

ORIENTATION OF HIGH RESOLUTION OPTICAL SPACE IMAGES

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ABSTRACT

High resolution space images like IKONOS, QuickBird and OrbView-3 today compete with classical aerial images. The information contents of the space images can be compared with aerial photos having a scale up to 1:30000, but also the geometric conditions should be on a similar level. For QuickBird and OrbView-3 close to original images as well as images projected to a specified object surface are available.

The different orientation methods like bias corrected Rational Polynomial Coefficients (RPC), geometric reconstruction and approximate solutions like 3D affine transformation and its extension, DLT and terrain dependent RPCs are investigated. The strict solutions, bias corrected sensor oriented RPC and geometric reconstruction, guarantee accurate orientation with the smallest number of control points and the highest flexibility of control point distribution. The results of terrain dependent RPC orientation cannot be controlled and such commercial solutions only can be refused. The DLT requires a higher number of well distributed control points and the results are only acceptable for IKONOS Geo, while the 3D affine transformation is sufficient for IKONOS Geo. For the large QuickBird scenes the 3D-affine transformation has to be extended for parameters taking care for not parallel view direction. A further extension is required for the handling of close to original images like QuickBird and OrbView Basic. The different orientations are analyzed in detail, including the advantages and disadvantages of original and projected scenes and the comparison of the OrbView Express and Enhanced version.

INTRODUCTION

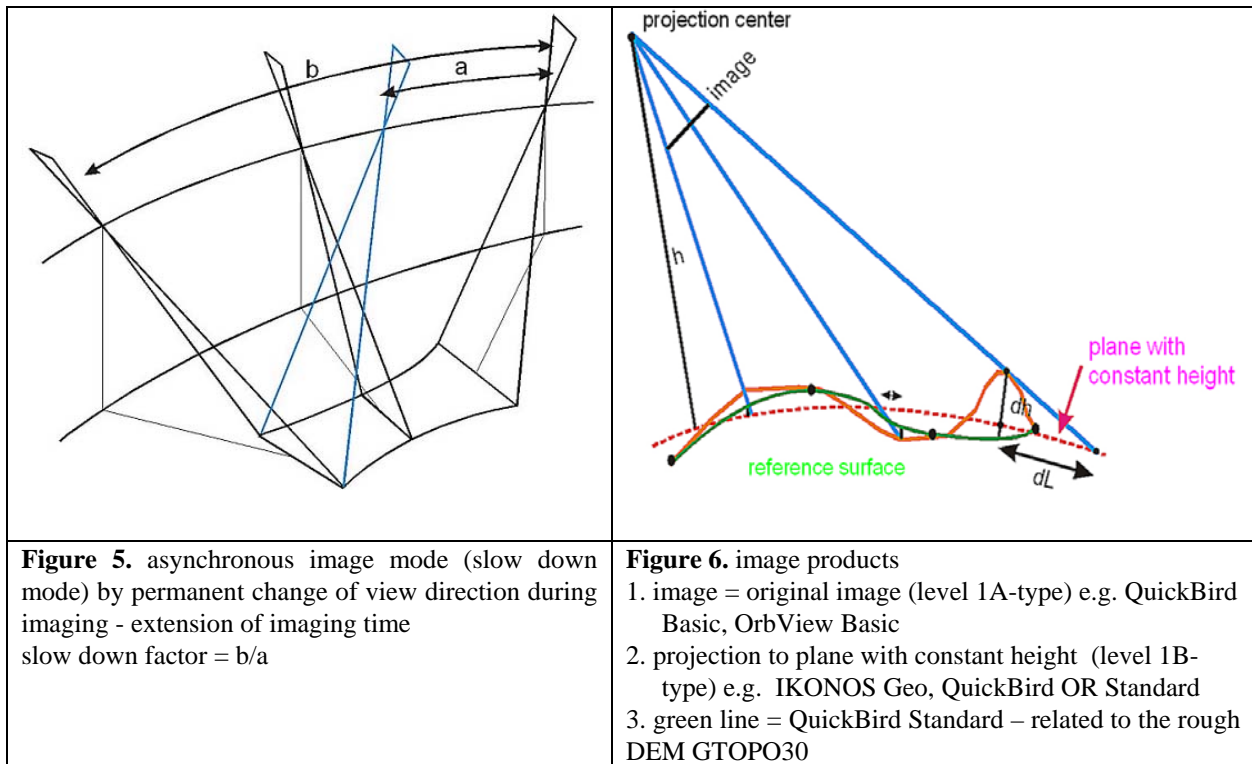
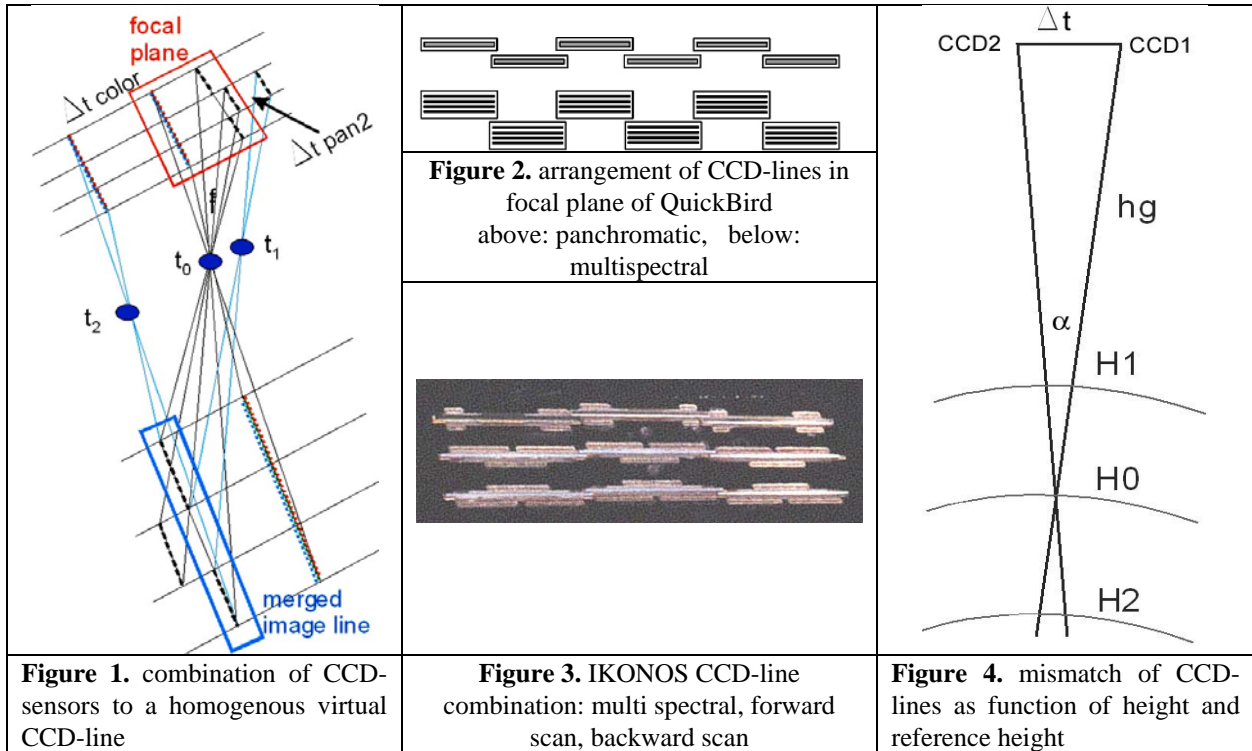
Any geo-referenced image product is based on scene orientation. Today the high resolution satellites are equipped with direct sensor orientation – a combination of a positioning system, like GPS, together with gyros and star sensors. Based on this, any scene orientation is known at least approximate. For some purposes the orientation accuracy of some optical sensors, without improvement by control points, may be accurate enough, but usually an improvement or at least a reliability check with control points is required. The satellite images partially are available as close to original images (level 1A-type according to SPOT) and as images projected to a surface with constant height (level 1B-type according to SPOT), requiring a different orientation process. Sometimes the full orientation information is given as rational polynomial coefficients (RPC), partially as metadata and partially only the view direction from the scene centre is published. The orientation process has to respect the individual situation. Nevertheless also some orientation methods with approximate solutions, not using the available orientation information exist.

USED IMAGE DATA

The very high resolution optical satellite sensors are equipped with a combination of shorter CCD-lines; that means the generated sub-images have to be merged together, using also the inner orientation information (figures 1 up to 4). These merged images are still named original images, because the real original images are not available for the user. The merged images by theory are only correct for the reference height H_0 (figure 4), for another height like H_1 or H_2 , a mismatch of neighbored sub-scenes occur. So for IRS-1C and IRS-1D a mismatch of 1 pixel appears for height differences of 450m against the reference height H_0 , for QuickBird 1 pixel mismatch will appear

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at a height difference of 2.8km, that means it is never important. The orientation is not respecting the merging of the sub-scenes.



The classical optical satellites have had a fixed orientation in relation to the satellite orbit during imaging. Today the imaging satellites are equipped with reaction wheels or control moment gyros, allowing a permanent and precise change of the view direction. So usually the images are not taken in the orbit direction just based on the movement of the satellite, they are scanned directly in relation to the specified ground window. This may be in north-south direction, but for stereo imaging it is often also in east-west direction. IKONOS is equipped with a second CCD-line, allowing also the scan with the TDI-sensor against the movement in the orbit; that means from south to north. Not all satellites are able to generate a sufficient image quality according to the speed of the satellite in the orbit; they are extending the imaging time by the asynchronous or slow down mode (figure 5). So the sampling rate of QuickBird is limited to 6900 lines/sec, with the 0.61m ground sampling distance (GSD) corresponding to 4.2km/sec, but the satellite has a foot print speed of 7.1km/sec requiring a slow down factor of 1.7. OrbView-3 has to use the asynchronous mode also for a sufficient image quality. This asynchronous mode has to be respected by the orientation procedure.

For IKONOS only images projected to a surface with constant height are distributed as Geo-images (figure 6). There is still a confusion with the product names – the expression level 1B is used for QuickBird Basic Imagery (original images) while the expression level 1B traditionally is used for projected images. For QuickBird in addition to the original images (Basic Imagery) and the images projected to a surface with constant height (OrthoReady Standard) also images projected to the rough DEM GTOPO30 (Standard Imagery) are distributed. For OrbView-3 at first only the original images (OrbView Basic), but now also projected images can be ordered as OrbView Geo.

METHODS OF SCENE ORIENTATION

Sensor oriented Rational Polynomial Coefficients (RPC)

The sensor oriented RPC describe the relation between the object coordinates (ground coordinates) and the scene coordinates by the ration of third order 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. They are based on the direct sensor orientation known by the satellite image vendors. This relation has to be improved by means of control points – named also bias corrected RPC solution. Without this bias correction also the level 1B-type images are not orthoimages, like shown in figure 5. A point with a height difference dh against the reference height is displaced depending upon the view direction by dL (figure 6).

$$x_{ij} = \frac{Pi1(X, Y, Z)_j}{Pi2(X, Y, Z)_j} \quad y_{ij} = \frac{Pi3(X, Y, Z)_j}{Pi4(X, Y, Z)_j}$$

$$Pn(X, Y, Z)_j = a_1 + a_2*Y + a_3*X + a_4*Z + a_5*Y*X + a_6*Y*Z + a_7*X*Z + a_8*Y^2 + a_9*X^2 + a_{10}*Z^2 + a_{11}*Y*X*Z + a_{12}*Y^3 + a_{13}*Y*X^2 + a_{14}*Y*Z^2 + a_{15}*Y^2*X + a_{16}*X^3 + a_{17}*X*Z^2 + a_{18}*Y^2*Z + a_{19}*X^2*Z + a_{20}*Z^3$$

Formula 1. rational polynomial coefficients

xij, yij =scene coordinates X, Y = geographic object coordinates Z=height

Reconstruction of imaging geometry

For the scene centre or the first line, the direction to the satellite is available in the metadata. From the given geo-location this direction can be intersected with the orbit of the satellite published with its Kepler elements. Depending upon the location of an image point in the scene, the location of the corresponding projection centre in the satellite orbit and with this, the view direction can be computed. For the location of the individual projection center in the orbit, the slow down factor (figure 5) has to be respected as well as the earth rotation. 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 or it requires the same additional transformation of the computed object points to the control points like the sensor oriented RPCs.

The sensor oriented RPC and the reconstruction of the imaging geometry are using the given direct sensor orientation, that means these methods can reconstruct the scene orientation with the smallest number of control

points. The following described procedures are not using any pre-information about the sensor orientation. Of course this leads to simple handling and simple software solutions, but with the disadvantage of the requirement of a higher number of three-dimensional well distributed control points. For flat areas these simplified methods may fail.

Terrain dependent RPCs

The relation scene to object coordinates can be approximated by a limited number of polynomial coefficients based on control points. The number of chosen unknowns (polynomial coefficients) is quite depending 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 dangerous. A test with a commercial program using this method was leading with IKONOS-data to control point residuals below 1m. Even in an area within the range of the control points, at check points discrepancies in the range of 50m and outside the range of the control points, even to discrepancies exceeding 500m appeared. This method cannot be controlled; it has to be avoided and it is absolutely not serious. No more details of this method are shown.

Three-dimensional affine transformation

The mathematical model of the three-dimensional affine transformation is a parallel projection. Of course the CCD-line scanner images have perspective geometry in the CCD-line, but the field of view is so small, that in not too mountainous areas this model may be a sufficient approximation of the imaging geometry (Hanley et al 2002). 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-dimensional well distributed control points are required.

$$\begin{aligned} x_{ij} &= a_1 + a_2 * X + a_3 * Y + a_4 * Z \\ y_{ij} &= a_5 + a_6 * X + a_7 * Y + a_8 * Z \end{aligned} \quad \text{Formula 2. 3D-affine transformation}$$

For larger height differences and used asynchronous mode (figure 5), extended formulas, to respect the changing view direction, are available in the Hannover program TRAN3D.

$$\begin{aligned} x_{ij} &= a_1 + a_2 * X + a_3 * Y + a_4 * Z + a_9 * X * Z + a_{10} * Y * Z \\ y_{ij} &= a_5 + a_6 * X + a_7 * Y + a_8 * Z + a_{11} * X * Z + a_{12} * Y * Z \end{aligned} \quad \text{Formula 3. extended 3D-affine transformation}$$

For the handling of original images a further extension has been made to respect also the scale change in the scene (formula 4).

$$\begin{aligned} x_{ij} &= a_1 + a_2 * X + a_3 * Y + a_4 * Z + a_9 * X * Z + a_{10} * Y * Z + a_{13} * X * X \\ y_{ij} &= a_5 + a_6 * X + a_7 * Y + a_8 * Z + a_{11} * X * Z + a_{12} * Y * Z + a_{14} * X * Y \end{aligned} \quad \text{Formula 4. extended 3D-affine transformation for original images}$$

Direct Linear Transformation (DLT)

The mathematical model of the DLT is perspective geometry including also the determination of the inner orientation. Like the 3D-affine transformation this is an approximation because without asynchronous mode, in the orbit direction in relation to the national coordinate system the real geometry is close to a parallel projection. 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. There is no justification for the use of this method for the orientation of satellite images having more unknowns as required.

$$\begin{aligned} x_{ij} &= \frac{L_1 * X + L_2 * Y + L_3 * Z + L_4}{L_9 * X + L_{10} * Y + L_{11} * Z + 1} \\ y_{ij} &= \frac{L_5 * X + L_6 * Y + L_7 * Z + L_8}{L_9 * X + L_{10} * Y + L_{11} * Z + 1} \end{aligned}$$

Formula 5. DLT transformation

EXPERIENCES

Projected images (level 1B-type)

In the mountainous area of Zonguldak, IKONOS Geo, QuickBird OR Standard Imagery and other satellite images have been investigated. The height differences of the control points up to 440m are good conditions for the approximate orientations 3D affine transformation and DLT. The same control points, determined by GPS survey, have been used for both described scenes as well as for the orientation of OrbView-3 images mentioned later.

Several IKONOS Geo scenes, also in other areas, have been used. With good control points – well defined in the image and accurate – sub-pixel accuracy can be reached without problems. In most cases 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 as orientation accuracy without ground control. 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 about the exact national datum. For more precise and reliable orientation, control points are required.

The orientation of level 1B-type images based on sensor oriented RPC and the geometric reconstruction will be done in 2 steps. At first the point positions are corrected for the individual height location in relation to the reference height (named terrain relief correction) (correction by dL – figure 6) and after this a two-dimensional transformation to the control points is required. For IKONOS just a simple shift in X and Y is sufficient, a higher type of transformation is not improving the results. Only old IKONOS scenes, not including the reference height in the metadata, have to be transformed by a 2D-affine transformation. For the other satellites an affinity transformation is required to use the full accuracy potential. By this reason the shown results (figures 7 and 8) are starting for IKONOS with 1 control point and for QuickBird with 3 control points.

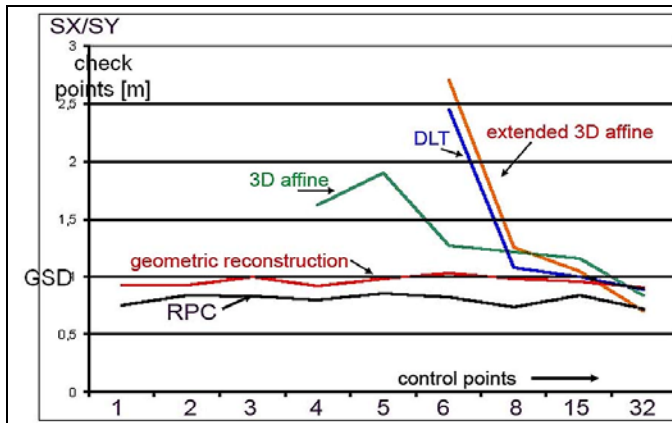


Figure 7. orientation of IKONOS, Zonguldak (mountainous) 1.0m GSD
 root mean square discrepancies at independent check points as function of number of control points
 exception: 32 GCPs = discrepancies at GCPs

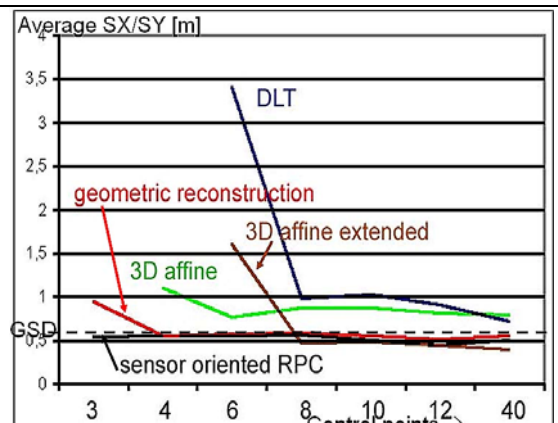
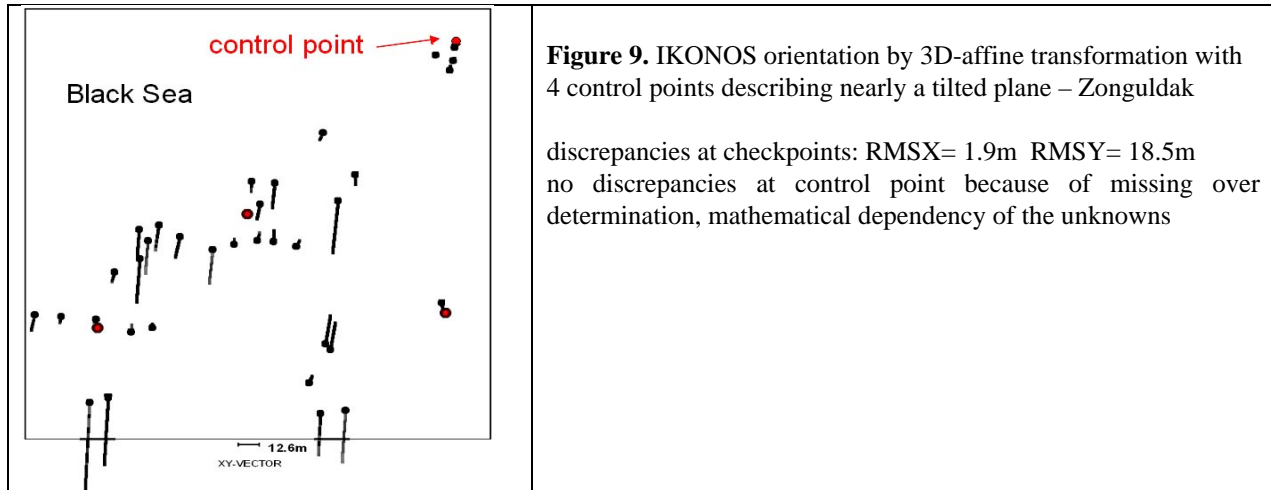


Figure 8. orientation of QuickBird, Zonguldak 0.62m GSD
 root mean square discrepancies at independent check points as function of GCP number
 exception: 40 GCPs = discrepancies at GCPs

. For IKONOS and QuickBird with bias corrected sensor oriented RPCs, as well with geometric reconstruction, sub-pixel accuracy was possible with 1 control point for IKONOS and 4 control points for QuickBird. The approximate solutions 3D affine transformation and DLT require at least 2 more control points than the theoretical limit. That means, starting with 6 well distributed control points the 3D affine transformation and starting with 8 well distributed control points the DLT results are reliable, but the results are not as accurate as the strict solutions. The larger field of view and the asynchronous mode of QuickBird limits even with the highest

number of control points the result to standard deviations of the approximate solutions to 1.3 GSD. Only with the extended 3D affine transformation (formula 3), which is respecting the asynchronous mode and the perspective relation in the CCD-line, starting with 8 control points, at independent check points a sub-pixel accuracy has been reached with QuickBird.

The view direction has to be computed for the approximate solutions 3D affine transformation and DLT based on control points. This is only possible with a variation of the control points in Z, but even just different height values are not enough, the control points have to enclose a volume. So in a random case, the 4 selected control points have been located nearly on a tilted plane causing large discrepancies at independent check points (figure 9). For more than the minimal number of control points such problems can be seen at high correlation of the unknowns, but warnings like shown by the Hannover program TRAN3D are missing in commercial programs.



QuickBird images are also distributed as Standard Imagery; they are projected to the rough DEM GTOPO30. That means the image is more close to the geometry of an orthoimage. But the free of charge available GTOPO30 has a limited accuracy and only a spacing of 30 arcsec corresponding to 926m at the equator. Also the QuickBird Standard Imagery requires a terrain relief correction like the OR Standard with just difference that instead of the height against the reference height level, the height difference against the GTOPO30 has to be used. This has no influence to the geometry, only the handling of QuickBird Standard Imagery requires more organizational steps.

Original images (level 1A-type)

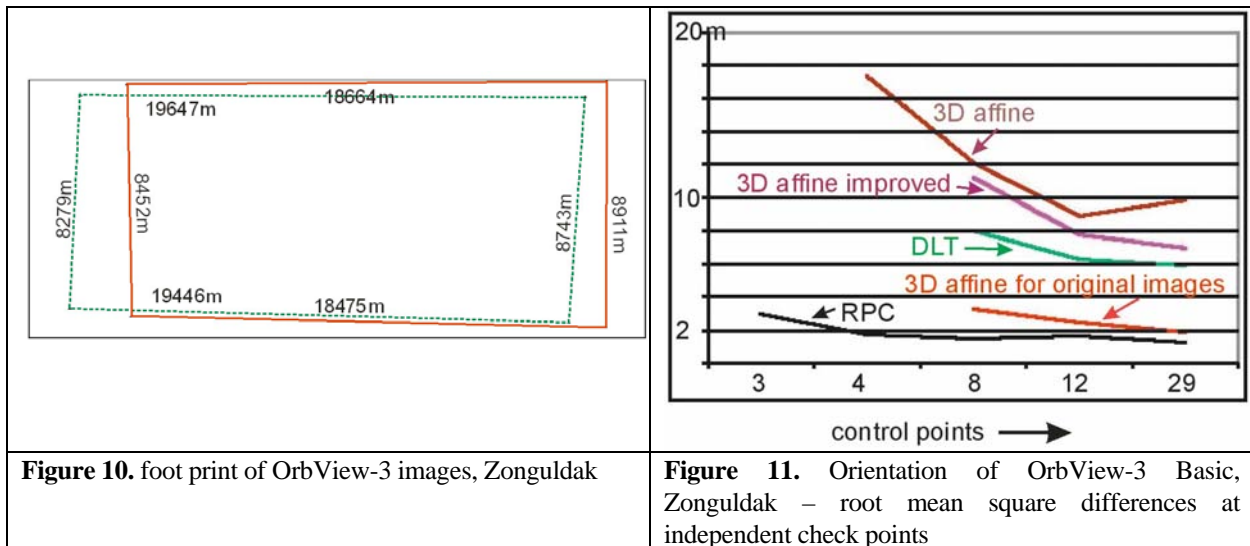
In general similar orientation methods like used for the level 1-B type images can be used for the orientation of original images; but the handling of original images is more difficult – they are not corrected by a change of the orientation during the scene e.g. a permanent line rotation (see figure 10). The level 1B-type images are geo-coded and only have to be corrected for the local height and the general scene orientation which is close to a datum problem. By this reason the basic conditions for the approximate solutions are more difficult for original images.

The scene orientation of original space images by geometric reconstruction is not new. At first it had 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. 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 use the 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 level 1B-type images, 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 sensor oriented RPC. It has to be improved by

means of control points leading to bias corrected RPC solution (see above).

The orientation of OrbView-3 Basic images with approximation methods shows the expected problems. The scene boundaries are not parallel, caused by the permanent rotation of the satellite during imaging (figures 10 and 5) and so the conditions for use of the 3D affine transformation and the DLT are not given. Even with 29 control points the standard 3D affine transformation (formula 2) is limited in the average of the both analyzed scenes to 10m accuracy. Also the extended 3D affine transformation (formula 3) leads only to an improvement of 7m. Only the 3D affine transformation extended for original images (formula 4), having 14 unknowns, comes with root means square discrepancies of 2m for 29 control points close to the result of the sensor oriented RPC solution. The DLT is limited to 6m accuracy. For 1m GSD of Orbview-3 such results cannot be accepted. Only the RPC solution is reaching root mean square differences of 1.3m based on 29 control points; with 4 to 12 control points it is in the range of 1.6m. This is still more like for IKONOS having the same GSD. One of the reasons is the OrbView-3 image itself. OrbView-3 is using staggered CCD-lines – that means, neighbored pixels are over-sampled by 50%; so from the projected pixel size of 2m, images with 1m GSD are generated. This is of course not leading to the same image quality like for images having 1m original pixel size. Using the same points, the control point measurement was more difficult like for IKONOS. The pointing accuracy of the control and check points is indicated by the relative accuracy – the accuracy of one check point in relation to the neighbored. For distances up to 1km for IKONOS the relative accuracy is 0.75m while it is 1.0m for OrbView-3. For QuickBird the relative accuracy is, with the same control and check points of the Zonguldak area, 0.44m corresponding to 0.71 GSD.

The same stereo pair was available as OrbView Express and as OrbView Enhanced. No difference in accuracy of independent check points could be detected.



	BLASPO 14 add. par	BLASPO 6 unknowns	RAPORIO RPCs	3D affine	3D affine improved	3D affine original image	DLT
RMSX [m]	0.65	2.63	0.95	16.1	7.1	4.8	9.9
RMSY [m]	0.66	4.97	0.63	9.6	6.0	2.9	9.1

Table 1. orientation of QuickBird Basic Imagery Atlantic City with 380 control points

Similar experiences have been made with QuickBird Basic Imagery (table 1). The orientation based on geometric reconstruction with the Hannover program BLASPO resulted in root mean square discrepancies at 380 control points of RMSX=0.65m and RMSY=0.66m (Passini, Jacobsen 2004), but this required 16 additional parameters in BLASPO. With the minimum of orientation elements it was restricted to RMSX=2.63m and RMSY=4.97m. The Hannover program RAPORIO reached with sensor oriented RPCs an average accuracy of 80cm or 1.3 GSD. The relative accuracy for distances up to 300m is 0.37m or 0.6 GSD. The limitation of the absolute accuracy to 1.3 GSD may be explained by the used control points. Only the 3D affine transformation extended for

original images (formula 4) came close to this, but it is still outside the tolerance. The results of the standard 3D-affine transformation and DLT solution cannot be accepted.

Usually single images have to be oriented because of the very limited number of available stereo scenes. This has been changed with the stereo satellites Cartosat-1 and ALOS/PRISM equipped with 2 respectively 3 cameras. So in any case stereo combinations are given. Of course these images can be oriented also individually and the model can be computed by intersection, but also a direct 3D-solution is possible. Some Cartosat-1 models have been handled within the frame of the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP). Table 2 shows the result of the orientations.

		RMSX [m]	RMSY [m]	RMSZ [m]
Mausanne	after	2.36	2.13	
	forward	2.04	2.06	
	3D solution	2.10	2.70	3.37
Warsaw	after	1.41	1.50	
	forward	1.35	1.27	
	3D solution	1.33	1.14	1.76
Table 2. root mean square discrepancies at control points of the Cartosat-1 orientation by bias corrected, sensor oriented RPC Mausanne: 32 control points Warsaw: 33 control points				

The achieved results of the RPC orientation of Cartosat-1 are very satisfying in relation to the 2.5m GSD. So in the average for RMSX and RMSY 0.7 GSD have been reached for the handling of single images as well as the model. The results for Z have to be divided by the height to base relation of 1.6 for Cartosat-1, also leading to 0.7GSD for the x-parallax. In the flat Warsaw area, the 3D-affine transformation resulted in a similar accuracy like the RPC solution, but the Hannover program TRAN3D warned for large correlation listed as c=1.00. That means an extrapolation out of the control point volume can lead to large discrepancies. The correlation of the DLT unknowns are even larger. In the Mausanne area height differences between the control points up to 170m are given. So there was no problem with the correlation of the unknowns, but the results can not be accepted. A simple 3D-affine transformation leads to remaining control point discrepancies exceeding 20m. With the 3D-affine transformation for original images (formula 4) the discrepancies are still twice as large like for the RPC orientation.

With the strict solutions of geometric reconstruction and sensor oriented RPCs, the same accuracy level has been reached for the original like for the projected images. In the Zonguldak area the same SPOT 5 images were available as level 1A and also as level 1B leading exactly to the same accuracy.

Achieved results

	level type	GSD	SX/SY	SX / SY [GSD]
ASTER, Zonguldak	A	15 m	10.8 m	0.7
KOMPSAT-1, Zonguldak	A	6.6 m	8.5 m	1.3
SPOT, Hannover	A	10 m	4.6 m	0.5
SPOT 5, Zonguldak	A	5 m	5.1 m	1.0
SPOT 5, Zonguldak	B	5 m	5.1 m	1.0
SPOT HRS, Bavaria	A	5m x 10m	6.1 m	0.7 / 1.1
IRS-1C, Hannover	A	5.7 m	5.1 m	0.9
IRS-1C, Zonguldak	B	5.7 m	9.1 m	1.6
Cartosat-1, Warsaw	B	2.5 m	1.4 m	0.6
OrbView-3, Zonguldak	A	1m (2m pixel)	1.3 m	1.3 *
IKONOS, Zonguldak	B	1.0 m	0.7 m	0.7
QuickBird, Zonguldak	B	0.61m	0.5 m	0.8
Table 3. standard deviation of scene orientation * OrbView-3 1m GSD, 2m projected pixel size				

A view to the standard deviations of ground coordinates based on the orientation of high resolution space images (table 3) shows a homogenous accuracy in units of the ground sampling distance. All listed orientations are based on geometric reconstruction or bias corrected RPC solution. Under usual conditions sub-pixel accuracy has been reached. In the case of KOMPSAT-1 and IRS-1C, Zonguldak, the achieved accuracy was limited by the control point quality. In the case of OrbView-3, the accuracy exceeds the GSD, but it is below the projected pixel size. No significant difference between the orientation of level 1A-type and level 1B-type scenes can be seen. Under operational conditions with well defined control points, pixel- or even sub-pixel-accuracy can be reached.

CONCLUSION

The orientation of high resolution optical space images should be made with a strict solution, using the available information about direct sensor orientation. With the geometric reconstruction and the bias corrected, sensor oriented RPC solution, the best results with the smallest number of control points, has been reached. Using the support of the given scene orientation, the control points may be located even in a plane. Under optimal conditions with the 3D-affine transformation or the extensions of this method, a similar accuracy can be reached, but more and three-dimensional well distributed control points are required. There is no justification for the use of the DLT, its possible use is limited and has only disadvantages. The terrain related RPC-solution, computing a limited number of the polynomial coefficients based on control points, cannot be controlled – it never should be used. As conclusion, no advantage can be seen for using the approximations. If RPC-values are given, the bias corrected RPC-solution should be used, without RPC-values, the geometric reconstruction. Both strict methods require the same number of control points – for IKONOS by theory just one control point, for the other images three control points are required, but never the orientation should be made without over determination. At least one control point more than the minimum is recommended. With well defined and accurate control points, usually pixel- or even sub-pixel accuracy can be reached.

The level 1A-type (original scenes) or 1B-type images (projected to plane with constant height) are leading to similar accuracy. The handling of the level 1B-type images is a little easier.

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REFERENCES

- Dial, G., Grodecki, J., 2003: IKONOS Stereo Accuracy without Ground Control, ASPRS annual convention, Anchorage 2003
- Grodecki, J., 2001: IKONOS Stereo Feature Extraction – RPC Approach, ASPRS annual conference St. Louis
- Hanley, H.B., Yamakawa, T., Fraser, C.S. (2002): Sensor Orientation for High Resolution Imagery, Pecora 15 / Land Satellite Information IV / ISPRS Com. I, Denver
- Passini, R., Jacobsen, K., 2004: Accuracy Analysis of Digital Orthophotos from Very High Resolution Imagery, ISPRS Congress, Istanbul 2004, IntArchPhRS. Band XXXV, B4, pp 695-700