PROS AND CONS OF THE ORIENTATION OF VERY HIGH RESOLUTION OPTICAL SPACE IMAGES

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ABSTRACT:

Very high resolution optical space images are coming more and more into competition to classical aerial images making them more important for mapping projects. The orientation process of the dominating CCD-line scanner images taken from space is quite different from the orientation of perspective photos. Different image products like nearly original images and images projected to a plane with constant height are available, this requires corresponding orientation solutions. All optical satellites are equipped with direct sensor orientation based on a positioning system, gyros and star sensors, so they can estimate the orientation parameters. For IKONOS, QuickBird and OrbView-3 this can be made without control points with a standard deviation of the ground coordinates in the range of 10m and better. The orientation information is available as view direction from the scene centre or start of scene or as ephemeris and as rational polynomial coefficients (RPCs). This allows the determination of the scene orientation by geometric reconstruction or bias corrected RPCs using control points. In addition approximations like 3D-affine transformation, direct linear transformation and terrain related RPCs are in use. The accuracy of the methods is compared in relation to the number and distribution of the control points and the limitations of the approximations are investigated. The approximations of the orientations by 3D affine transformation and direct linear transformation can only handle images projected to a plane with constant height like IKONOS Geo and QuickBird OR Standard. For original images they are not leading to acceptable accuracy. In any case they require more and three-dimensional well distributed control points.

1. INTRODUCTION

Optical satellites are equipped with direct sensor orientation devices – a combination of a positioning system like GPS or DORIS, gyros and star sensors. For the very high resolution imaging systems IKONOS, QuickBird and OrbView-3 the geo-location only based on the direct sensor orientation is reaching worldwide accuracy in the range of 10m. This opens possibilities for the scene orientation reaching high precision with a minimum of control points. Nevertheless orientation methods are in use not respecting available orientation information and using simplified mathematical models. Partially with these alternative methods the same accuracy is reached like with strict models, but quite more and three-dimensional well distributed control points have to be used.

2. ANALYZED SENSORS

system	launch	GSD [m] pan / MS	swath [km]	remarks
IKONOS	1999	0.82 / 3.24	11	TDI
QuickBird	2002	0.62 / 2.48	17	TDI, slow down mode
OrbView-3	2003	1 / 4	8	Staggered CCD, slow down mode

Table 1: characteristics of analysed sensors

For the panchromatic image, IKONOS has a ground sampling distance (GSD) – the distance of the centres of neighboured pixels in the object coordinate system – of 0.82m for nadir view even if it is mostly distributed with 1m GSD. QuickBird originally was constructed for a flying height of 680km. With the allowance in distributing images with up to 0.5m GSD, the flying height was reduced to 450km but the sampling rate stayed at 6900 lines/sec. With the GSD of 0.62cm this would correspond to 4.2km/sec, but QuickBird has a speed of the footprint on ground level of 7.1km/sec, by this reason a slow down factor of 1.7 has to be used (see figure 1).

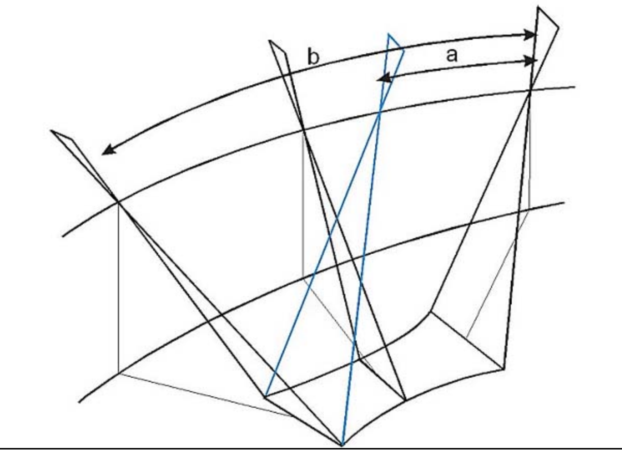

Fig. 1: slow down mode b/a by permanent rotation of view direction

The mentioned satellites are equipped with reaction wheels, fast rotating gyros which can be accelerated or slowed down – this will cause a moment to the satellite which starts to rotate. Based on the reaction wheels a fast and precise rotation of the satellites can be reached which can be used also during imaging without loss of image accuracy. So the view direction can be changed permanently during imaging to enlarge the acquisition time. The flexibility in the view direction can be used also for imaging not parallel to the orbit. The future satellites will be equipped with control moment gyros which are keeping the gyro orientation in the inertial space; they are allowing a faster rotation of the satellites for a better selection of areas to be imaged.

Without slow down factor for the imaging of a ground pixel of 0.82m only 0.11msec are available. This is not a sufficient exposure time for generating detailed images. By this reason IKONOS and QuickBird are equipped with transfer delay and integration sensors (TDI) (figure 2).

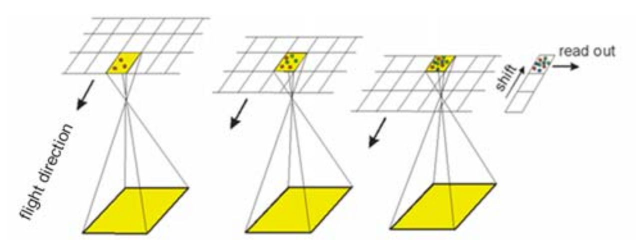

Fig. 2: time delay and integration sensor (TDI)

The TDI is using instead of a CCD-line a small CCD array. The energy reflected from the ground is generating a charge in a CCD-element. With the fast movement of the satellite, the object a short time later is imaged in the neighboured CCD-element. The charge generated in the first CCD-element is shifted with the speed of the image motion to the neighboured element and the charge generated in this element is added. So by shifting the charge and adding the additional charge a longer exposure time for the same ground element is reached. IKONOS and QuickBird usually use 13 elements for summing up the reflected energy. OrbView-3 is not equipped by TDI; instead of this staggered CCD-lines are used.

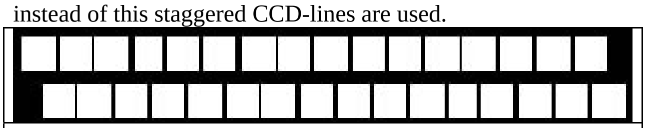
Fig. 3: staggered CCD-lines

Staggered CCD-lines are shifted half a pixel against each other (figure 3). The images generated by the two neighboured lines are merged and presented as a homogenous image having half the size the projected pixel on the ground as GSD. OrbView-3 images do have 2m pixel size on the ground, but 1m GSD. Neighboured pixels are over-sampled by 50%. Of course this will not generate images with the same quality like original 1m ground-pixel images, but the loss is limited.

The sampling rate of OrbView-3 is limited to 2500 lines/sec, requiring in addition to the staggered CCD-lines a slow down mode of 1.4.

The imaging characteristics of the sensors may influence also the geometric quality determined by scene orientation.

Different image types are used, so for IKONOS not the original images, only the IKONOS Geo – a projection to a plane with constant height is distributed (figure 4); for QuickBird this image type is named OR Standard. For QuickBird and OrbView-3 the original images are available, they are only corrected by the inner orientation and the combination of CCD-lines is joint together.

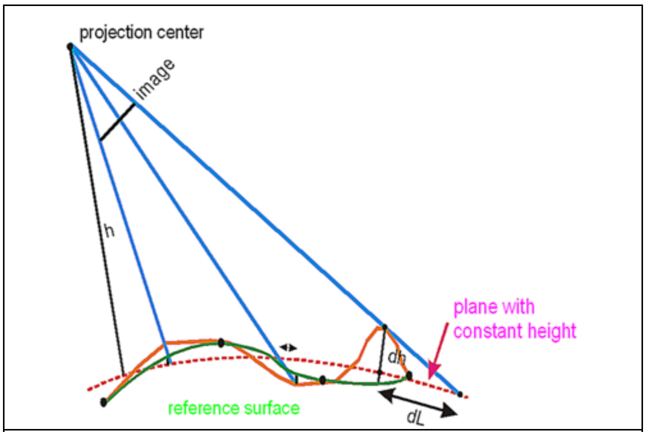

Fig. 4: image products - image = original image; projection to plane with constant height = IKONOS Geo and QuickBird OR Standard

3. METHODS OF IMAGE ORIENTATION

The orientation has to respect the available image type. There are some solutions trying to reconstruct the original images from the projections to a plane with constant height – this is possible, but not necessary. Rigorous mathematical models are in use like also approximations. In addition the available orientation information may be used completely, partially or even not.

3.1 Images Projected to Plane with Constant Height

Sensor oriented Rational Polynomial Coefficients (RPCs) from the satellite image vendors – they describe the location of image positions as a function of the object coordinates (longitude, latitude, height) by the ration of polynomials (Grodecki 2001) – see formula 1. These sensor related RPCs are based on the direct sensor orientation of the satellite together with information about the inner orientation and do have an accuracy depending upon the quality of the direct sensor information. 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. The RPC-information can to be improved by means of control points leading to the **bias corrected RPC solution**. For IKONOS for example a simple shift of the terrain relief corrected scene to control points is usually sufficient, for other sensors or old IKONOS images without the information of the reference height, a two-dimensional affinity transformation of the computed object coordinates to the control points is required.

$xij = \frac{Pi1(X,Y,Z)j}{Pi2(X,Y,Z)j}$	$yij = \frac{Pi3(X,Y,Z)j}{Pi4(X,Y,Z)j}$
$Pn(X,Y,Z)j = a_1 + a_2*Y + a_3*X + a_4*Z + a_5*Y*X + a_6*Y*Z + a_7*X*Z + a_8*Y^2 + a_9*X^2 + a_{10}*Z^2 + a_{11}*Y*X*Z + a_{12}*Y^3 + a_{13}*Y*X^2 + a_{14}*Y*Z^2 + a_{15}*Y^2*X + a_{16}*X^3 + a_{17}*X*Z^2 + a_{18}*Y^2*Z + a_{19}*X^2*Z + a_{20}*Z^3$	
Formula 1: rational polynomial coefficients xij, yij =scene coordinates X,Y = geographic object coordinates Z=height	

The RPC may have some accuracy limitations for very large scenes. In a scene with 20km length the centred coordinates are reaching 10^4 m; that means the third power is reaching 10^{12} – so even a numerical discrepancy of the used coefficients of 10^{-12} is causing a discrepancy of 1m.

Reconstruction of imaging geometry: For the scene centre or the first line, the direction to the satellite is available in the image header data. This direction can be intersected with the orbit of the satellite published with its Keppler elements. Depending upon the location of an image point and the slow down factor, the location of the corresponding projection centre on the satellite orbit together with the view direction can be computed. So the view direction from any ground point to the corresponding projection centre can be reconstructed. This method requires the same number of control points like the sensor oriented RPC-solution; that means it can be used also without control points if the direct sensor orientation is accepted as accurate enough. It requires the same additional transformation of the computed object points to the control points like the sensor oriented RPCs.

The **three-dimensional affine transformation** is not using available sensor orientation information. The 8 unknowns for the transformation of the object point coordinates to the image coordinates have to be computed based on control points located not in the same plane (formula 2). At least 4 three-dimensionl well distributed control points are required. The computed unknowns should be checked for high correlation values between the unknowns – large values are indicating numerical problems which cannot be seen at the residuals of the control points, but they may cause large geometric problems for extrapolations outside the three-dimensional area of control points. Three dimensional means also the height, so problems with the location of a mountain top may be caused if the control points are only located in the valleys. A simple significance check of the parameters, e.g. by a Student test, is not sufficient. The 3D-affinity transformation is based on a parallel projection which is approximately given in the orbit direction but not in the direction of the CCD-line. The transformation can be improved by a correction term for the correct geometric relation of the satellite images (Hanley et al 2002).

$$xij = a1 + a2 * X + a3 * Y + a4 * Z$$
$$yij = a5 + a6 * X + a7 * Y + a8 * Z$$

Formula 2: 3D-affine transformation

The mathematical model of parallel projection is not a problem for the narrow field of view if the height differences are not very large. For large height differences and unknown slow down mode, extended formulas are available in the Hannover program TRAN3D.

$$xij = a1 + a2 * X + a3 * Y + a4 * Z + a9 * X*Z + a10*Y*Z$$
$$yij = a5 + a6 * X + a7 * Y + a8 * Z + a11*X*Z + a12*Y*Z$$

Formula 3: extended 3D-affine transformation

For the handling of original OrbView-3 images a further extension has been made (formula 4)

$$xij=a1 +a2*X +a3*Y +a4*Z +a9 *X*Z +a10*Y*Z +a13*X*X$$
$$yij =a5+a6*X +a7*Y +a8*Z +a11*X*Z + a12*Y*Z+a14*X*Y$$

Formula 4: extended 3D-affine transformation for original images

Direct Linear Transformation (DLT): Like the 3D-affine transformation the DLT is not using any pre-information. The 11 unknowns for the transformation of the object point coordinates to the image coordinates have to be determined with at least 6 control points. The small field of view for high resolution satellite images together with the limited object height distribution in relation to the satellite flying height is causing quite more numerical problems like for the 3D-affine transformation. The DLT is based on a perspective image geometry which is available only in the direction of the CCD-line. There is no justification for the use of this method for the orientation of satellite images having more unknowns as required.

$$xij = \frac{L1*X + L2*Y + L3*Z + L4}{L9*X + L10*Y + L11*Z + 1}$$
$$yij = \frac{L5*X + L6*Y + L7*Z + L8}{L9*X + L10*Y + L11*Z + 1}$$

Formula 5: DLT transformation

The mathematical model of the DLT is a perspective image including its inner orientation. Like the 3D-affine transformation this is an approximation because without slow down factor in the orbit direction in relation to the national coordinate system the real geometry is close to a parallel projection.

Terrain dependent RPCs: The relation scene to object coordinates can be approximated based on control points by a limited number of the polynomial coefficients shown in formula 1. The number of chosen unknowns is quite dependent upon the number and three-dimensional distribution of the control points. Just by the residuals at the control points the effect of this method cannot be controlled. Some commercial programs offering this method do not use any statistical checks for high correlations of the unknowns making the correct handling very difficult. A selection of the unknowns may lead to the three-dimensional affine transformation.

3.2 Original Images

The solutions for geometric correct image orientation of original space images are not new, at first they have been developed for SPOT images. In the Hannover program BLASPO, the image geometry is reconstructed based on the given view direction, the general satellite orbit and few control points. Based on control points the attitudes and the satellite height are improved. The X- and Y-locations of the projection line are fixed because they are nearly numerical dependent upon the view direction. In addition two additional parameters for image affinity and angular affinity are required. For these 6 unknowns 3 control points are necessary. More additional parameters can be introduced if geometric problems exist. Only for scenes with totally unknown orientation the full sensor orientation with 6 orientation elements will be adjusted together with necessary additional parameters. This requires a good vertical distribution of control points; for flat areas the full orientation cannot be computed. Other solutions do use the full given sensor orientation together with some required correction parameters. On the other hand sometimes no pre-information will be used with 3D-affine transformation, DLT and terrain dependent RPCs (see above). Like with the solution for images projected to a plane with constant height, more control points with a good three-dimensional distribution are required if the existing sensor orientation information will not be used. The orientation of the original images can be made also with rational polynomial coefficients (RPCs) based on the direct sensor orientation. It has to be improved by means of control points leading to bias corrected RPC solution (see above)

In general the orientation of original images with approximations is more difficult like the orientation of images projected to a plane with constant height because by the projection some geometric characteristics are respected.

4. COMPARISON OF IMAGE ORIENTATION

4.1 IKONOS

Several IKONOS scenes have been used. With good control points – well defined in the image and accurate – sub-pixel accuracy can be reached without problems. Often the accuracy is limited by the quality of the control points. By sensor oriented RPC or geometric reconstruction the orientation is possible without control points just based on the direct sensor orientation. Dial and Grodecki, 2003 are reporting upon circular error on 90% probability level (CE90) of 10.1m. The CE90-value has to be divided by 2.3 for a transformation to the standard deviation of the horizontal ground coordinates. CE90 of 10.1m corresponds to the standard deviation of the X- and the Y-coordinates SX and SY of 4.3m. Own results confirmed this level, but often the accuracy is limited by missing knowledge of the national datum.

Experiences with terrain dependent RPC-solution available in commercial software was very disappointing. The scene orientation by a polynomial solution just based on control points and without any use of the existing approximate orientation information cannot be controlled by the discrepancies at the check points. The commercial software did not include any check and warning about high correlation of the orientation unknowns, so independent check points resulted in discrepancies up to 50m even not extrapolated out of the frame of the control points. This solution should never be used – it is an absolute unserious method.

The other orientation methods have been compared in different areas. As example the results achieved in a flat and in a very mountainous area are shown.

	geometric reconstruction		3D-affine		DLT	
GCP	SX	SY	SX	SY	SX	SY
0	2.83	3.80	-	-	-	-
1	1.19	0.94	-	-	-	-
2	1.41	0.90	-	-	-	-
4	1.20	0.90	7.06	4.95	-	-
6	1.02	0.86	1.72	0.86	1.07	1.16
10	1.06	0.94	1.33	1.00	1.35	0.97
25	*1.07*	*0.85*	*0.98*	*0.75*	*0.94*	*0.82*

Table 2: orientation of IKONOS, New Jersey (flat area) root mean square discrepancies at independent check points [m] dependent upon number of ground control points (GCP) – 25 GCP = discrepancies at control points

Table 2 shows the results of the IKONOS scene orientation in the area of New Jersey. For this scene no sensor oriented RPCs are available. The height values are varying only between 30.5m and 49.5m. The incidence angle (nadir angle from scene centre to sensor) of 27.3° has limited the accuracy because of not very precise height information. For the geometric reconstruction it is not important if the area is flat or mountainous while this is of dominating influence for the orientation methods not using any known orientation information. Even based on 10 three-dimensional well distributed control points the unknowns of the 3D-affine transformation are highly correlated.

	1	2	3	4	5	6	7	8
1	1.00	.03	.44	-1.00	.00	.00	.00	.00
2	.03	1.00	-.19	-.03	.00	.00	.00	.00
3	.44	-.19	1.00	-.44	.00	.00	.00	.00
4	-1.00	-.03	-.44	1.00	.00	.00	.00	.00
5	.00	.00	.00	.00	1.00	.03	.44	-1.00
6	.00	.00	.00	.00	.03	1.00	-.19	-.03
7	.00	.00	.00	.00	.44	-.19	1.00	-.44
8	.00	.00	.00	.00	-1.00	-.03	-.44	1.00

Table 3: correlation matrix of 3D affine transformation unknowns based on 10 control points (flat area of New Jersey)

The correlation of unknowns 1 and 4 (a1 and a4 in formula 2) and unknowns 5 and 8 are listed as -1.00. That means they are nearly linear dependent. Similar problems exist for the DLT.

The orientation of this scene without control points reaching 2.8m and 3.8m is very precise. The geometric reconstruction with 1 control point has similar accuracy like with a higher number of control points. Of course with just few control points it is dominated by the individual point discrepancies. The 3D-affine transformation is usable starting with 6 GCPs but is not as accurate like the geometric reconstruction. The DLT needs at least 6 GCPs. The good results of the DLT even with just this minimal number of 6 GCPs are a random result which cannot be confirmed by other data sets. Usually with 3D-affine transformation better results like with DLT has been reached.

The New Jersey scene has been taken with the "forward mode" – it was scanned against the movement in the orbit. This is respected by the geometric reconstruction by the Hannover program CORIKON, but by theory it should have an influence for 3D-affine transformation and DLT. But the differences in the object heights are so small that there is no remarkable effect.

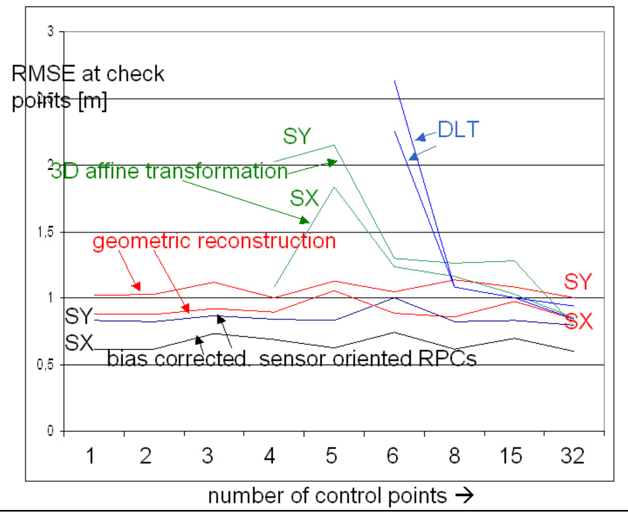

Fig. 5: orientation of IKONOS, Zonguldak (mountainous); root mean square discrepancies at independent check points as function of GCP number - 32 GCPs = discrepancies at GCPs

In the mountainous area of Zonguldak also the sensor oriented RPC have been available. With height variation of the control points from 6m up to 440m quite different conditions for the approximate orientation methods are given.

The best results have been achieved with the sensor oriented RPCs followed by the geometric reconstruction. The discrepancies generated by the 3D-affine transformation are clearly higher. The Hannover program TRAN3D gave some warnings because of high correlation values for the DLT-method based on 6 control points. The unrealistic root mean square discrepancies at the control points of 2cm and 8cm are caused by the poor over-determination – 6 control points are giving 12 observations and the DLT-method has 11 unknowns. By this reason the not so bad discrepancies at the check points have been a surprise. But this is just a random result; if just 1 control point is exchanged with a neighboured point, the discrepancies at the check points have been in the range of 4m. If all control points are used, it is possible to include more unknowns in the geometric reconstruction. With additional 2 orientation parameters and 2 additional parameters for the orientation dependent upon the location in the scene, the geometric reconstruction went down to RMSX=0.48m and RMSY=0.46m.

Randomly the 3D-affine transformation has been used with 4 control points well distributed in X and Y and with 55m difference in height (figure 6). But the control points are nearly located in a tilted plane. Because of the missing over determination no discrepancies at control points are shown, but the discrepancies at independent check points went up to 56m. The Hannover program TRAN3D gave a warning because of high correlation of the unknowns; in standard commercial programs such a warning is not given.

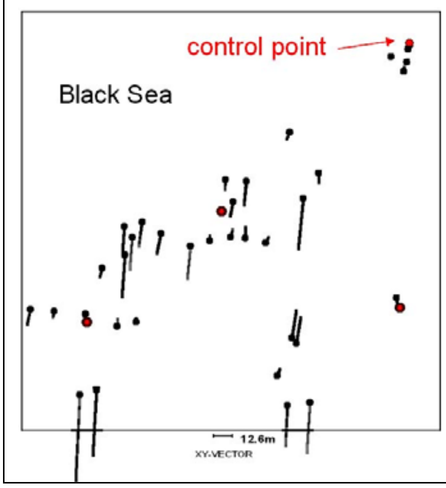

Fig. 6: 3D-affine transformation with 4 GCP describing nearly a tilted plane

at checkpoints:
RMSX= 1.9m
RMSY= 18.5m

The bias corrected RPC solution as well as the geometric reconstruction is computing as first step the terrain relief correction. After this, a two-dimensional transformation to the control points is required. In all cases with given reference height in the metadata file no geometric improvement has been reached by a transformation against a simple shift in X and Y. Only old data sets without the information of the reference height could be improved by an affine transformation after terrain relief correction.

4.2 QuickBird

A QuickBird Standard Imagery (original image) from the area of Atlantic City, New Jersey with maximal heights of 19m, has been oriented based on control points determined by automatic matching of large scale aerial orthophotos and the QuickBird image (Passini, Jacobsen 2004). For the orientation of the original image in the Hannover program BLASPO additional parameters were required to fit the image geometry to 25 control points. The root mean square discrepancies at 355 independent check points were with RMSX=0.69m and RMSY=0.72m close to the ground sampling distance of 63cm. An orientation of the original image by 3D affine transformation could not fit to the scene geometry. Even with the extended 3D affine transformation with 14 unknowns (formula 4) at 380 control points only RMSX=5.66m and RMSY=3.68m have been reached. Neighboured points are strongly correlated with r=0.82 for X and Y. Corresponding to this the relative standard deviation for distances up to 300m is $RMSX_{rel}$=0.82m and $RMSY_{rel}$=0.57m. The DLT transformation reached with 380 control points only RMSX=9.83m and RMSY=8.81m.

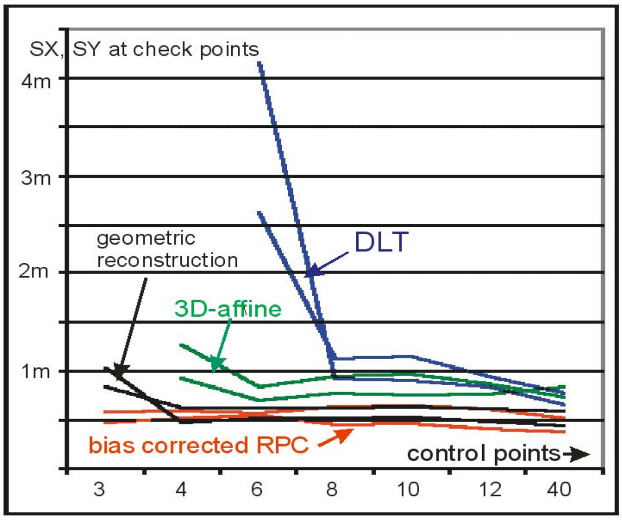

Fig. 7: orientation of QuickBird, Zonguldak (mountainous); root mean square discrepancies at independent check points as function of GCP number - 40 GCPs = discrepancies at GCPs

In the area of Zonguldak, with the same control points like used for IKONOS, a QuickBird OR Standard Imagery (image projected to plane with constant height) has been oriented (figure 7). The general trend of the orientation accuracy is the same like for IKONOS (figure 5) but on an absolute higher accuracy level because of the higher resolution with 0.62m GSD. In relation to the ground resolution with 0.8 up to 0.9 GSD a similar accuracy has been reached. The bias corrected RPC solution as well as the geometric reconstruction requires after the terrain relief correction a two-dimensional affine transformation to the control points. With a simple shift based on all control points the Hannover program RAPORI reached at the control points RMSX=1.64m and RMSY=0.70m. With affine transformation this was reduced to RMSX=0.38m and RMSY=0.55m. The same experience has been made with other QuickBird scenes. The results based on the bias corrected RPC solution are very close to the results reached by geometric reconstruction.

The 3D affine transformation, as well as the DLT requires 2 control points more like the minimum to achieve acceptable results, but nevertheless both solutions did not reach the same accuracy level like the both strict solutions.

4.3 OrbView-3

OrbView-3 is the latest launched optical satellite having a GSD of 1m or better. It is a low cost system, having no TDI (see above) and instead of this staggered CCD-lines. The fact of 2m projected pixel size on the ground, but 1m GSD is reducing the image quality slightly. So the control point measurement was a little more difficult. But nevertheless edge detection did not show a lower effective resolution than 1m, but this can be influenced by an edge enhancement.

A stereo model of original images has been investigated in the area of Zonguldak using the same control points like for IKONOS and QuickBird described before. One scene has been scanned from East to West and the other reverse. As it can be seen in figure 8, the first and the last scan line are not parallel, so in advance problems in orientation with 3D affine transformation and DLT have been expected.

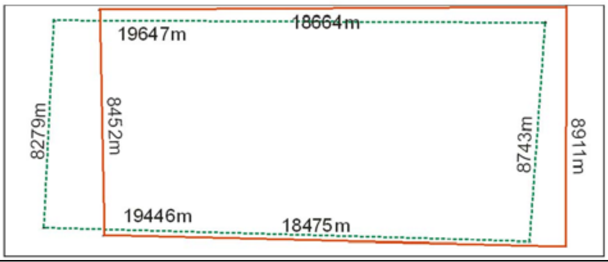

Fig. 8: area covered by OrbView-3 images, Zonguldak

The 3D-affine transformation resulted for the first scene in RMSX=6.71m, RMSY=11.95m and for the second scene in RMSX=8.06m and RMSY=21.16m. This cannot be accepted for images with 1m GSD. Figure 9 shows very clear systematic effects for the second scene; for the other scene it is similar. The original images are not rectified to the ground like IKONOS Geo and QuickBird OR Standard. So the varying image scale is still available in the original image.

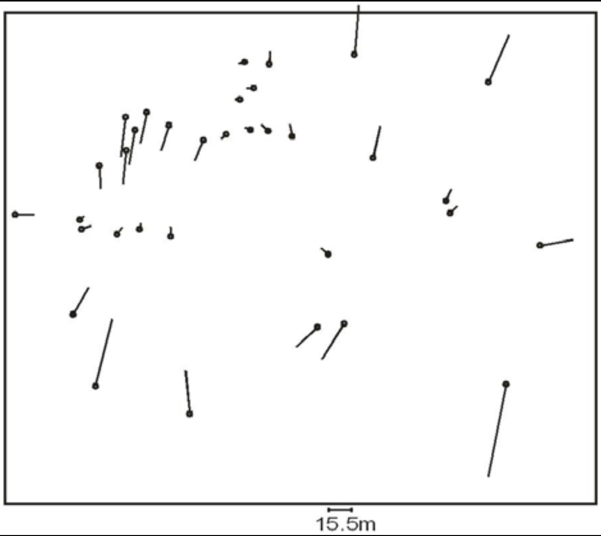

Fig. 9: discrepancies at control points, 3D-affine transformation OrbView-3 second scene

With the extended 3D affine transformation (formula 3) the results have been improved only slightly for the both scenes to RMSX=5.14, RMSY=7.72m and RMSX=6.69m, RMSY=14.89. Again there are clear systematic effects caused by the image geometry described above. By this reason 2 more unknowns have been introduced into the extended 3D affine transformation (formula 4) and this reduced the discrepancies at the control points to RMSX=3.28m, RMSY=1.90m and RMSX=1.56m, RMSY=2.63m what's quite better like before but still not optimal. Of course the model could be extended more, but even for 14 unknowns, 7 three-dimensional well distributed control points are required and this is a too high number for the operational orientation of space images. The relative standard deviation up to distances of 600m was $RMSX_{rel}$=1.0m and $RMSY_{rel}$=1.4m. This indicates the pointing accuracy being for the same points larger for OrbView-3 than for IKONOS having also 1m GSD.

The DLT was leading to RMSX=4.98m, RMSY=7.80m and RMSX=7.69m, RMSZ=11.79m, this result cannot be accepted for 1m GSD. Also because of the high correlation of the unknowns, listed with values up to 1.000, that means exceeding 0.9995, this mathematical model is not usable for the orientation of original space images.

	first scene		second scene	
	RMSX	RMSY	RMSX	RMSY
3D affine	6.71	11.95	8.06	21.16
extended 3D affine	3.28	1.90	1.56	2.63
DLT	4.98	7.80	7.69	11.79
RPC without control points	8.37	8.56	3.58	-13.61
RPC shift	1.55	1.57	2.21	2.09
RPC affine	1.54	1.26	1.68	1.89

table 3: orientation of OrbView-3, Zonguldak (mountainous); root mean square errors at 34 control points [m], only RPC without control points is showing the mean discrepancies

The accuracy of the direct sensor orientation is named in the header files as CE90 with 32.98m and 33.00m for the used OrbView-3 images; this corresponds to a standard deviation of 14m for the coordinate components. The achieved results listed as "RPC without control points" in table 3 are better. The bias corrected RPC solution could be improved after transformation to the image plane in the Hannover program RAPORIO by two-dimensional affine transformation against a simple shift. The average root mean square discrepancy of 1.6m has not reached the GSD level, but nevertheless it is below the pixel size projected to the ground.

5. CONCLUSION

The orientation approximations 3D-affine transformation and DLT do not lead to sufficient results with the more complex geometry of original space images. They only can be used for the orientation of images projected to a plane with constant height like IKONOS Geo and QuickBird OR Standard or QuickBird Standard. By the transformation of the original images to a plane with constant height several details of the image geometry are respected and by the orientation only the terrain relief correction has to be made in addition to the bias determination and for this often the approximate solutions are sufficient. They are not using any of the available orientation information, so also the view direction has to be determined and this is only possible with height differences of the control points. For sufficient results 2 control points more than the minimum is required – 6 GCP for the 3D affine transformation and 8 for DLT. But even with such a number of control points they are not so accurate like the rigorous solution of bias corrected RPC solution or geometric reconstruction.

With bias corrected RPC solution and geometric reconstruction the orientation of IKONOS and QuickBird scenes is possible with sub-GSD accuracy. For IKONOS after terrain relief correction only a two-dimensional shift to the control points is required while QuickBird and OrbView-3 needs a two-dimensional affine transformation.

In general there is no justification for the limitations of the approximate solutions; the rigorous orientation methods can solve the geo-reference with a smaller number and not so good distributed control points. The missing warnings of commercial programs handling 3D affine transformation, DLT and terrain related RPCs make it difficult to guarantee reliable results based on the approximate orientation solutions. There is also no justification for the loss of accuracy caused by these methods.

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