OPTIMIZED GEOMETRIC HANDLING OF HIGH RESOLUTION SPACE IMAGES

Gürcan Büyüksalih*
Karsten Jacobsen**

*Karaelmas University, Zonguldak, Turkey; gbuyuksalih@yahoo.com
**University of Hannover, Germany; jacobsen@ipi.uni-hannover.de

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ABSTRACT

High resolution space images do have an excellent geometric potential. This only can be used with a correct data handling. Different solutions are available like rational polynomial coefficients (RPCs) or geometric reconstructions. Some images are available with different geometric representations e.g. SPOT level 1A and 1B or QuickBird Basic, Standard or OrthoReady products. The geometric handling and the potential of these products has been evaluated. With satisfying control points and the correct geometric handling sub-pixel accuracy has been reached with all products. The exact definition of the control points in the images has been shown as a key problem. For some solutions like the terrain relief affine corrected transformation and the terrain dependent RPCs an optimal three-dimensional distribution of control points is important while some other methods like geometric reconstructions based on sensor information or sensor based RPCs can handle the orientation process with a smaller number of control points which must not be distributed in an optimal manner.

1. INTRODUCTION

High resolution space images are available as perspective photos, as traditional line scanner images taken with the movement of the satellite and from the flexible satellites scanned in all possible directions, even against the movement of the satellite. In addition they are distributed as products with different geometry, starting from the close to original scenes e.g. QuickBird Basic Imagery or SPOT and IRS 1C level 1A, as projection to a plane with constant height or even as rough ortho images (QuickBird Standard). All imaging systems are equipped with a positioning system like GPS, gyroscopes and star sensors. So without control points the geolocation can be determined with accuracies depending upon the system. The information about the sensor orientation is distributed as full data set, including all elements of inner and exterior orientation, as reduced information including only few elements or as polynomial functions describing the relation between the image and the object space. For using the full accuracy potential of space images control points are required together with the correct mathematical model. Different models are in use, based on available sensor information or just based on control points with a higher number of orientation parameters. The orientation process of high resolution space images is analyzed in this presentation.

2. POINT DEFINITION

For the orientation of space images or at least for the geometric analysis control points are required. Points in digital images are not mathematical points with no dimension but the centers of well defined areas or the intersection of edges. A bright target in the object space will be shown with a larger size in the image. This has no influence to the position of a symmetric target as shown by the gray value profile of figure 1c. Independent upon the chosen gray value shoulder for the point identification, the center will not be affected in its location. This is different for edges. The gray value situation of edges is shown by the right hand part of figure 1c. The location of the edge is depending upon the used gray value shoulder and this is not well defined. In general corner positions are shifted from the bright to the dark parts, by this reason control and check points defined by edges should be avoided for accuracy analysis.

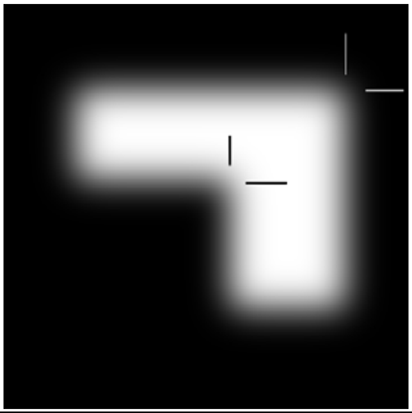

Fig. 1a: corner points – the thin lines are indicating the original corner positions

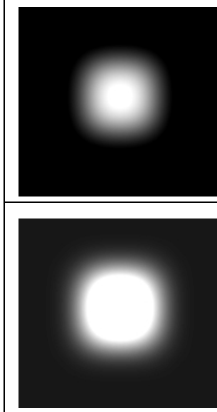

Fig. 1b: image of same original square

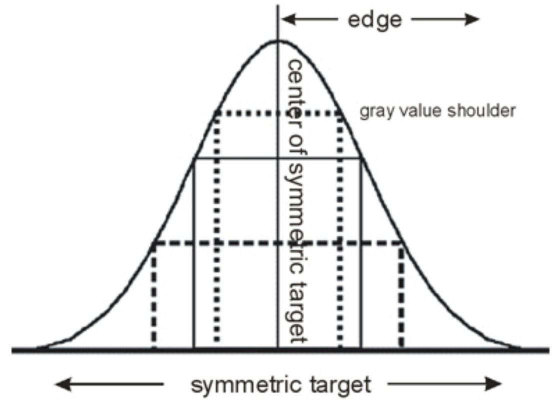

Fig. 1c: gray value profile of a symmetric point – independent upon used gray value shoulder same center position

Fig. 1: definition of position of corner and center points

3. IMAGING GEOMETRY

3.1 General Information

The classic satellite line scanners are imaging with an unchanged orientation of the view direction against the orbit (figure 2a). The view direction can be changed only in the across orbit direction and during the change no images are taken. Caused by the earth rotation, the scene area on the ground is not a rectangle. The angular affinity of the projected scene is in the range of 3.8° at the equator. SPOT 5 is avoiding this effect of the earth rotation by a "yaw control" – a permanent change of the view direction across the orbit during imaging (figure 2a). This is generating a rectangular shape of the scene on the ground, but the scene is still oriented in relation to the orbit and not to the coordinate system.

With the highly agile satellites a scan in any direction is possible. The satellites are equipped with reaction wheels - gyroscopes rotating with high speed. By accelerating or reducing the speed of the gyros an angular moment is caused to the satellite, changing the view direction. With three reaction wheels the satellites can be rotated in any direction just based on solar power. IKONOS is able to take images also in the direction against the movement of the satellite (figure 2d). But for imaging against the orbit different CCD-lines are used.

The very high resolution satellites do have only a very short time interval for the generation of electric charge in a CCD-element. The satellite speed projected to the ground is in the range of 7 km/sec. So for a pixel size of 0.8m only 0.1ms exposure time is available. This is not enough for the generation of a satisfying image quality. The effective integration time for a pixel can be extended by a transfer and delay integration (TDI) sensor which corresponds to electronic forward motion compensation. Some very high resolution sensors like EROS A1, TES and the coming Cartosat-1 are not equipped with TDI-sensors; they do extend the exposure time by a permanent rotation of the satellite, so they are imaging the scene over a longer orbit path (figure 2e). This is generating a sufficient image quality, but it is reducing the capacity and of course it is influencing the imaging geometry.

The original images improved by the inner sensor geometry are not available in any case. For IKONOS also no information about the sensor geometry is published, only the CARTERRA Geo is distributed as lowest level product. This is a projection of the image to a plane with constant height like a simple rectification (figure 2f). Corresponding products are available also from other sensors like QuickBird OR Standard and SPOT or IRS level 1B. From all distributors together with the images, header or metadata information is delivered. They include the information of the view direction from the ground to the sensor and for the sensors with flexible view direction also azimuth from the scene center to the corresponding projection center.

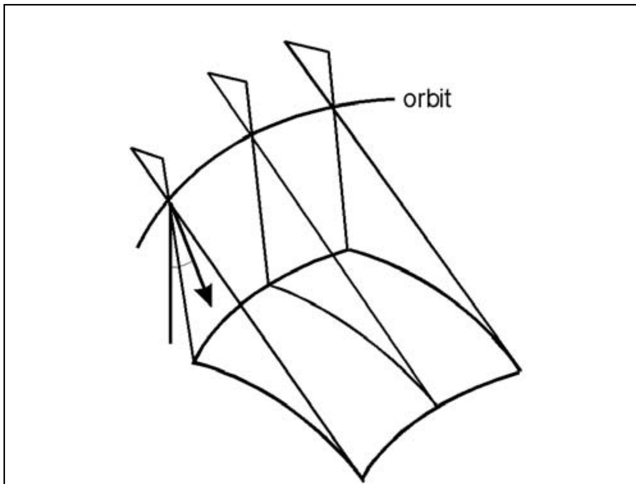

Fig. 2a: classical satellite scan – unchanged orientation against orbit

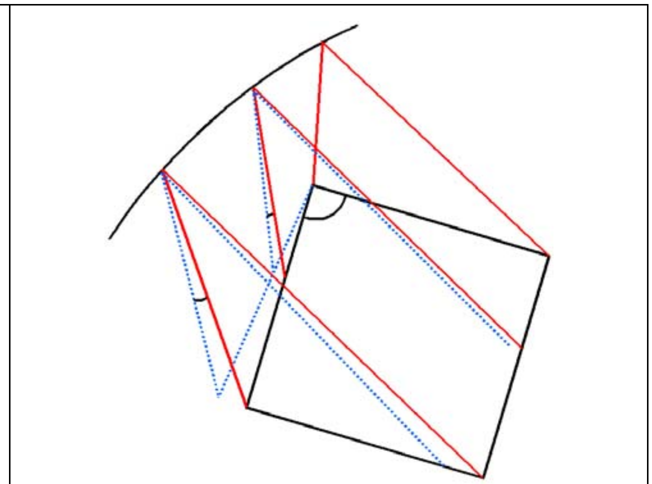

Fig. 2b: yaw control by SPOT 5 – permanent change of view direction across orbit

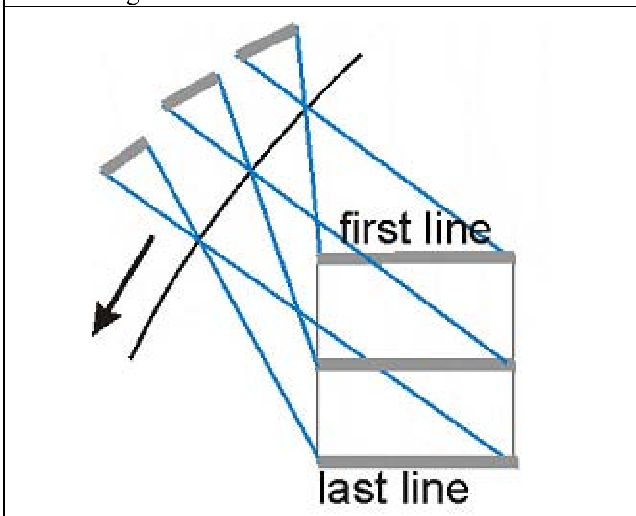

Fig. 2c: flexible view direction - scan in any direction

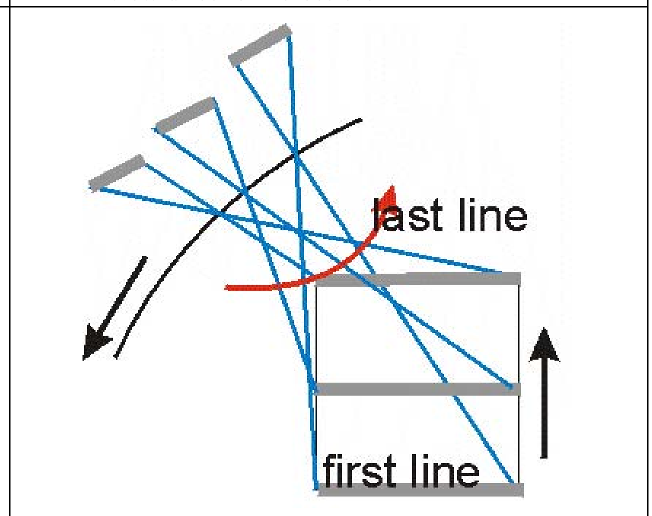

Fig. 2d: flexible view direction – scan against orbit

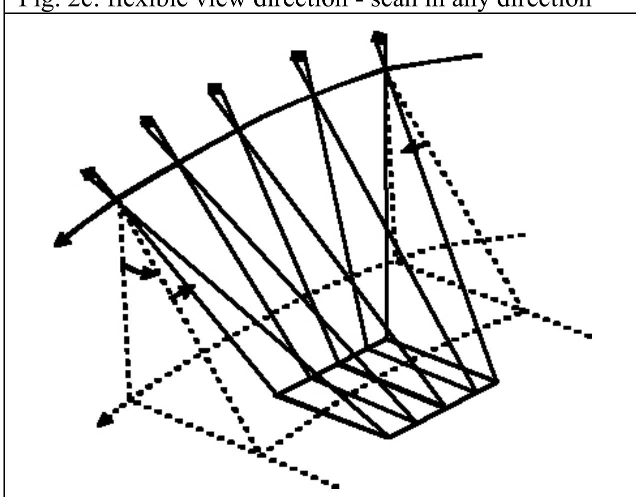

Fig. 2e: enlargement of integration time by continuous change of view direction

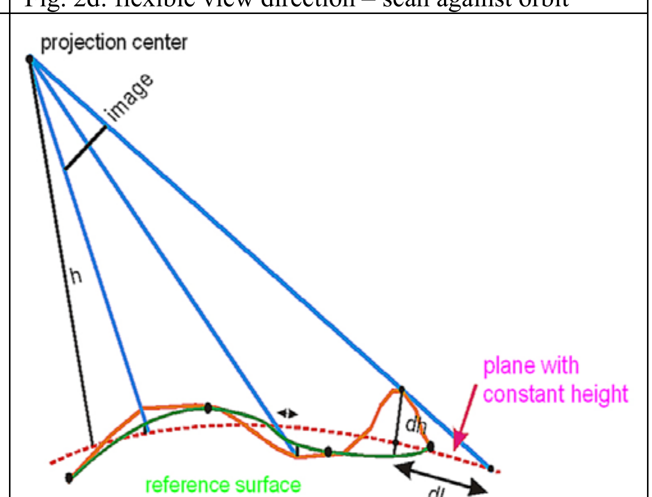

Fig. 2f: level 1B, IKONOS Geo, QuickBird OR Standard = projection to plane with constant height

The orientation of standard satellite line scanner images like SPOT 1-4, IRS-1C / 1D or KOMPSAT-1, are determined with the Hannover program BLASPO based on the given view direction, the general satellite orbit and few control points. By theory 3 control points are sufficient, but for operational handling a sufficient over-determination is required by reliability reasons.

For the orientation of the Russian space photos TK350 and KFA3000 the Hannover program for bundle block adjustment BLUH has been used, it can handle also the panoramic images of the KVR1000.

The quite different geometry of the images projected to a plane with constant height like IKONOS Geo, QuickBird OR Standard, SPOT level 1B, IRS-1C level 1B and KVR1000 level 1B requires a different mathematical model. In the Hannover program CORIKON the geometry is reconstructed based on the given view direction (nominal collection elevation and azimuth for IKONOS, in /cross track view angle for QuickBird) and the standard satellite orbit specified with the semi major axis, semi minor axis and the inclination. The satellite orbit is shifted in the longitude up to the intersection with the view direction from the scene center. With the knowledge of the scan direction and the satellite speed the location of the correct projection center corresponding to a scene point can be computed. This leads to the actual view direction required for the correct handling. Based on control points a shift of the geocoded scene or an affinity transformation can be adjusted. It is also possible to include the view direction as unknown, but this requires control points with different height levels. For the handling of the QuickBird scene it was also necessary to introduce two unknowns as a function of the object height and the Y-direction. All unknowns are checked for their significance and can be used individually. If the vertical control point distribution does not allow the determination of the view direction, this will be eliminated automatically as unknown to avoid uncontrolled extrapolations out of the range of the control points.

3.2 Russian Space Photos

Russian space photos have been taken up to the year 2000. These images still can be ordered. Of course the use for mapping purposes is limited because of the not actual information, but they still can be used for some special reasons like generation of height models or change detection. The handling of the perspective images from TK350 or KFA3000 is as the handling of standard photos, only the earth curvature has to be respected (Büyüksalih at al 2004). In addition the image positions can be improved by means of reseau crosses. The photo quality is not on the same level as for digital images and the possible ground resolution is named too optimistic. An edge analysis was leading to an effective ground sample distance (GSD) of 13m for the TK350 (Jacobsen 2004). The reached accuracy of the image orientation shown in table 1 is strongly affected by the accuracy and identification of control points - in general this is the dominating effect for the handling of space images.

3.3 ASTER

ASTER is a standard CCD-line scanner with the advantage of an additional backward view in the orbit direction. So in any case a stereo coverage is available. As a preparation very often a radiometric normalization of the individual rows is required for the removal of striping effects. The stereo coverage in the near infrared range has some advantages especially in the rural areas having better contrast like the panchromatic spectral range. The reached orientation accuracy of 10.8m, corresponding 0.7 pixels for X and Y and 0.6 pixels for the x-parallax, is in the range of the expectation for well defined and accurate control points. Of course it is easier to have an accurate control for images with 15m GSD as for higher resolution.

3.4 KOMPSAT-1

The South Korean KOMPSAT-1 having a GSD of 6.6m is similar to SPOT 1 – 4. It has the possibility of a view change in the direction across the orbit. The scene is limited to 2592 x 3000 pixels (17 km x 20 km). It was necessary to adjust the view direction in the orbit and across orbit direction. The changes against the nominal view direction are in the range up to 5°. Root mean square discrepancies at 48 control points of RMSX = 9.07m, RMSY = 8,02m, RMSZ = 14.90m has been reached. This corresponds to 1.4 pixels, 1.2 pixels and for the x-parallax to 1.1 pixels for the height to base relation of 2.03 (see figure 3). The control point quality was not optimal causing such values exceeding 1 pixel.

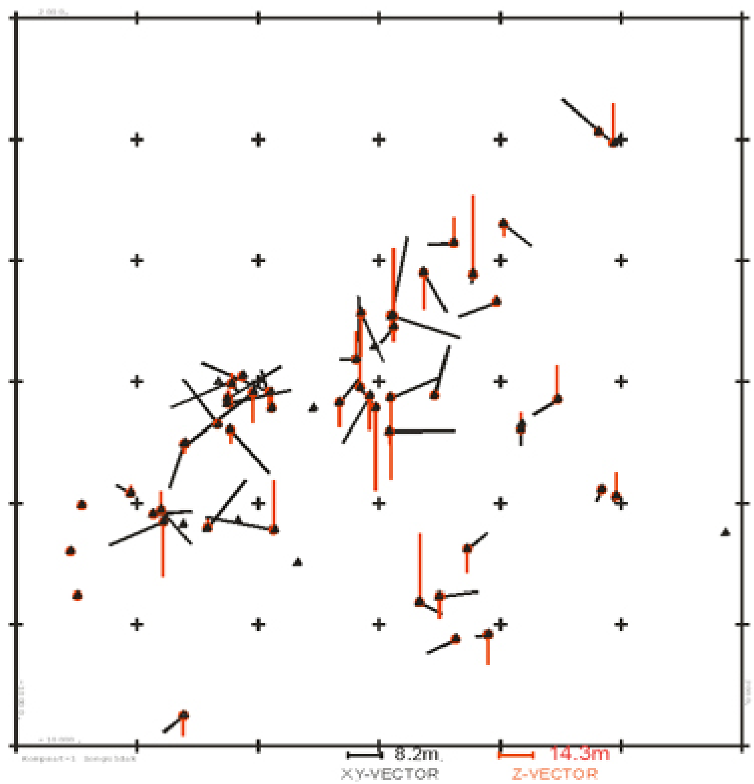

Fig. 3: bundle orientation of a KOMPSAT-1 model – residuals at the control points

black vectors = XY-discrepancies

red vectors = Z-discrepancies

covered area: 17 km x 20 km

upper left area = Black Sea

3.5 SPOT

With very precise control points in the area of Hannover by bundle orientation of level 1A SPOT 2 scenes root mean square discrepancies at control points of 4.6m corresponding to 0.5 GSD were computed. In the Zonguldak area the control point definition was not as good, so with SPOT 5 images having a GSD of 5m only root mean square discrepancies at 40 control points of +/-5.1m has been reached corresponding to 1.0 pixel. The same scenes are available as level 1A (close to original image) and as level 1B (projected to plane with constant height) products. The level 1A scenes handled with program BLASPO and the level 1B scenes handled with program CORIKON were leading to nearly the same results. Also the generated digital elevation models have had the same quality, so it does not matter which image product will be handled.

3.6 SPOT 5 HRS

SPOT 5 has as an independent sensor the high resolution stereo (HRS) viewing with one optic forward and with the other optic backward having a height to base relation of 1.2. The images with a GSD of 5m in the orbit direction and 10m across, are usually not available, only for a test handled by the ISPRS, HRS scenes have been distributed (Jacobsen 2004). A bundle orientation was leading in the average to RMSX= 6.9m, RMSY= 5.4m and RMSZ=3.7m. The larger pixel size is mainly in the X-direction, so this corresponds in the image space to RMSx'=0.7 pixels, RMSy'=1.1 pixels and to RMSpx=0.6 pixels. The limited horizontal accuracy was caused by a not very precise control point definition in the images.

3.7 IRS-1C

In the area of Hannover a calibration of original IRS-1C images based on the 3 sub-images from the 3 individual panchromatic CCD-lines has been made based on a configuration of 3 different view directions (Jacobsen 1998). Special additional parameters for the fitting of the 3 sub-images are required leading to horizontal object coordinate accuracy of 5.1m or 0.9 pixels. In the Zonguldak area a level 1B scene has been handled with control points having only a limited accuracy, so the resulting root mean square error of the X- and Y-coordinates of 9.1m or 1.6 pixels reflects more the quality of the used points than the geometric quality of the scene.

3.8 IKONOS

For IKONOS images the sensor model is not published. Different solutions for the orientation of the Geo product as well as for corresponding level 1B or ORStandard images can be used:

1. Rational Polynomial Coefficients (RPCs) from the satellite image vendors – they do describe the location of image coordinates as a function of the object coordinates (longitude, latitude, height) by the ration of polynomials (Grodecki 2001). Third order polynomials with 20 coefficients are used, so with 80 coefficients the relation of the image coordinates to the object coordinates can be described based on the direct sensor orientation of the satellites. The RPCs have to be improved by means of control points, but often a simple shift is sufficient.

2. Reconstruction of imaging geometry: For the scene centre the direction to the satellite is available in the header data of the images. This direction can be intersected with the orbit of the satellite which is published with its Keppler elements. So the view direction from any ground point to the corresponding projection center can be computed. This method requires the same number of control points like the sensor oriented RPC-solution.

3. Three-dimensional affine transformation: It is not using available sensor orientation parameters, the 8 unknowns have to be computed based on control points. At least 4 well distributed control points, not located in the same height level are required.

4. Direct Linear Transformation (DLT): The 11 unknowns do require at least 6 control points.

5. Terrain dependent RPCs: A limited number of polynomial coefficients are calculated based on control points.

The terrain dependent RPC-solution is very sensitive for the control point distribution. Outside the area of the control points the accuracy may be very poor – see figure 4 (Büyüksalih et al 2003). The used commercial program did not indicate any problems and showed accuracy better than 1m. The DLT does not lead to the same accuracy like the other methods and requires a high number of control points (Hanley 2003). With the first three methods similar accuracy has been achieved, but for the 3D-affine solution more control points with a sufficient three dimensional distribution are required. Even in mountainous areas the three dimensional distribution of control points is difficult, usually the control points are located in the easy accessible valleys causing problems with the correct location of the top of the mountains based on the orientations 3 up to 5.

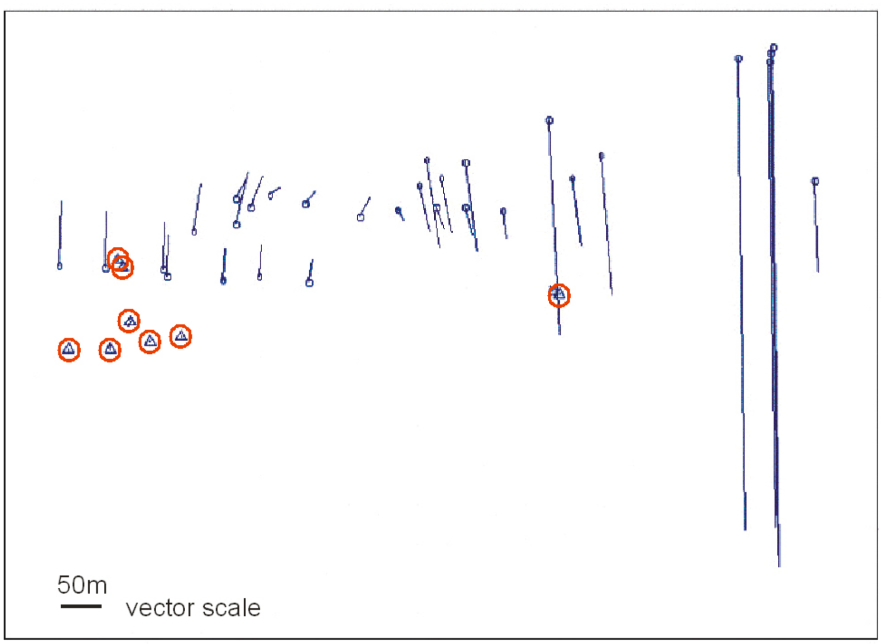

Fig. 4: discrepancies at check points determined by terrain dependent RPCs with unfavorable control point distribution

used control points marked

In the Zonguldak area the orientation of two IKONOS scenes has been analyzed. For one scene RPCs are given. The computation with the Hannover program RAPORI for the handling of the RPCs and the program CORIKON were leading to similar results (see table 1).

program	unknowns	RMSX	RMSY
CORIKON	2 just shift parameters (see figure 5)	0.76 m	0.74 m
CORIKON	6 affinity transformation	0.67 m	0.71 m
CORIKON	8 affinity + view direction	0.67 m	0.70 m
CORIKON	10 affinity + view direction + 2 additional parameters	0.66 m	0.67 m
RAPORI	2 just shift parameters	0.63 m	0.60 m
RAPORI	6 affinity transformation	0.61 m	0.64 m

Table 1: orientation of IKONOS Geo scenes with reconstruction of imaging geometry (CORIKON) and based on RPCs (RAPORI) – root mean square discrepancies at approximately 40 control points

Table 1 shows a sub-pixel accuracy of 0.7 – 0.6 GSD which is nearly independent upon the number of unknowns. Just a simple shift of the relief corrected ground coordinates is leading close to the optimal results. The results achieved with the RPCs are not significant better as with the reconstruction of the imaging geometry. With the exception of the shift parameters all other unknowns have not been highly significant.

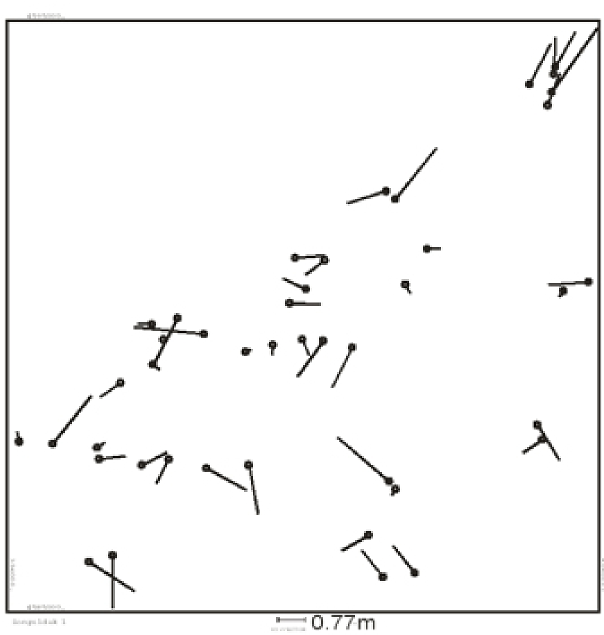

Fig. 5 IKONOS, discrepancies at control points

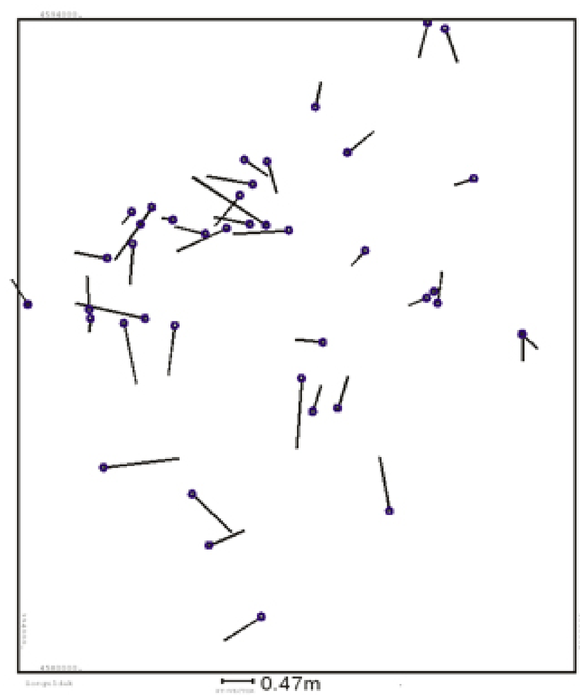

Fig. 6 QuickBird, discrepancies at control points

3.9 QuickBird

In the Zonguldak a QuickBird ORStandard scene was available with control points measured by GPS. As IKONOS Geo this is a projection of the image to a plane with constant height. So in general the same solutions like described before can be used. In other areas QuickBird Basic and QuickBird Standard images have been handled. Basic imageries are the original images only improved by the inner sensor geometry. They have to be handled with a corresponding mathematical model which is used in the program BLASPO. Some special additional parameters were required for the optimal solution (Passini et al 2004). The QuickBird Standard is a projection to the rough GTOPO30-DEM. For the relief correction only the height difference of the actual point to the GTOPO30 has to be used. This makes an adjustment of the view direction difficult because of the small height range, but on the other side this is also not important because of the same reason. The handling of the Standard Imagery is not much more complicate like the handling of the ORStandard, only the GTOPO30 DEM is required as additional input. Because of the not optimal control point quality in the other areas the accuracy was limited to approximately 1m.

unknowns	RMSX	RMSY
2 only shift	1.84 m	0.89 m
6 affinity transformation	0.81 m	0.66 m
8 affinity + view direction	0.67 m	0.65 m
10 affinity + view direction + 2 additional parameters	0.48 m	0.46 m

Table 2: orientation of QuickBird ORStandard scene with reconstruction of imaging geometry (CORIKON) – root mean square discrepancies at 41 control points

As it can be seen in table 2, for the optimal results more unknowns have been necessary, but finally also with this very high resolution image a sub-pixel accuracy has been reached (GSD = 0.62 m). For the best results the view direction had to be improved, but also after this some systematic errors could be seen, so 2 special additional parameters with DX=F(DZ,Y) and DY=F(DZ,Y) had to be introduced.. The Student test values (T-test) for the 10 unknowns are in the range of 0.9 up to 12.2, these are not very high values but the table 2 shows the requirement.

4. SUMMARY AND CONCLUSION

	RMSX / RMSY [m]	RMSx' / RMSy' [ground pixel]
TK 350, Zonguldak	*8.3*	*(0,8)*
KVR 1000, level 1A, Duisburg	*3.3*	*(1.6)*
KVR 1000, level 1B, Zonguldak	*10.2*	*(5.1)*
KFA 3000, Vienna	*2.5*	*(2)*
ASTER, Zonguldak	10.8	0.7
KOMPSAT-1, Zonguldak	8.5	1.3
SPOT, level 1A, Hannover.	4.6	0.5
SPOT 5, level 1A / 1B, Zonguldak	5,1	1,0
SPOT HRS, Bavaria	6.1	0.7 / 1.1
IRS-1C, level 1A, Hannover	5.1	0.9
IRS-1C, level 1B, Zonguldak	9.1	1.6
IKONOS Geo, Zonguldak	0.7	0.7
QuickBird, OR Standard, Zonguldak	0.47	0.76

Table 3: standard deviation of ground coordinates achieved with different space images *(space photos)*

The summary of the results shown in table 3 demonstrates, with well defined and accurate control points usually a sub-pixel accuracy of the orientation of the different high and very high resolution space images is possible. In all cases with a lower quality there have been some problems with the control points. A correct mathematical model for the image orientation is required. The available information about the scene orientation should be used to lead the solution to the smallest possible number of unknowns. If only a shift of a relief corrected scene is required, the location of the control points is not any more important. On the other hand a three dimensional solution is sensitive for the extrapolation out of the range of the control points. Especially the solution with terrain dependent RPCs do not allow an effective control of the orientation quality in the whole scene.

The number of used unknowns should be checked by statistical analysis and the not justified parameters should not be used in the final solution. This is reducing the unknowns to the really required values and it reduces problems with the extrapolation out of the three dimensional range of control points.

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http://www.ipi.uni-hannover.de/news_en/index.php