Geometric Aspects of MOMS-2P Three-Line Imagery for Mapping Applications

Gurcan Büyüksalih[1] and Karsten Jacobsen[2]

[1]Dept. of Geodesy and Photogrammetry,
Zonguldak KaraclmasUniversity,
67100 Zonguldak, Turkey
Email: bsalih2000@usa.net

[2]Inst. for Photogrammetry,
University of Hannover
Nienburger Str. 1
D-30167 Hannover, Germany
Email: karsten@ipi.uni-hannover.de

Annual Meeting of the Remote Sensing Society

RSS2000

Leicester, UK

Abstract

The first three-dimensional mapping with digital data from space was possible with SPOT-images. SPOT has the disadvantage of a stereoscopic imaging from neighboured orbits which sometimes makes it difficult to get a sufficient stereoscopic impression. This problem is avoided by the MOMS-sensor which was flown in the Space Shuttle mission STS-55 in 1993. Based on the goods results, the same sensor was as MOMS-2P since April 1996 on the Russian Space Station MIR/Priroda and active until the end of the manned MIR-mission in 1999. During this period more stereo scenes have been taken than with other comparable sensor.

A cloud free scene combination of 104km x 103km in South-West-Germany, with parts from France and Switzerland has been analysed. It contains the panchromatic forward view and the backward view – each with a nadir angle of 21.4° - and 2 vertical views (green and NIR). So a height-to-base-relation of 1.25 is available. The pixel size on the ground is 17.5m. Image coordinates of the control points have been measured with the Hannover data acquisition program DPLX on a simple PC. The bundle orientation with program BLASPO, an extension of the Hannover bundle adjustment program system BLUH, resulted in a sigma 0 of approximately 1 pixel, a horizontal accuracy in the range of up to 12.7m – the accuracy of the map 1 : 25 000, which was used for the control points and a vertical accuracy in the range of 32m - for the pixel size on the ground of 17.5m a sufficient accuracy. The result has not been improved by the vertical scenes. This is caused by the limited improvement of the geometric configuration by the vertical scenes and also the lower contrast of the green and NIR-band in relation to the panchromatic channels. For the bundle orientation mainly the view direction of the sensors against nadir has been used in addition to the control points – it was not necessary to include information about the recorded orbit.

Based on the scene orientation, the Digital Elevation Model has been determined by image matching with the program LISA-FOTO, which has been shown as very robust.

1. Introduction

The first sensor created especially for mapping from space was SPOT with the first launch in 1986. For a stereoscopic imaging the HRV-instrument of SPOT can change the view direction across the orbit. So from 2 neighboured orbits a stereoscopic coverage of the mapping area is possible. The practical use of this system has shown some limitations – very often the area is covered by clouds if the satellite is in a good position for getting the second image for a stereo pair. So a larger time interval in imaging both images of a stereo pair may occur. This includes problems caused by the change of the vegetation in the mapping area – sometimes even no stereoscopic impression can be reached. In addition only a limited number of SPOT-stereo-scenes with sufficient height-to-base-relation are available. The standard deviation of the Z-coordinates is identical to the height-to-base-relation multiplied with the scale number of the scene and the accuracy of the x-parallax, so a poor relation corresponds to a poor vertical quality.

The MOMS-system is a combination of 5 optics with a fixed connection. One sensor is viewing forward, one afterward and the other vertical. The pixel size on the ground, depending upon the flying height, was for the used scene-combination 17.5m. The high resolution sensor in the center with 5.5m pixel size was not active because of problems with the focus. The 2 active optics, viewing in the vertical direction, do have each 2 sensor lines behind optical filter. The active sensor lines have a length of 5800 pixel corresponding to a swath width of 104km.

For the investigations cloud free images taken with MOMS-2P at 8th of May 1998 in the imaging mode D, covering the area of the Black Forest in South-West-Germany, have been used.

channel	spectral range	focal length	View direction
1	449 – 551 nm (green)	220.030 mm	Vertical
4	772 – 815 nm (near infrared)	219.900 mm	Vertical
6	524 – 763 nm (panchromatic)	237.200 mm	-21.457° (forward view)
7	524 – 763 nm (panchromatic)	237.200 mm	21.457° (backward view)

Table 1: characteristics of used scenes

The focal length of the used scenes is corresponding to a pixel size in the sensor of 10µm. With these scenes, the geometric constellation shown in figure 1 is given. Within a very short time frame the object points have been imaged from 3 directions.

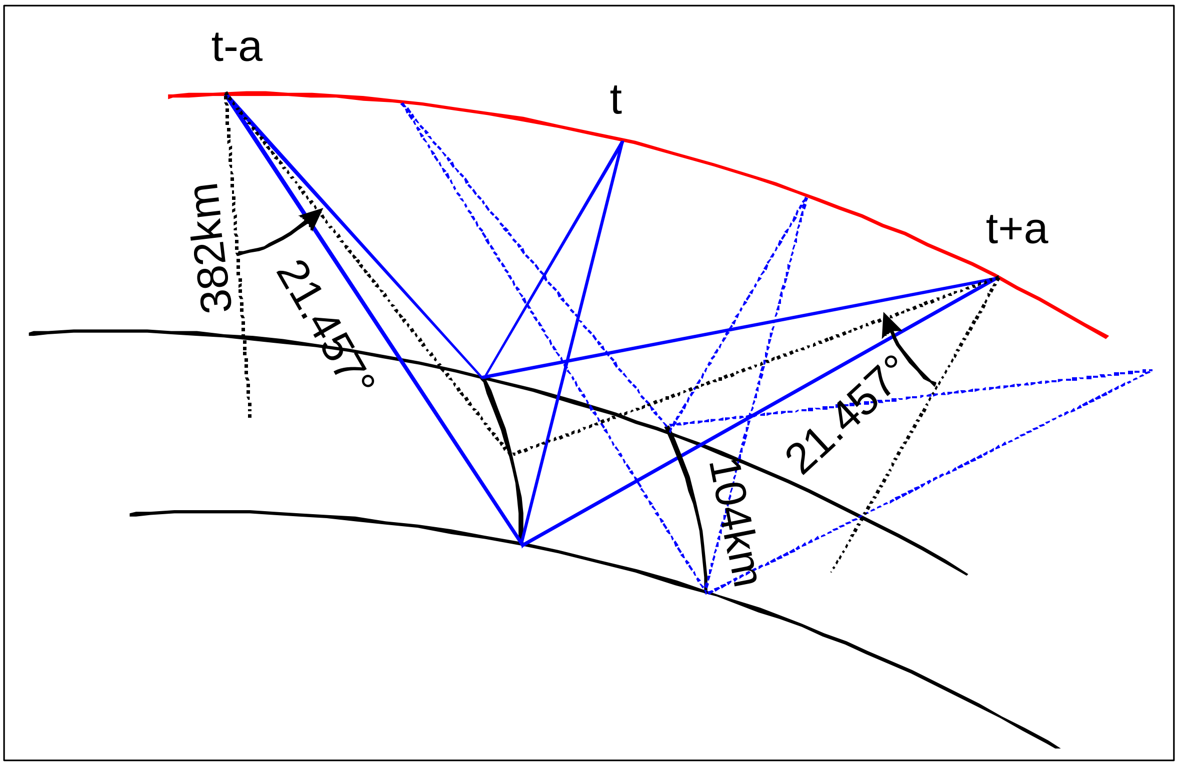

figure 1: geometric situation of MOMS-2P

2. Scene Orientation

Because of problems with the synchronisation, the recorded sensor orientation has not been used. The scene orientation was determined by bundle orientation based on control points with program BLASPO, an addition of the Hannover bundle block adjustment system BLUH.

Line scanner images do have the perspective geometry only within the line. Each line has a different exterior orientation. Without additional information the image orientation of such a geometry cannot be solved, but the satellite orbit is usually not disturbed, so as first approximation, the image orientation against the local nadir line is the same for the whole scene. The determination of the scene orientation has to respect the orbit and in addition changes of the orientation in relation to the nadir have to be modelled.

For BLASPO the required approximate orbit information will be generated by program SATRAC. Based on an approximate orbit information and the view direction against nadir, the image points of a scene are projected to the ground and transformed to the control points. The transformation parameters are used for an improvement of the orbit inclination, the semi mayor axis of the orbit and parameters for a constant shift in X and Y – so the approximate orbit information may be very rough.

Based on the orbit information coming from SATRAC, a bundle orientation will be computed by BLASPO. As first approximation the view direction against the nadir will be fixed and the projection centres for the individual CCD-lines are located on the orbit, which has been improved by SATRAC. Because of the different influence of the orientation elements to the ground coordinate system for line scanner images, compared to perspective images, it is not possible to introduce the 6 standard elements of the exterior orientation as unknowns. Instead of this, a shift of the orbit in the 3 coordinate components, a change of the orbit inclination and an affine deformation of the scene will be introduced. These 6 orientation elements are totally sufficient if the satellite will not be disturbed during imaging. An angular affinity can be caused if the CCD-line is not directly perpendicular to the orbit (corresponding to a kappa of the satellite) and an affinity in scale can be caused by several circumstances.

The MOMS-2P was located on the manned MIR-space-station, so a disturbance of sensor orientation during imaging a scene may happen. Also the unmanned satellites do show some periodical changes of the attitude data. These possible influences have to be modeled by self calibration with additional parameters – additional unknowns in the solution which can respect such influences.

```
Y = Y +  P1 * Y
X = X +  P2 * Y
X = X +  P3 * X * Y
Y = Y +  P4 * X * Y
Y = Y +  P5 * SIN(Y * 0.06283)
Y = Y +  P6 * COS(Y * 0.06283)
Y = Y +  P7 * SIN(Y * 0.12566)
Y = Y +  P8 * COS(Y * 0.12566)
Y = Y +  P9 * SIN(X * 0.04500)
X = X + P10 * COS(X * 0.03600)
X = X + P11 * (X-14.)     if x >  14.
X = X + P12 * (X+14.)     if x < -14.
Y = Y + P13 * (X-14.)     if x >  14.
Y = Y + P14 * (X+14.)     if x < -14.
```

table 2: additional parameters of BLASPO

The additional parameters 11 – 15 are special parameters which can determine the geometric problems of the IRS-1C / 1D PAN-camera, which is equipped with 3 CCD-lines not totally fixed one against the other (Jacobsen 1998 a). This group of parameters should not be used for other sensors. The self calibration by additional parameters requires control points distributed over the scene. Depending upon the number and distribution of the control points in the scenes, the additional parameters may be highly correlated and of course not all effects which can be compensated by the parameters are available in the used scenes. By this reason a statistical test of the additional parameters is required and only not too high correlated parameters which can be determined by the actual geometric constellation should be used. Program BLASPO is reducing the number of introduced parameters automatically, so an over-parameterisation can be avoided.

3. Experimental Results of Bundle Orientation

For the orientation of the MOMS-2P scenes in the area of the Black Forest, control points have been digitised from German topographic maps 1 : 50 000 which are including also parts of France and Switzerland.

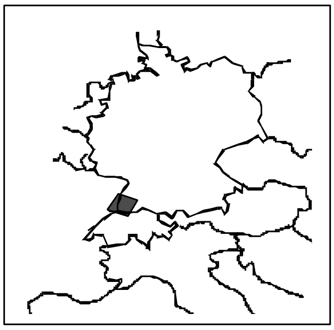

Figure 2: location of project area

The image measurement has bean done with DPLX, developed by the University of Hannover. It is based on the script language TCL/TK and can be used by this reason on different computer platforms. DPLX is able to handle also large images on standard PC’s, by this reason not the whole image with the full resolution will be loaded but a sub-image.

An image with a reduced number of pixel will be used for an overview, showing also the location of the actual sub-image. Control points can be automatically identified by an ellipse operator, but usually not in the case of space images. With digital images a sub-pixel accuracy can be reached if the points are well defined, because “points” in a digital image are not points in the mathematical definition, but they are the centre of a group of pixel. By this reason and for a more simple manual pointing, a zoom window can be created which will be used as standard for the manual measurement.

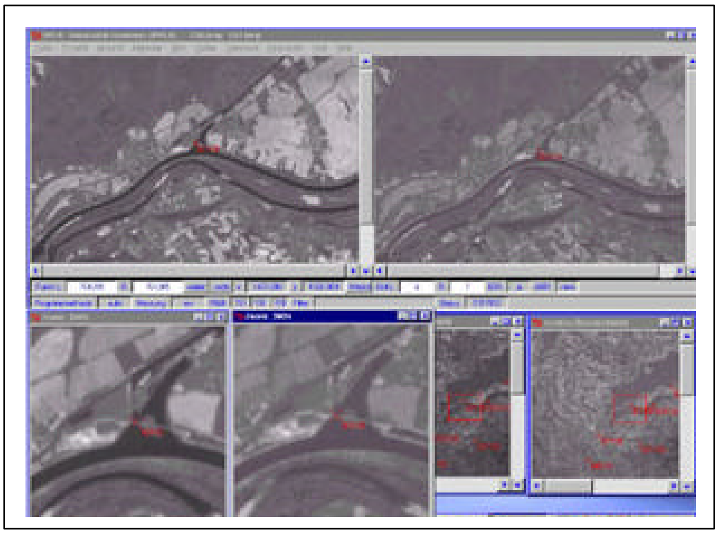

Figure 3: DPLX

above: sub-images (1:1)

below left: zoom windows

below right: overview images

The identification of control points – points which can be identified in the space images and the topographic maps - has to respect possible object shifts by map generalisation. In images with a pixel size of 17.5m, road crossings and bridges are belonging to the preferred objects. Points which can be seen clear in one scene must not be visible in the others. In general the contrast was better in the panchromatic scenes, the inclined views of channel 6 and 7. Especially in the near infrared channel 4 it was more difficult, this scene gave the impression to be not so sharp. With DPLX at first the images of channel 6 and 7 have been used for the search for control points. By means of displaying the points, identified in channel 6 in the left hand zoom window, the points have been transferred to the corresponding right hand zoom window, showing a part of the remaining channels 1 and 4. So it was possible to determine the image positions of points which could not been identified by the crossings but by surrounding elements.

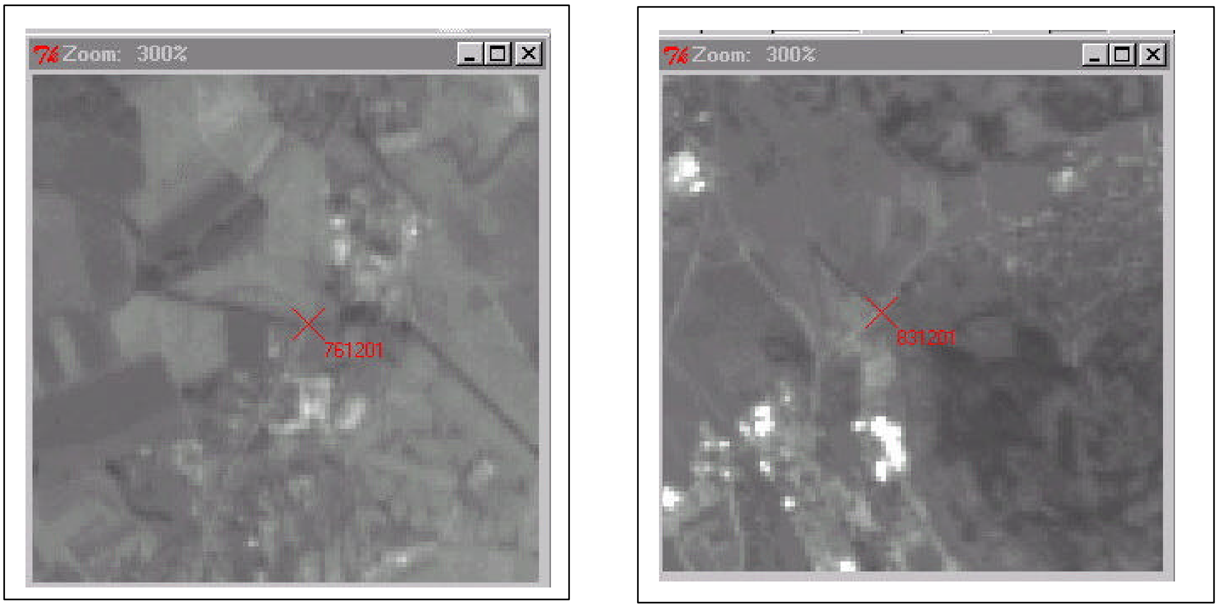

Figure 4: identified control points in the DPLX-zoom-window

Nevertheless, errors in point identification cannot be avoided by the handling of space images with such a resolution. In addition sometimes the chosen element does not fit anymore between map and space image. So for example, the intersection of waterways shown in figure 3 has been rebuild, causing a displacement of 100m. In general approximately 20% of the identified control points cannot be used because of misidentification or mismatch. But also a manipulation of the results by elimination of the not so good points has to be avoided for a realistic estimation of the achieved accuracy. In program BLASPO, the identification of blunders will be done automatic by the statistic method of data snooping.

For the analysis of the bundle orientation quality, 10 control points have been used and the result was checked with 17 independent check points, which have not been used as control points. For the orientation 4 control points at the corners of the covered area would be enough and the accuracy is also sufficient if the control points are not affected by misidentification. As mentioned, this cannot be avoided in the case of the selection of the control points from maps, by this reason an over-determination is required and usual practice.

used channels	height / base relation	sigma 0 [pixel]	Independent check points			inner accuracy (from bundle abjustment)		
			RMSX [m]	RMSY [m]	RMSZ [m]	MSX [m]	MSY [m]	MSZ [m]
6, 7	1.25	1.02	9.0	15.5	32.4	16.2	15.1	33.7
6, 7, 4	1.25	0.92	11.7	17.0	32.2	12.0	11.5	30.2
6, 7, 1	1.25	0.94	11.5	16.8	31.9	12.1	11.6	31.1
6, 7, 1, 4	1.25	0.89	12.7	16.7	32.0	10.0	9.7	29.4
6, 4	2.5	1.02	24.9	17.9	69.1	21.9	19.1	78.1
7, 4	2.5	0.92	28.1	18.2	56.6	21.2	15.0	55.1
6, 1	2.5	1.11	18.9	18.5	63.0	21.6	18.4	79.6
7, 1	2.5	1.04	18.9	17.4	29.2	20.7	16.9	58.7

Table 3: results of bundle orientation

The standard deviation of unit weight, the sigma 0, is identical to the accuracy of the image coordinates. The achieved accuracy in the range of one pixel corresponds to the expectations – the control points could not be identified more precise in the images, the pointing with zoom factor 3 made the pointing more simple but it could not improve the point identification. The root mean square differences at the independent check points are not too far away from the inner accuracy listed by BLASPO as it can be seen in table 3. The inner accuracy, which is available for each coordinate, has a variation in the range of 20% for X and Y and up to 30% for Z, that means the accuracy is depending upon the location of the points within the scene – this cannot be investigated for the limited number of independent check points.

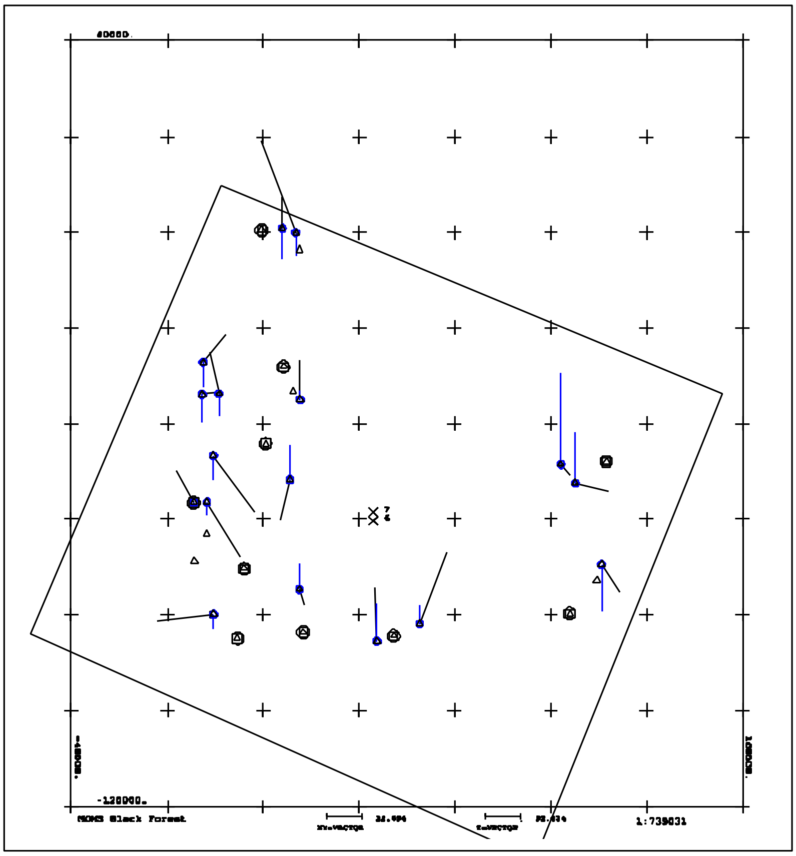

Figure 5: block configuration

thick points = control points,

check points with error vectors

In general, the use of the vertical scenes together with the forward view of channel 6 and the backward view of channel 7 has not improved the experimental results achieved with independent check points, but here we have to take into account that the independent check points are not free of errors, the accuracy of the points digitised from the German map 1 : 50 000 is usually limited in X and Y to approximately 12 – 13m. The combination of a vertical view together with one inclined view, by theory should have larger root mean square errors in Z by the factor of 2 – this is also the case. Only the combination of channel 7 and 1 is leading to a much better accuracy than expected. This has happened with other space images only in the case a stereoscopic measurement of the control and check points, which is causing a correlation of the x'-coordinates, which improves the height, but is not respected by the calculation of the inner accuracy. The more poor results of the horizontal components for the case of the use of the near infrared channel 4 was expected because of the more poor image quality.

An internal quality check is also possible by an affine transformation of one scene to the other. The discrepancies in the x-direction are corresponding to the x-parallaxes, that means, they are depending upon the height variation. Only in case of the comparison of the both nadir channels 1 and 4, the results can be checked. The discrepancies in the y-direction can be used for an internal data check. The root mean square differences in the y-direction are between 0.7 and 0.9 pixel – this has to be divided by $\sqrt{2}$, so for the single image point measurement an accuracy of 0.5 – 0.7 pixel can be estimated.

The results listed in table 3, are based on a bundle orientation with self calibration by additional parameters. Most of the additional parameters have not been significant and removed by BLASPO, only the additional parameters 3 and 4 in addition to 1 and 2, which are belonging to the standard solution, where required. The influence of the parameters to the image coordinates is dominated by the influence of the earth rotation, causing an angular affinity (figure 6 left hand side). It is reaching 1.1mm or 110 pixel. With the additional parameters 3 and 4 a change of the attitude values in relation to the nadir direction during imaging will be covered, it is reaching an influence of up to 15 pixel – the additional parameters do have test values of the Student test between 5 and 15, that means they are significant exceeding the probability level of 99.9%.

The reached horizontal accuracy is in the range of the existing accuracy of the German topographic map 1 : 50 000, so it cannot be excluded that a better accuracy can be reached with the MOMS-data if the control points are more precise – this is indicated by the internal quality check with the figures of 0.5 – 0.7 pixel for the transformation of one scene to the other. On the other hand the achieved accuracy is sufficient for mapping. As a rule of thumb, a pixel size of 0.05 – 0.1mm/pixel is required for mapping with the required contents (Jacobsen et al 1998 b). That means, based on a pixel size of 17.5m, maps in the scale range of 1 : 200 000 can be created. If the mapping accuracy shall be 0.2mm, a horizontal accuracy of +/-40m is required and this is guaranteed by the MOMS data.

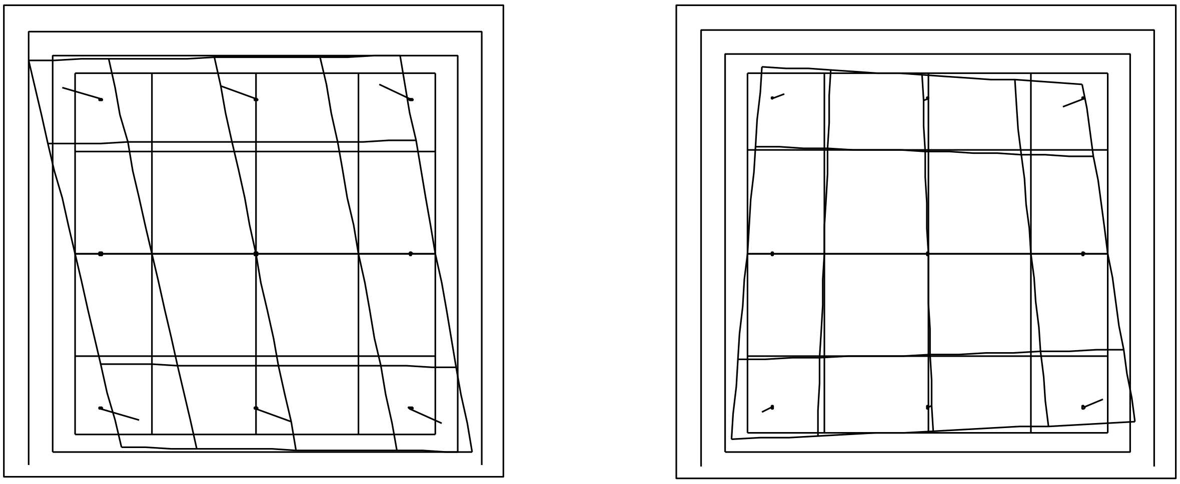

Figure 6: influence of additional parameters to image coordinates

left: parameters 1 – 4 (channel 6) (right: parameters 3 and 4 (channel 6)

4. Image Matching

Based on the image orientation the digital elevation model (DEM) has been generated by program LISA-FOTO. LISA-FOTO generates the DEM by correlation in a region growing mode. The basic problem of the start values for the image correlation is solved by start with image and ground coordinates generated by bundle orientation. Starting from corresponding points in both used scenes, the correlation of neighboured points will be computed which do have a distance from the previous points in a chosen distance. From the new generated corresponding points, the program will also go to the points located in the 8 mayor directions (left, upper left, up, upper right, right, ...) with the exception of the always correlated points. If the region growing will be stopped by some object elements like a large river, the remaining region will be reached, starting from other corresponding points of the bundle orientation or the region growing can also go over bridges. This method has been shown as very robust. Also dark forest regions in the mountains could be handled. But in such regions miscorrelation cannot be avoided because of too poor object information and partially very steep areas. This can be seen in figure 7, showing a rough wire frame model of the DEM computed without filtering.

The DEM has to be filtered for blunders and also for points located on the visible surface, but not on the solid ground. Especially in the Black Forest an influence by high trees cannot be neglected. With the program RASCOR nearly all points, not located on the ground, can be automatic identified and removed. RASCOR is checking if the relation of neighboured points can correspond to a continuous surface and is not affected by sudden height changes caused by miscorrelation or elements not belonging to the surface like high trees or buildings.

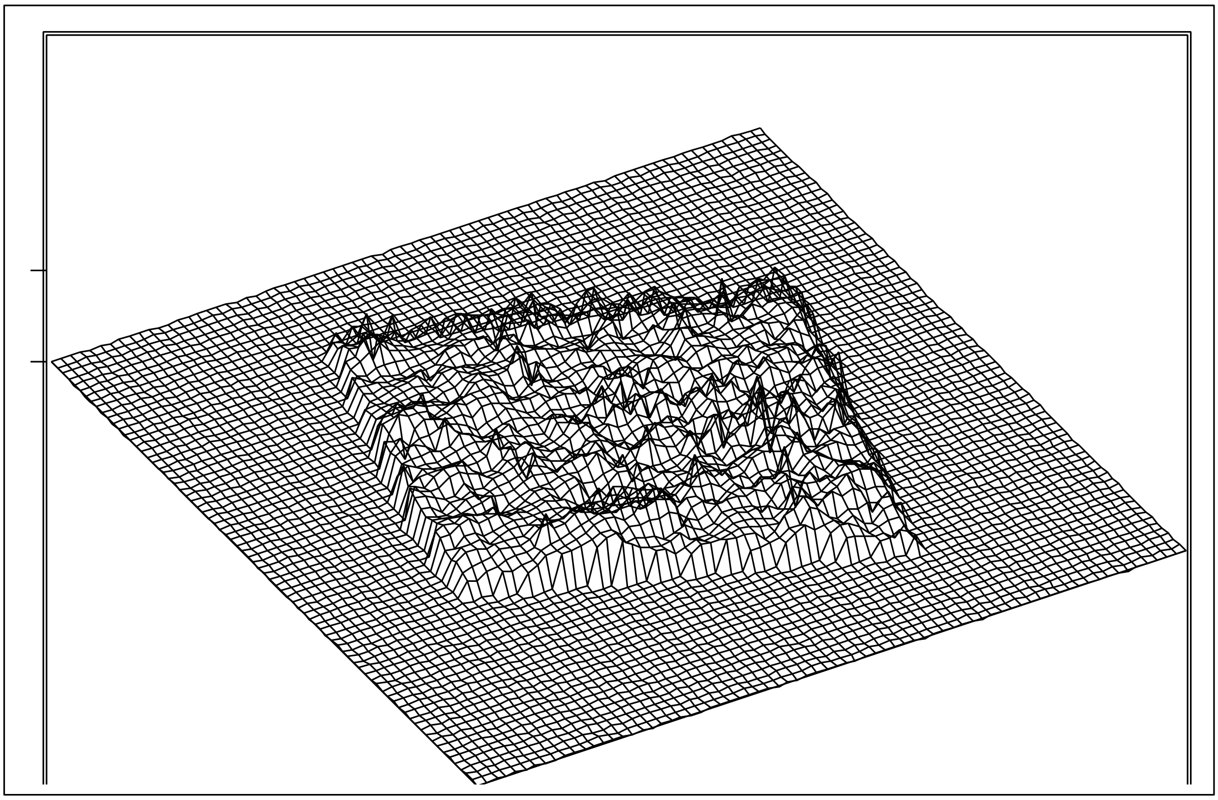

Figure 7: correlated DEM – without filter

5. Conclusion

The bundle orientation of MOMS-2P-images is possible with a horizontal accuracy in the range of 1 pixel – this is sufficient for mapping. The space images taken with the MOMS-sensor do have the advantage of a general stereoscopic coverage. Based on this, the generation of DEM is possible with the accuracy which is required for orthophotos. The vertical accuracy of well defined points is depending upon the scene combination. With a combination of the backward and forward view, leading to a height to base relation of 1.25, approximately +/-32m could be reached. The additional use of vertical scenes has not improved the result. With automatic image matching, which requires a filtering for the removal of points not located on the bare ground, the required DEM can be generated without problems.

The existence of the coverage of large parts of the world by stereo-MOMS-data is not well known. This does not correspond to the potential of this spaceborne mapping system.

6. References

Jacobsen, K. 1998 a: Geometric Potential of IRS-1C PAN-Cameras, ISPRS Com I, Bangalore 1998

Jacobsen, K., Konecny, G., Wegmann H., 1998 b: High Resolution Sensor Test Comparision with SPOT, KFA 1000, KVR 1000, IRS-1C and DPA in Lower Saxony, ISPRS Com IV, Stuttgart 1998