLA points. In addition, the points have to be suitably arranged.

4.2 Fitting HRSC points in MOLA surface

Another approach could be applied, if there are less HRSC points than MOLA points, i.e., if the MOLA meshes are smaller then the HRSC meshes. In this case we could take three MOLA points in the surroundings of a HRSC point. Now, the MOLA points define the plane which must contain the HRSC point (see Figure 5).

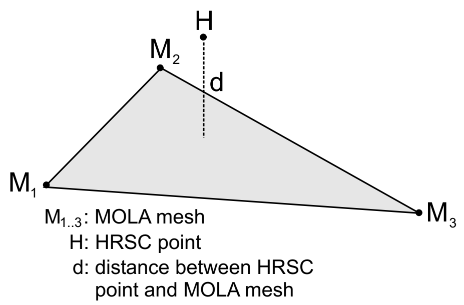

Figure 5: Fitting HRSC point in plane defined by MOLA points

The observation equation (Equation (4)) for this case is similar to Equation (3) in Section 4.1. It describes the mathematical relation between the distance d from the MOLA plane to the HRSC point.

$$\hat{v}_d + d = f(\hat{X}_H, \hat{Y}_H, \hat{Z}_H, X_{M_i}, Y_{M_i}, Z_{M_i}) \qquad (4)$$

For each mesh the number of unknowns will be reduced to three unknowns ($\hat{X}_H, \hat{Y}_H, \hat{Z}_H$) compared to Section 4.1. The total number of unknown point coordinates does not change. But now there are separate equations for each HRSC point. Furthermore, we have again one observation ($d = 0$) and now nine constants ($X_{M_i}, Y_{M_i}, Z_{M_i}$, $i = 1...3$). Here, the standard deviation σ_d will be determined by the standard deviation of three MOLA points M_1, M_2, and M_3.

This approach is advantageous, if we have more MOLA points than HRSC points. However, the problem remains that the HRSC and MOLA points must be 'suitably' arranged.

4.3 Fitting HRSC points in grid based MOLA DTM

The last approach we want to discuss uses a DTM which is derived from MOLA points. This approach corresponds to (Ebner and Strunz, 1988) in Section 3. In this case, the HRSC points have to lie on a bilinear surface defined by four neighboring DTM points, which enclose the HRSC point (see Figure 6).

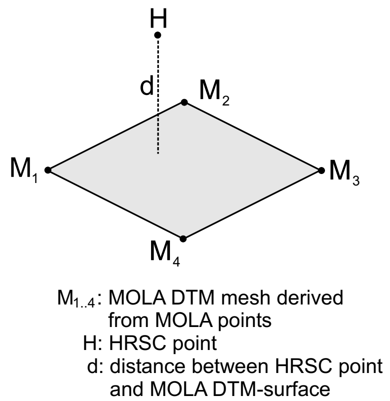

Figure 6: Fitting HRSC point in bilinear surface defined by MOLA DTM

The advantage of this approach is that the effort to search for adequate neighboring MOLA points is reduced because the DTM is regular. Also, there is no need for a special parameterization of the matching algorithm to find conjugate points next to suitable MOLA points. The main drawback of this approach is that it does not use the original MOLA points but interpolated DTM points.

In this case the observation equation is the similar to the preceding approach (Equation (4)). Only the number of constants increases to twelve ($X_{M_i}, X_{M_i}, Z_{M_i}$, $i = 1...4$) and standard deviation σ_d will be determined by the standard deviation of four DTM points M_1, M_2, M_3, and M_4. The number of unknowns and observations ($d = 0$) are the same.

5 SUMMARY AND OUTLOOK

In principle, all the approaches described in Section 4 can be employed in a bundle adjustment to achieve an improved exterior orientation. But the effort to integrate them in a bundle adjustment program differs and what is even more important, some approaches cause implications on previous image matching steps.

Most MOLA points can be used in bundle adjustment. But, the use of MOLA points with scan errors causes problems. It is necessary to eliminate these errors before the bundle adjustment, since the GCP's should be reliable.

Based on the results of the simulations in (Ebner and Ohlhof, 1994) with aerial imagery we expect that the MOLA points lead to high global accuracy of exterior orientation and object coordinates. Furthermore, the simulations show that the planimetric accuracy depends on terrain slope. If the terrain slope increases, the planimetric accuracy increase, too.

This discussion of the pros and cons of these different approaches will serve as basis for our decision to select the most appropriate one. Then our next step will be to carry out simulation studies for the most promising approaches in order to evaluate the potential of the use of MOLA points as control information. As well, the number and selection of the MOLA points must be clarified in these future simulations.

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