EXPERIENCES IN PROCESSING MOMS-02/D2 STEREO IMAGE DATA

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ABSTRACT

The first experiences of the German MOMS research groups in processing MOMS-02/D2 stereo image data have been presented at a MOMS workshop in Cologne in 1995. Focus was on the evaluation of the photogrammetric processes of point transfer, line-image orientation, point determination, DTM acquisition, ortho-image generation and topographic mapping. The accuracy level for geometric 3-D reconstruction achieved in those work was of 6 to 10 meter for the horizontal coordinates and 7 to 15 meter for the height.

This paper presents new experimental results of our ongoing work in automatic 3D point determination and DTM generation using MOMS three-line stereo images. Our interest is in the verification and exact assessment of precision and reliability of photogrammetric processes. Therefore, we focus the investigation on images taken over a testfield in Australia for which a GPS network of image identifiable control points and, additionally, a 3-D profile of about 16 km length is surveyed. This GPS profile is resolved with a 5 m spacing interval that delivers 3228 DTM check points.

For the first time we have now been able to proof that DTM and 3-D point determination with MOMS data is possible at an accuracy level better than 5 m. Comparison with the dense ground truth profile shows that in our feature based DTM solution an accuracy of 7.6 m is obtained. A further improvement could be achieved with an area based least squares solution for MOMS three-line images, which increases the precision of the height, again verified along the GPS profile, to 4.3 m.

1. INTRODUCTION

Following up the German Spacelab D2 Mission in April 1993, in which MOMS-02 imagery over parts of Africa, Asia, Middle East, South and Central America, and Australia have been recorded, a considerable number of investigations has been carried out with the multispectral and panchromatic image data. The primary interest of the photogrammetric community is in the potential of the high resolution three-line stereo images for generation of Digital Terrain Models and ortho-images as well as topographic data collection.

The MOMS-02 camera is designed with seven channels which can be operated in different modes. For topographic applications mode 1 is most important with the three panchromatic CCD line images. In this case image data are taken with 4.5 m pixel size by the nadir looking channel and with 13.5 m pixel size by the forward and backward looking channels. Another mode of interest for stereo restitution is mode 3 in which a combination of two panchromatic and two multispectral channels is selected. The multispectral channels are all nadir looking thus two of them are used to substitute the panchromatic nadir channel. Together with the two off-nadir channels a similar geometric configuration exists as in the mode 1 case.

For several years the Institute of Photogrammetry of Stuttgart University is developing procedures for reliable and precise point transfer, 3-D point measurement, DTM acquisition and ortho-image generation. Further tasks and the overall scientific objective of

MOMS-02/D2 have been defined at the end of the eighties (Ackermann et al., 1990).

The first results of the experimental investigations into the quality of photogrammetric stereo processing derived from different scenes, e.g. from the orbits 115 (Andes) and 75B (Australia), have been presented by some Photogrammetric Institutes of the German MOMS research group at a MOMS workshop in Cologne in July 1995. The results can concisely be summarized as follows:

- point transfer was done feature based as well as area based with a 13.5 m ground pixel size for forward, backward and nadir looking channels. Experimentally a matching precision was found of about 0.7 pixels and 0.3 pixels, respectively.
- the orientation of three-line imagery and 3D point determination with the area based matched points led to a 6 to 10 m horizontal accuracy and 7 to 15 m in height, depending on the block adjustment model.
- for the accuracy of the reconstructed DTM rms-values of 10 to 20 m have been obtained.

1.1 Location of the Test Site

The investigations in this paper are exclusively devoted to the analysis of processing scene 17 of the mode 1 images from orbit 75B captured during the D2 mission. The location and the area covered by this images is shown in figure 1.

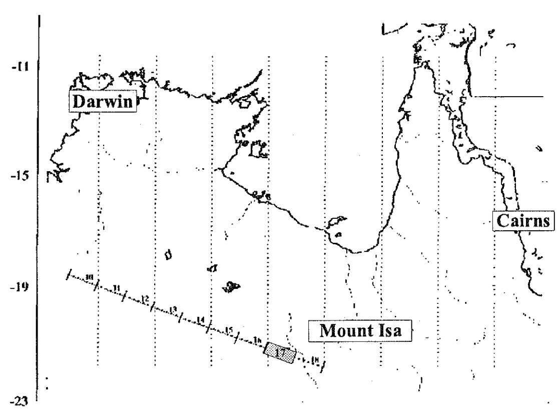

Figure 1: Location of scene 17 of orbit 75B.

This scene covers a fairly flat terrain in the Lake Nash/Georgina River area of the south-east Northern Territory with a size of 110 km × 40 km. In co-operation of the Istitute of Photogrammetry, Stuttgart University and the Department of Geomatics at the University of Melbourne a testfield for scene 17 of orbit 75B has been established. The GPS survey has been carried out in two campaigns. In the first campaign (1994) a GPS network of 79 control points was established which are distributed across the test site. The site was re-visited in 1995 and in this survey a 3-D profile for DTM evaluation was measured. The control point distribution including the DTM evaluation profile is depicted in figure 2.

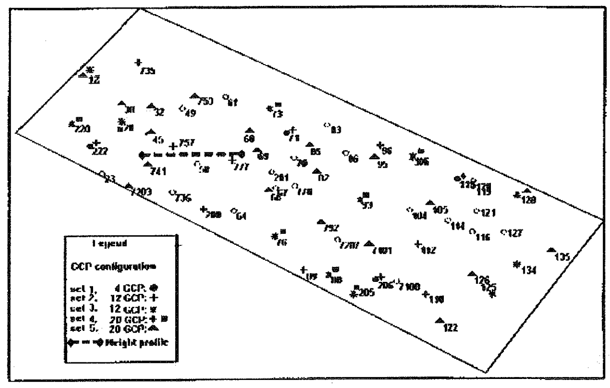

Figure 2: Control points and DTM evaluation profile (taken from Fraser et al., 1996).

Even though it was tried to select image-identifiable ground control points a number of problems occurred in measuring these points at digital photogrammetric workstations. In general, this region in the Northern Territory is quite featureless. Thus it was really difficult to find suitable points. An exception are the embankments which can be well identified by the two dams (see figure 3) in the images. But also for this type of ground control target the definition of the 3-D reference point location in the field was not easy (Fraser et al., 1996).

Figure 3: Example of a dam embankment.

The exterior orientation of scene 17 together with some interior/calibration parameters are determined by the Chair of Photogrammetry and Remote Sensing, Technical University of Munich. The orientation is estimated by a bundle solution for three-line images, in which a large number of tie points together with 56 of ground control points is introduced. The first results (Kornus et al., 1995) have been summarized above. In the meantime a certain improvement was achieved by this group so that for the recent orientation an accuracy level of 6 to 8 m in all three coordinates is expected.

2. DTM GENERATION

For DTM generation with MOMS stereo images a feature based procedure was proposed by Hahn and Schneider (1991). In the meantime a matured software module is developed which is highly efficient in processing three-line images (Schneider and Hahn, 1995). The trinocular stereo solution consists of the following steps: (1) Image pyramids are generated for all channels and matching is started on a coarse resolution level of the pyramid. Processing then proceeds from coarse to fine with (2) the extraction of interest points and edge points; (3) the matching of corresponding features of all three channels using given orientation; (4) the determination of 3-D point coordinates; and (5) surface reconstruction by finite element modelling.

DTM generation is performed with scene 17 of the Australia orbit 75B. An area of about 14.5 km × 14.5 km, in which the DTM evaluation profile can be seen, is shown in figure 4.

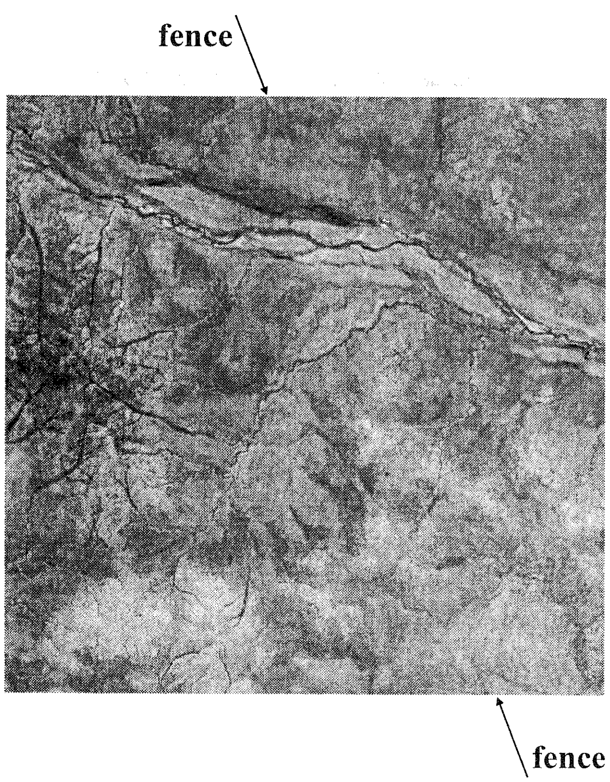

Figure 4: Ortho-image of an area of 14.5 km × 14.5 km

In this figure an ortho-image is displayed that is calculated from the forward looking channel. The markings "fence" indicate a very long straight line, presumably of a grazing fence. Along this fence there is a track on which the 3-D profile is recorded. This track is visible in the image (see figure 5).

Figure 5: Detailed view: the track along the fence can be easily recognized.

A perspective view of the derived DTM is shown in figure 6. In this case the ortho-image is overlayed to enhance the visual impression of the terrain surface. Because of the very flat terrain the height component is amplified by a factor of 20. The grid width of this DTM is 240 m.

3. INVESTIGATION OF THE DTM ACCURACY

So far the experimental investigations of the geometric accuracy in MOMS DTM reconstruction have been very limited due to the lack of sufficient ground truth data. The test field for evaluating the metric performance of the stereo module (figure 2) was quite useful for the analysis of sensor models and line-image orientation but of very limited evidence in assessing DTM accuracy.

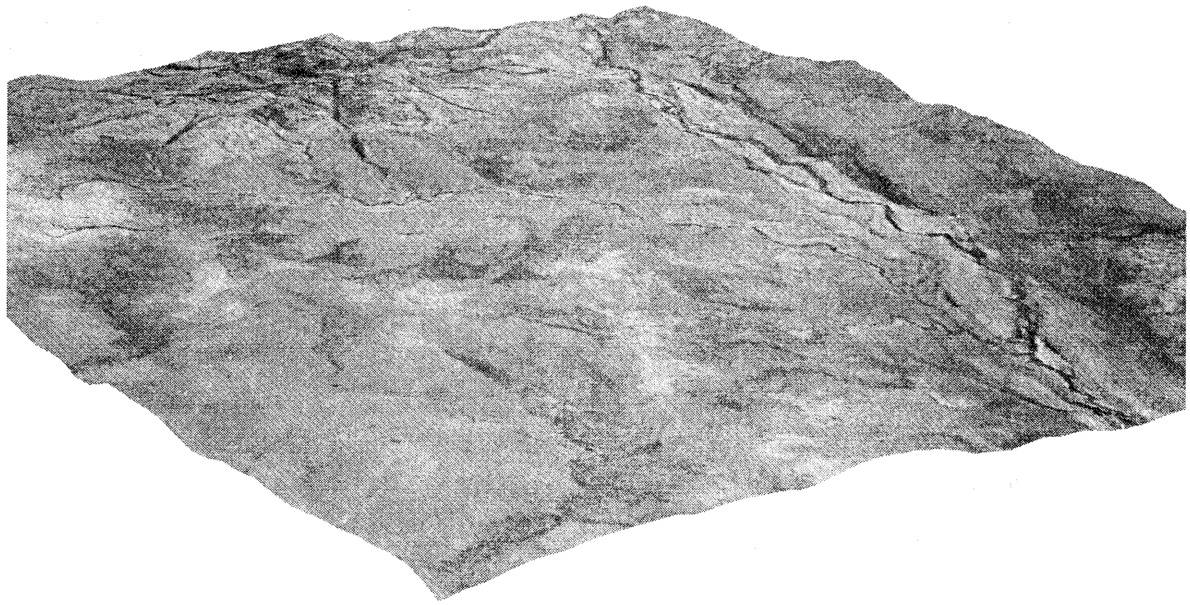

Figure 6: Perspective view of the DTM. The ortho-image is overlayed in this projection.

With the GPS profile addressed above the opportunity is given for the first rigorous evaluation of the MOMS potential for DTM generation. Therefore, the present investigation focuses on this profile. In figure 7 the height profile is plotted as a function of the profile length. Even though precisely the ellipsoidal height difference with respect to a reference point is shown, we just want to refer to this height difference as the profile height.

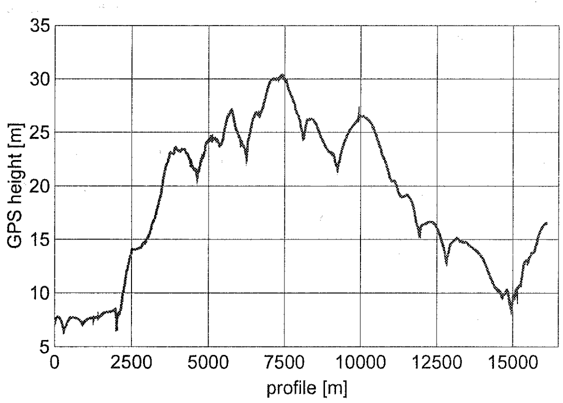

Figure 7: GPS profile with 3228 DTM check points

The first look at the data shows an extremely flat terrain of less than 25 m height difference on a length of more than 16 km. The profile is resolved with a 5 m spacing interval which delivers 3228 DTM check points. To get an impression on the undulation of the terrain the first derivatives are calculated (figure 8). Apart from one point (at profile length 2000 m) the height gradients are below 0.5 m, i.e. the slope is even locally less than 10 %.

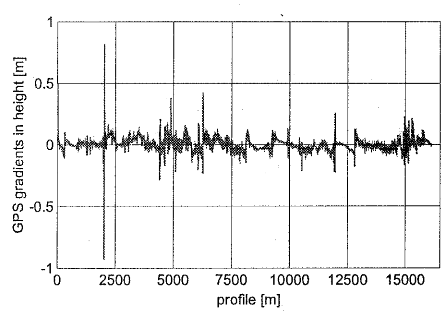

Figure 8: Gradients of height profile

The DTM evaluation profile was recorded with a roving GPS antenna. The 3-D profile data have been collected in a kinematic mode of GPS surveying. For that purpose the antenna was mounted on a Landcruiser and the vehicle was slowly driven parallel to the fence along the track. Projection of the 3-D profile into all three channels using the given orientation shows nearly perfect straight lines. For a closer look at each of these lines, straight lines are fitted to the data. The deviations of the projected image lines from the straight lines are plotted in figure 9 for all three channels.

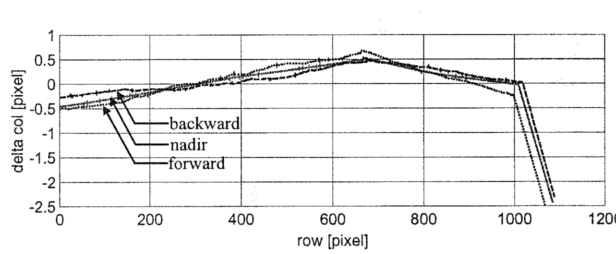

Figure 9: Deviation of the projected 3-D profile from straight lines.

Each line has creases at approximately row 650 and row 1000 (at a pixel size of 13.5 m). This is a consequence of the surveying process in which the measurement of the whole profile was subdivided in three parts with two control points in between. Obviously, in this profile the horizontal coordinates between adjacent control points have been calculated with a 5 m spacing interval and the appropriate height data are determined by the GPS measurements.

An impression of the DTM quality is given by figure 10. Along the profile the DTM height is interpolated and the difference to the GPS profile is calculated. A mean difference of about 60 m is subtracted which indicates that there are still some systematic influences (see discussion below). The remaining differences (figure 10) are in an interval of $\pm$ 10 m with an accuracy of 7.6 m.

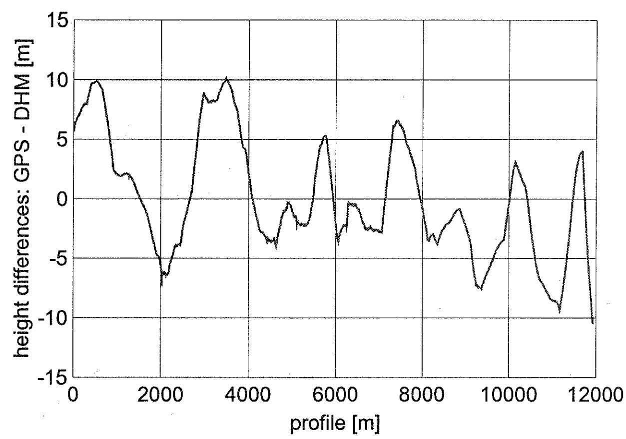

Figure 10: Height difference between GPS and DTM measurement along the profile

A further improvement of the DTM quality is achieved with the developed area based least squares solution for MOMS three-line images. The basic concept of this approach is to match the three channels in various combinations which provides high quality measurements and allows a sensitive selfdiagnosis. For more details please cf. Fritsch et al. (1995) and Schneider and Hahn (1995).

The matching result with this area based solution along the DTM evaluation profile is shown in figure 11. Displayed are the differences between the projected GPS coordinates and the measured image coordinates for the backward and the forward looking channels. The projected point location of the 3228 DTM check points in the nadir channel is taken as seed points to start the matching.

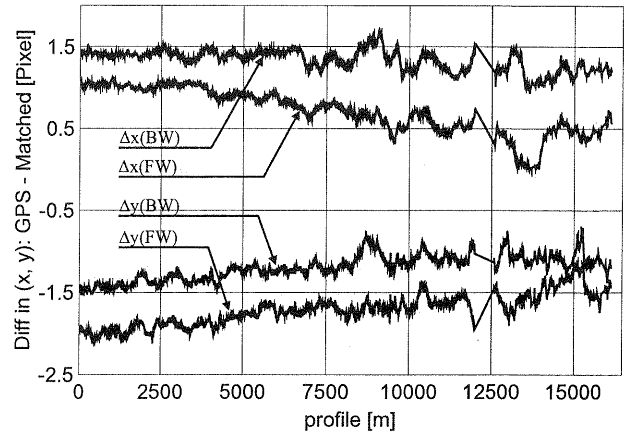

Figure 11: Coordinate differences between GPS and the matching result

So far we still observe some inconsistency with the orientation and calibration data which shows up in a systematic displacement of up to 2 pixels in image space. Because the reason for this displacement could not yet fully be explored the uncorrected differences between the GPS points and the matched points are plotted in this figure. Possible error sources are in an incorrect use of the given orientation data and in the definition of the datum. It is important to note, that the systematic displacement is constant and therefore can be eliminated. Substracting an arithmetic mean value, the following standard deviations are found: 0.23 pixels in x and 0.21 pixels in y direction of the forward looking channel and 0.13 pixels in x, 0.15 pixels in y in the backward looking channel. Altogether the selfdiagnosis process of the matching module indicated that 92.7 % of the 3228 profile check points have been matched successfully.

In a small region of about 150 GPS points (55 pixels, visible in figure 11 at profile length 12500 m) the matching failed. The reason for this failure is a blemished line which can be seen in figure 12.

In general a preprocessing should eliminate this kind of line distortions (which occurs only in the nadir channel). Unfortunately this was not carried out thoroughly in this area. On the other hand this example shows that the selfdiagnosis of matching procedure works well thus erroneous matches caused by this distortion are avoided.

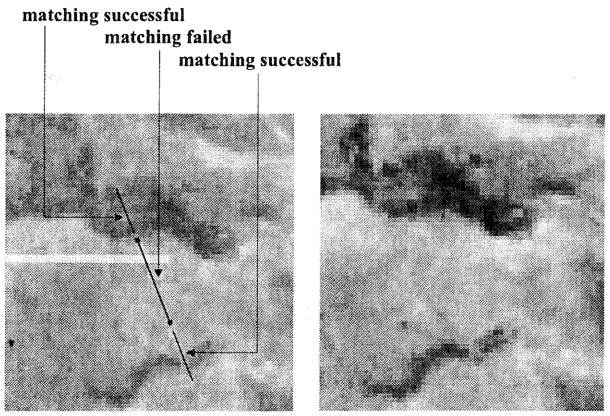

Figure 12: Left: distorted line in the nadir channel; right: corresponding area in the forward channel

The last figure shows the height profile derived by matching and provides a comparison with the GPS profile. The noise in the matching result can be directly seen from this plot.

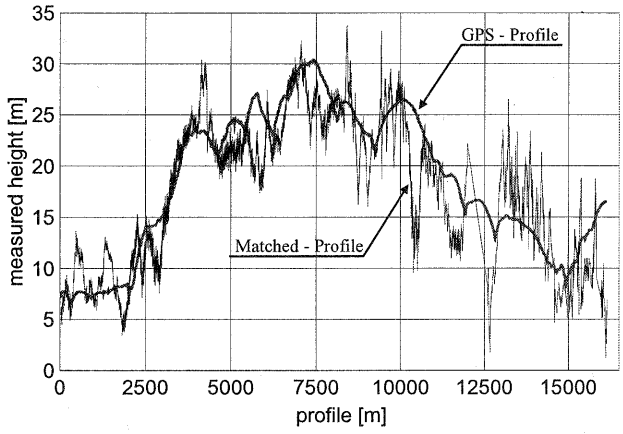

Figure 13: Height profiles of GPS and matched data

An accuracy of 4.3 m is obtained for the height measurement along the profile. With the differences in the horizontal coordinates of the 3228 check points a standard deviation of 0.3 m in X direction (approximately along the profile) and 3.6 m in Y direction (perpendicular to the profile) is derived. In summary, with the area based least squares solution for MOMS three-line images a height precision of 4.3 m is obtained, which is an excellent result, verified with a GPS profile of 16 km length.

4. CONCLUSION

This paper presents new experimental results of automatic 3D point determination and DTM generation using MOMS three-line stereo images. The investigation focuses on images which are taken over a testfield in Australia for which a GPS network and, what is most important for the DTM evaluation, a 3-D profile of about 16 km length is surveyed which gives 3228 DTM check points.

For the first time we have now been able to proof that DTM and 3-D point determination with MOMS data is possible at an accuracy level better than 5 m. Experimentally an accuracy of 7.6 m is achieved for our feature based DTM solution. This accuracy could be further improved with the developed area based least squares procedure. The comparison with the GPS profile shows that an excellent height precision with an rms value of 4.3 m is obtained.

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