Comparison of Image Orientation by IKONOS, QuickBird and OrbView-3

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Keywords: Orientation, Mathematical Models, IKONOS, QuickBird, OrbView-3

ABSTRACT: The generation of digital elevation models, maps and orthoimages requires the geometric reconstruction of the imaging conditions. This can be done with the exterior orientation of the satellites based on satellite positioning by GPS or a similar system and attitude determination with gyros, supported by star sensors. The accuracy of the exterior orientation is still good, but not accurate and reliable enough for all purposes, so it should be improved by means of ground control points. It is also possible to determine the orientation without any a priori information. The orientation can be based on a strict mathematical model, but also on approximations.

There are general differences of the orientation of original images and images projected to a surface with constant height like IKONOS Geo and QuickBird OR Standard. Projected images are pre-corrected by rotations of the satellite during imaging, so they can be handled also with the approximate solutions, 3D-affine transformation and direct linear transformation (DLT) even if they require a higher number of three-dimensional well distributed control points. But there are still some limitations for large QuickBird scenes caused by the slow down mode with the factor 1.66 for QuickBird. QuickBird is permanently rotating during imaging to reach a ground sampling distance (GSD) in the orbit direction like across and this is not respected by the simplified solutions 3D affine transformation and the DLT, reducing the orientation accuracy.

Original images like OrbView-3 Basic and QuickBird Basic can be handled without problems by the strict solution of sensor oriented RPCs and geometric reconstruction. An extension of the 3D affine transformation to 14 unknowns comes close to the accuracy of the strict solutions but requires quite more and well distributed control points. The results reached with DLT and the 3D affine transformation with 8 unknowns cannot be accepted for original images. In general with OrbView-3 images the usual accuracy below 1 ground sampling distance (GSD) has not been reached. This partially can be explained by the 2m size of the projected pixel on the ground, 50% over-sampled to get 1m GSD. This is still reducing the image quality.

The terrain depending RPCs, computing the coefficients based on control points, should not be used. It cannot be controlled for areas with poor control point distribution and the commercial solutions are not giving any warnings for strong correlations of the unknowns. This method is not serious.

1 INTRODUCTION

Any geo-referenced image product is based on scene orientation. The very high resolution satellite images from IKONOS, QuickBird and OrbView-3 are partially available as close to original images and as images projected to a surface with constant height requiring a different orientation process. In any case approximate orientation information is available based on the direct sensor orientation of the satellite using GPS positioning, gyros and star sensors. Partially the full orientation 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.

2 USED IMAGE DATA

The very high resolution 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 and 2). These merged images are still named original images because the real original images are not available for the user. The orientation doesn’t have to respect this fact. Remaining geometric discrepancies are usually in the sub-pixel range and unimportant for the standard purposes. For IKONOS only images projected to a surface with constant height are distributed as Geo-images (figure 3). 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 is traditionally 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 the projected images can be ordered as OrbView Geo.

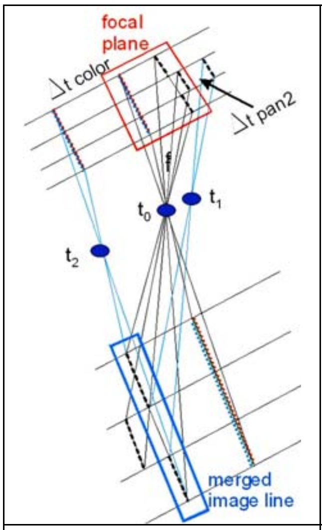

Fig. 1: combination of CCD-sensors to a homogenous synthetic CCD-line

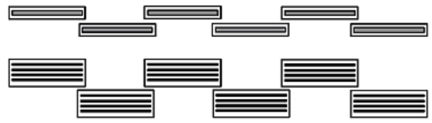

Fig. 2: arrangement of CCD-lines in focal plane of QuickBird above: panchromatic, below: multispectral

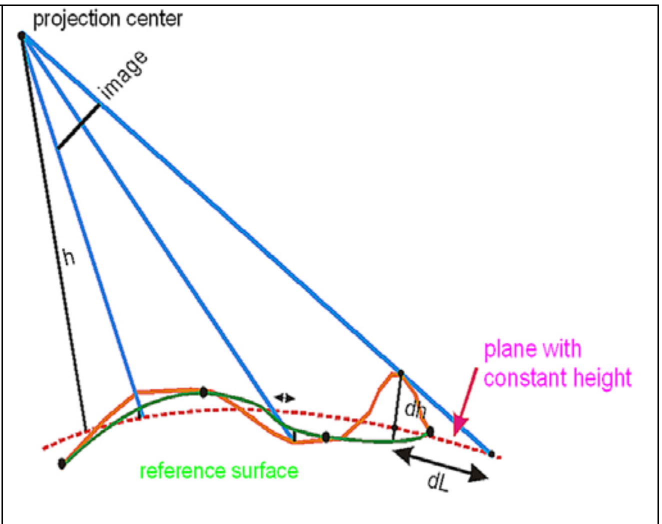

Fig. 3: image products - image = original image;
projection to plane with constant height = IKONOS Geo and QuickBird OR Standard,
green line = QuickBird Standard

3 ORIENTATION OF IMAGES PROJECTED TO SURFACE WITH CONSTANT HEIGHT

3.1 ORIENTATION METHODS

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). 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.

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, the location of the corresponding projection centre in the satellite orbit and 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 or 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 1). At least 4 well distributed control points are required. 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 (Hanley et al 2002).

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

Formula 1: 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 2: extended 3D-affine transformation

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

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

Formula 3: 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 problems with correlation of unknowns 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.

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

Formula 5: DLT transformation

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 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 selection of the unknowns may lead to the three-dimensional affine transformation.

3.2 EXPERIENCES

In the mountainous area of Zonguldak IKONOS Geo and QuickBird OR Standard Imagery have been investigated. The height differences of the control points up to 440m are good conditions for the approximations 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.

After a first very negative test, the terrain dependent RPCs have not further been used. This method is not serious and has to be avoided.

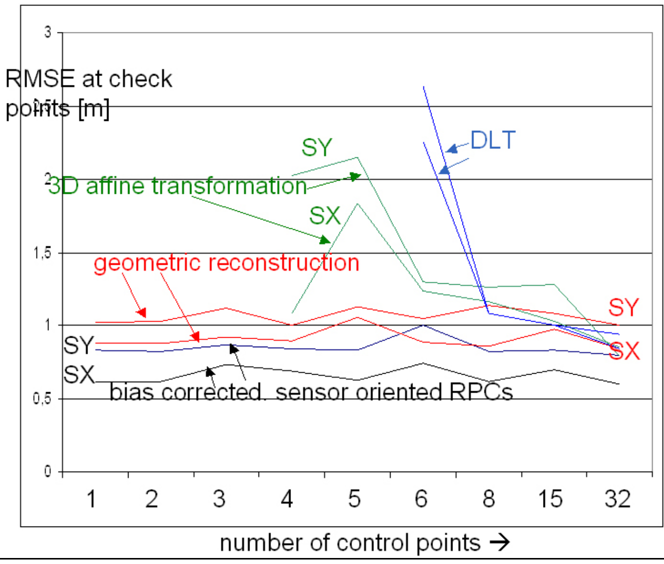	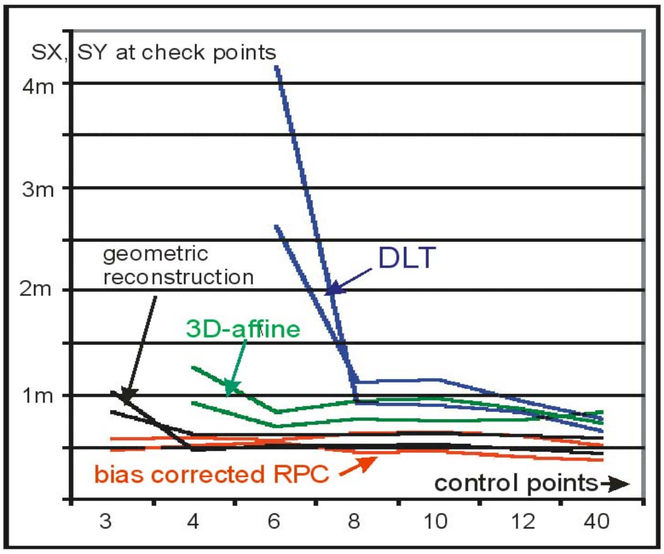
Fig. 4: Orientation of IKONOS Geo, Zonguldak	Fig 5: orientation of QuickBird OR Standard

The results achieved with IKONOS and QuickBird orientations are similar with the exception that QuickBird requires after the terrain relief correction by sensor oriented RPCs or geometric reconstruction (respecting the individual ground height) a 2D affine transformation to the control points while for IKONOS a simple shift is sufficient. So the orientation can start just with 1 control point in the case of IKONOS but with 3 control points in the case of QuickBird. Caused by the ground sampling distance (GSD) of 62cm for QuickBird more accurate results have been reached with this than with IKONOS based on 1m GSD. For both image types with 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 DLT and the 3D affine transformation required 15 control points for IKONOS to reach the level of 1 GSD. In addition it is absolutely necessary to have a good three-dimensional control point distribution. In a random case the control points have been located nearly on a tilted plane causing large discrepancies at independent check points (figure 6). 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.

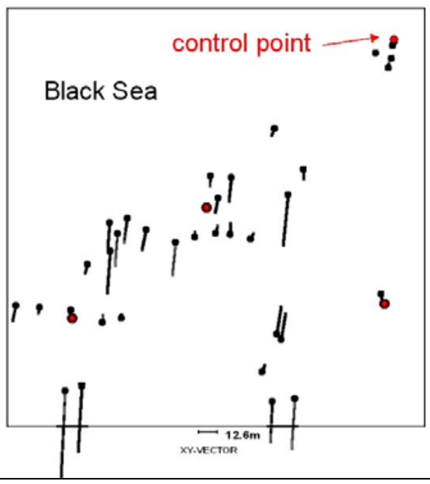	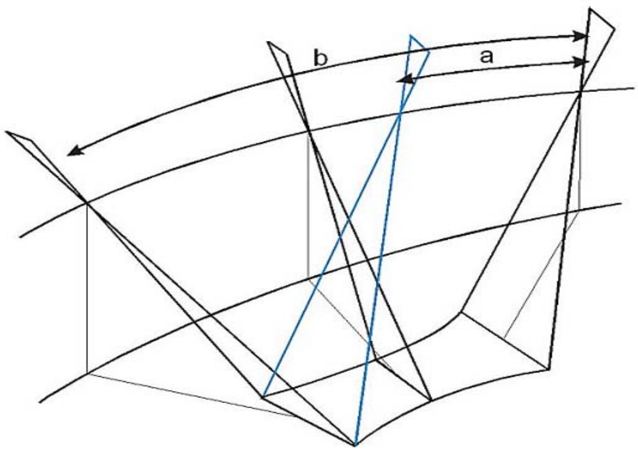
Fig. 6: 3D-affine transformation with 4 GCP describing nearly a tilted plane at checkpoints: RMSX= 1.9m RMSY= 18.5m	Fig. 7: slow down mode b/a by permanent rotation of view direction

QuickBird is limited to a sampling rate of 6900 lines / sec. By this reason during imaging the satellite has to rotate permanently to generate images with 0.62m projected pixel size in the orbit direction (figure 7). A slow down mode with the factor 1.66 has to be used. This causes larger discrepancies between the real scene geometry and the mathematical model of parallel projection used by the 3D affine transformation or the perspective geometry used by DLT. By this reason even with 40 control points both approximations did not reach the same accuracy level like the sensor oriented RPCs or the geometric reconstruction.

QuickBird images are also distributed as Standard Imagery, they are projected to the rough DEM GTPOPO30. That means, the image is more close to the geometry of an orthoimage. But the free of charge available GTOPO30 has only a grid width of 30 arcsec corresponding to 926m at the equator. Also such images have to be improved like the OR Standard Imagery, with the only 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.

These results listed above have been confirmed also with other data sets.

4 ORIENTATION OF ORIGINAL IMAGES

In general similar orientation methods like used for the images projected to a surface with constant height 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 8). The projected 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.

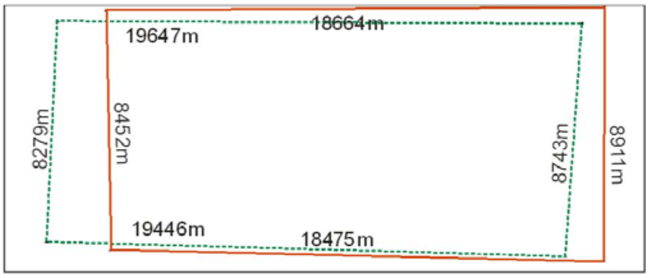

Fig. 8: area covered by OrbView-3 images, Zonguldak

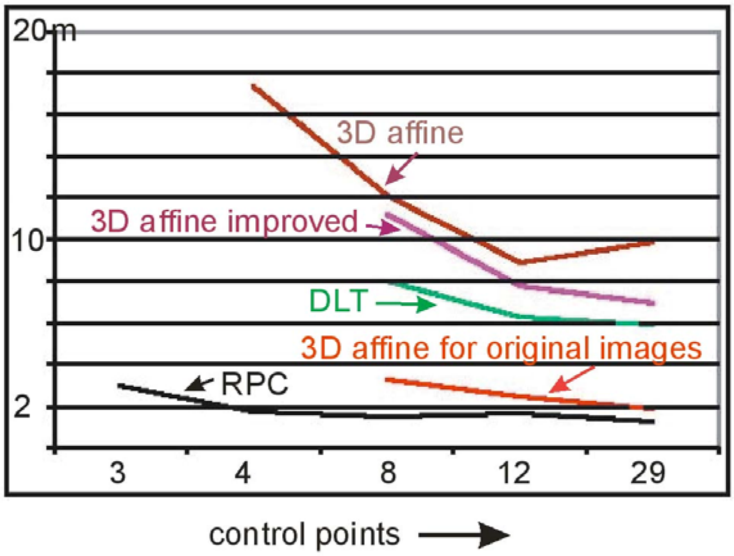

Fig. 9: Orientation of OrbView-3 Basic – root mean square differences at independent check points

The orientation of OrbView-3 Basic images with the approximate orientation methods show the problems like expected. The scene boundaries are not parallel caused by the permanent rotation of the satellite during imaging (figure 8) 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 1) is limited in the average of the both analyzed images to 10m accuracy. Also the extended 3D affine transformation (formula 2) leads only to an improvement of 7m. Only the 3D affine transformation extended for original images (formula 3) having 14 unknowns comes with root means square discrepancies of 2m for 29 control points close to the result of the 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. One of the reasons is the OrbView-3 image. OrbView-3 is using staggered CCD-lines – that means, neighboured pixels are over-sampled by 50%; so from the projected pixel size of 2m, images with 1m GSD can be generated. This is of course not leading to the same image quality like for images having 1m projected pixel size. The control point measurement was more difficult like for IKONOS. The pointing accuracy is indicated by the relative accuracy – the accuracy of one check point in relation to the neighboured. For distances up to 1km for IKONOS the relative accuracy is 0.75m while it is 1.0m for OrbView-3. For QuickBird it is with the same control and check points in the Zonguldak area 0.44m corresponding to 0.71 GSD.

	BLASPO 14 add. par	BLASPO 6 unknowns	RAPORIO RPCs	3D affine	3D affine improve d	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 for this 16 additional parameters have been required 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 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 3) came close to this, but it is still outside the tolerance. The results of the DLT solution cannot be accepted.

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 to exactly the same accuracy

5 CONCLUSION

With the strict solutions of geometric reconstruction and sensor oriented RPCs the orientation of very high resolution space images is possible with just few control points with accuracy in the range of the projected pixel size on the ground. That means for OrbView-3 images a little better than 2 GSD. The same accuracy can be reached with original like for images projected to a specified plane. The approximate solutions 3D affine transformation and DLT do require quite more and three-dimensional well distributed control points and can reach only for IKONOS the same accuracy like the strict solutions. Finally these approximations are not justified. The terrain dependent RPC solution should never be used.

ACKNOWLEGMENTS

Thanks are going to the Jülich Research Centre, Germany, and TUBITAK, Turkey, for the financial support of parts of the investigations and to Prof. Dr. Gürcan Büyüksalih, Zonguldak Karaelmas University and Dr. Ricardo Passini BAE Systems ADR, USA for the support of parts of the investigation.

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