

GEOMETRY OF ORBVIEW-3 IMAGES

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ABSTRACT:

OrbView-3 is in relation to the other very high resolution satellites like IKONOS and QuickBird a low cost system. This does not mean; the accuracy of the object point determination must be less than based on the other. Even because of the not so expensive imaging system, an edge analysis did not indicate a lower resolution than the ground sampling distance (GSD). An OrbView-3 stereo model has been oriented and checked for geometric property. The orientation is possible by means of the sensor related rational polynomial functions which have to be improved by means of control points but also by other methods like 3D-affine transformation and direct linear transformation (DLT). The 3D-affine transformation and the DLT do not use any available pre-information about the sensor geometry, so they have to be based on a higher number of three-dimensional well distributed control points. The different orientation methods are compared and the discrepancies at the control points have been analysed for remaining systematic errors. A covariance analysis and the relative accuracy do indicate the possible accuracy if any systematic effect has been taken into account.

1. INTRODUCTION

OrbView-3 is the latest optical satellite having a GSD of 1m or better. Because of the low cost system differences against IKONOS and QuickBird have to be expected. This starts with the imaging quality influenced by the over-sampled pixels. An edge detection did not show a lower effective resolution than 1m, but this can be influenced by an edge enhancement.

2. IMAGING

OrbView-3 has a ground sampling distance (GSD) of 1m for nadir view. GSD is the distance of the centres of neighbored to the ground projected pixels. The size of the projected pixels is 2m because the sensor is working with over-sampling by the factor 2. This is caused by staggered CCD-lines – instead of one CCD-line OrbView-3 has for the panchromatic band 2 CCD-lines, shifted by $\frac{1}{2}$ pixel against each other. Of course such images have a slightly reduced image quality in relation to sensors having the same size for the GSD and for the projected pixel like IKONOS and QuickBird.

OrbView-3 is limited to a sampling rate of 2500 lines/sec or for the staggered CCD-lines 5000 lines/sec. This sampling rate has been used for the images in the area of Zonguldak (line sampling rate 0.0004). For the flying height of 470km the satellite has a footprint speed of 7.1km/sec. By this reason OrbView-3 has to slow down the angular velocity by the factor $7100/5000=1.42$. This will be reached by a permanent rotation of the satellite during imaging (figure 1). Of course this imaging geometry has to be respected by the used mathematical model.

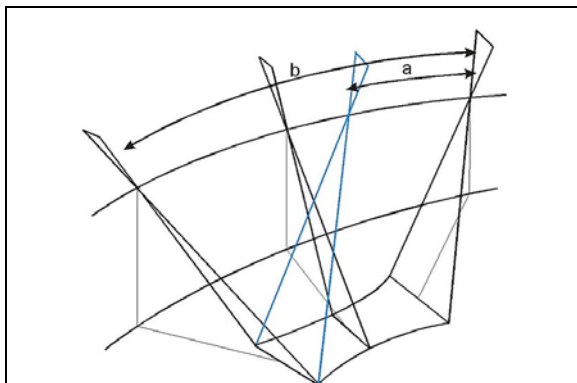


Fig. 1: slow down imaging by permanent change of the view direction slow down factor = b/a

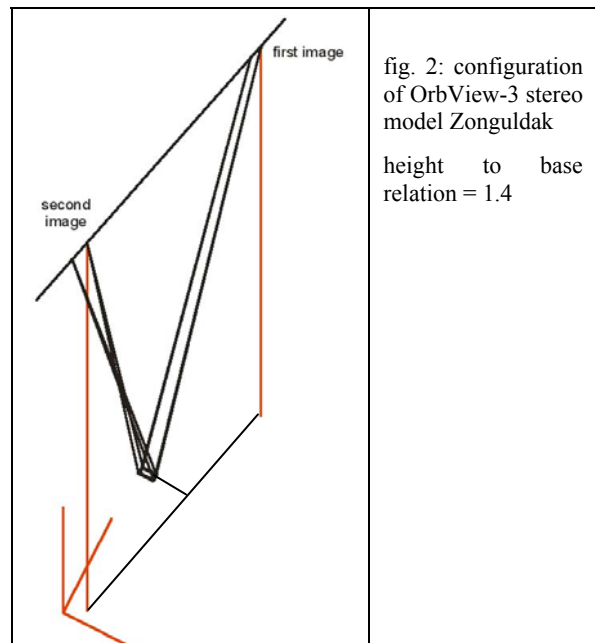


fig. 2: configuration of OrbView-3 stereo model Zonguldak

height to base relation = 1.4

The used stereo model has been scanned at first in east-west direction and in the second scene from west to east. The area is not directly below the orbit, but not too far away (see figure 2), that means, mainly the nadir angle component in the orbit direction has an influence to the

pixel size in north-south direction. The pixel size projected to the ground is directly a function of the nadir angle.

pixel view direction = pixel nadir / cos ² (nadir angle)
pixel across view = pixel nadir / cos (nadir angle)
formula 1: pixel size projected to ground

For the user the ground sampling distance, the distance of the neighbored pixel centres, is appearing as pixel size on the ground. In the scan direction the GSD is depending upon the sampling rate and not the projected pixel size. In the case of a scan across the orbit, the GSD in east west direction is defined by the sampling rate, while the GSD in the north-south direction is defined by the projected pixel size. According to this, in the used area, the GSD in north-south direction is dominated by the nadir angle.

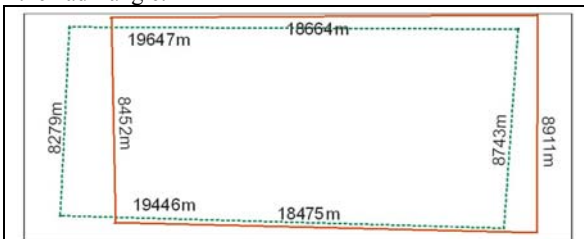


fig. 3: area covered by OrbView-3 images, Zonguldak

Figure 3 shows only the location of the scene corners, in addition the scene size in north-south direction is not changing linear with the X-coordinates. In the centre between the linear interpolation of the scene size in north-south direction and the real size there is a difference of 11m like shown as a sketch in figure 1. In addition the CCD-line changed the direction against north.

3. SCENE ORIENTATION

In the Zonguldak test field, the same control points have been used for the orientation of IKONOS, QuickBird and OrbView-3 scenes. The control points are determined by GPS ground survey and were leading for QuickBird to root mean square discrepancies in the range of 0.5m. The image quality of the OrbView-3 images is slightly less than for the IKONOS scenes having a similar GSD. The slightly reduced image quality of OrbView-3 may be explained by the staggered CCD-lines and the missing transfer delay integration (TDI) – an electronic forward motion compensation. By this reason the exact control point identification for OrbView-3 was more difficult like for IKONOS having the same GSD.

OrbView-3 images are distributed as original images and not as projection to a plane with constant height like IKONOS Geo, so a different mathematical model has to be used. In addition the OrbView-3 geometry is a little different like for the other very high resolution images.

The scene orientation has been made with the simplified methods of 3D-affine transformation, with an improved 3D-affine transformation, the direct linear transformation (DLT) and by using the rational polynomial coefficients distributed together with the images.

3.1 3D-affine transformation

The geometric model of the 3D-affine transformation (Hanley et al 2002) is a parallel projection. Of course the field of view is very small for the very high resolution

space images, so the loss of accuracy by this simplification may be small. In Jacobsen et al 2005 for IKONOS images in the Zonguldak test area with a sufficient number of three-dimensional distributed control points a similar accuracy has been reached like with the more strict solutions. This is not the case for OrbView-3.

$$\begin{aligned} x_{ij} &= a_1 + a_2 * X + a_3 * Y + a_4 * Z \\ y_{ij} &= a_5 + a_6 * X + a_7 * Y + a_8 * Z \end{aligned}$$

formula 2: 3D-affine transformation

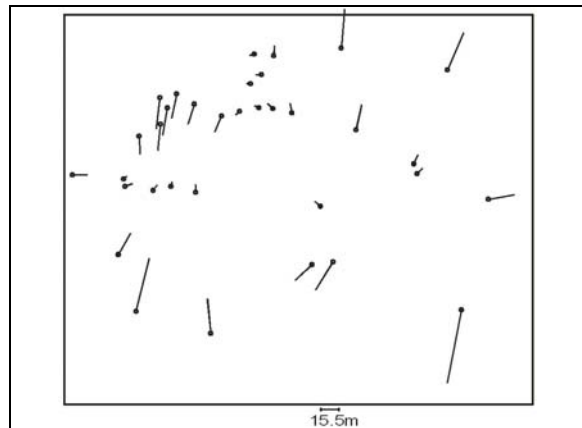


fig. 4: discrepancies at control points, 3D-affine transformation OrbView-3 scene 443940

The 3D-affine transformation resulted for the scene 471890 in RMSX=6.71m, RMSY=11.95m and for scene 443940 in RMSX=8.06m and RMSY=21.16m. This cannot be accepted for images with 1m GSD. Figure 4 shows very clear systematic effects for scene 443940; 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 but not in the rectified images. For the orientation of the images projected to a plane with constant height only the terrain relief correction has to be made by the orientation process and this is not so sensitive for the approximate solution of 3D-transformation.

Also the orientation of QuickBird OR Standard images could not be made with the same accuracy by 3D-affine transformation like based on RPC. QuickBird is also using a slow down factor because of the limited sampling rate and this has influenced the accuracy. With RPCs QuickBird reached RMSX=0.38m and RMSY=0.55m, while the 3D-transformation resulted in RMSX=0.57m and RMSY=0.96m with the same 39 control points. The change of the view direction can be respected as additional unknowns in an improved 3D-affine transformation by the Hannover program TRAN3D.

$$\begin{aligned} x_{ij} &= a_1 + a_2 * X + a_3 * Y + a_4 * Z + a_9 * X * Z + a_{10} * Y * Z \\ y_{ij} &= a_5 + a_6 * X + a_7 * Y + a_8 * Z + a_{11} * X * Z + a_{12} * Y * Z \end{aligned}$$

formula 3: 3D-affine transformation with additional unknowns for changing view direction

The improved 3D-affine transformation reduced the discrepancies at the control points for QuickBird to RMSX=0.37m and RMSY=0.42m – even a better result like achieved with the RPCs, but with 12 transformation parameters. For OrbView-3 there was also an improvement with this extended solution, but not leading to an acceptable result with RMSX=5.14, RMSY=7.72m

and RMSX=6.69m, RMSY=14.89 for the both scenes. Again there are clear systematic effects caused by the image geometry described above. By this reason 2 more unknowns have been introduced:

$$\begin{aligned} x_{ij} &= a_1 + a_2 * X + a_3 * Y + a_4 * Z + a_9 * X * Z + a_{10} * Y * Z + a_{14} * X^2 \\ y_{ij} &= a_5 + a_6 * X + a_7 * Y + a_8 * Z + a_{11} * X * Z + a_{12} * Y * Z + \\ & \quad a_{13} * X * Y \end{aligned}$$

formula 4: 3D-affine transformation with additional unknowns for changing view direction and special image geometry

This extended model has reduced the discrepancies at the control points to RMSX=3.28m, RMSY=1.90m and RMSZ=3.15m, RMSY=1.90m 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 orientation of space images.

3.2 Direct Linear Transformation

$$\begin{aligned} x_{ij} &= \frac{L1 * X + L2 * Y + L3 * Z + L4}{L9 * X + L10 * Y + L11 * Z + 1} \\ y_{ij} &= \frac{L5 * X + L6 * Y + L7 * Z + L8}{L9 * X + L10 * Y + L11 * Z + 1} \end{aligned}$$

formula 5: direct linear transformation

The DLT is based on perspective geometry, solving the interior and the exterior orientation together. Perspective geometry we do have only in the CCD-line, so it is also an approximation like the 3D-affine transformation.

With the Hannover Program TRAN3D RMSX=4.98m, RMSY=7.80m and RMSZ=7.69m, RMSZ=11.79m have been achieved, this result cannot be accepted. 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 high resolution space images.

3.3 Rational Polynomial Coefficients (RPC)

The optical satellites are equipped with a positional system like GPS, gyros and star sensors. This allows an absolute positioning of the images without control points. The orientation information is distributed as RPC, describing the image positions as functions of the ground coordinates X, Y and Z (Grodecki 2001).

$x_{ij} = \frac{Pi1(X, Y, Z)_j}{Pi2(X, Y, Z)_j}$	$y_{ij} = \frac{Pi3(X, Y, Z)_j}{Pi4(X, Y, Z)_j}$
$Pn(X, Y, Z)_j = a_1 + a_2 * Y + a_3 * X + a_4 * Z + a_5 * Y * X + a_6 * Y * Z + a_7 * X * Z + a_8 * Y^2 + a_9 * X^2 + a_{10} * Z^2 + a_{11} * Y * X * Z + a_{12} * Y^3 + a_{13} * Y * X^2 + a_{14} * Y * Z^2 + a_{15} * Y^2 * X + a_{16} * X^3 + a_{17} * X * Z^2 + a_{18} * Y^2 * Z + a_{19} * X^2 * Z + a_{20} * Z^3$	
<p>formula 6: rational polynomial coefficients x_{ij}, y_{ij} = scene coordinates X, Y, Z = geographic object coordinates</p>	

The accuracy of the direct sensor orientation is named in the header files as circular error with 32.98m and 33.00m for the used OrbView-3 images. It is based on 90%

probability level; this can be transformed into the standard deviation of the ground coordinates by dividing it with the factor 2.3 leading to a standard deviation of 14m for the coordinate components. Based on the RPC, the two scenes do have an average discrepancy at the control points, used as check points of MX=8.37m, MY=8.36m and MZ=3.58m, MY=-13.61m. All the values are below the estimated absolute accuracy.

Control points can be used for the refinement of the orientation named as bias corrected RPC solution. In the Hannover program RAPORIO the image positions computed by the RPCs can be transformed by affine transformation to the measured values. The program allows an individual selection of the transformation elements, so it can be reduced also to a simple shift. The adjusted coefficients are checked for correlation, total correlation (a value describing the possibility of compensating the effect of one parameter by the group of all other) and Student test (also named T-test). The not justified parameters are indicated.

$$\begin{aligned} x_{ij} &= a_1 + a_2 * x + a_3 * y \\ y_{ij} &= a_4 + a_5 * x + a_6 * y \end{aligned}$$

formula 7: 2D-affine transformation

For the model 471890 the affine parameters (formula 7) a2 and a3 and for model 443940 a3 and a5 for model 443940 have been shown as not justified. If they are taken out of the solution, the root mean square discrepancies are not changing.

	scene 471890		scene 443940	
	RMSX	RMSY	RMSX	RMSY
3D affine	6.71	11.95	8.06	21.16
3D affine improved	3.28	1.90	3.15	2.88
DLT	4.98	7.80	7.69	11.79
RPC absolute	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
RPC affine, relative	1.17	0.53	1.33	1.47

table 1: root mean square errors at 34 control points [m] test area Zonguldak, only RPC absolute is showing the mean discrepancies

The affine transformation to the control points is only a little better like the simple shift. The shift requires by theory only one control point, in reality at least a second should be used for independent check. The affine transformation requires by theory 3 control points, without the indicated not justified parameters, 2 control points are sufficient. But for testing the justification of the parameters at least 3 control points are necessary.

The results have been analysed with the Hannover program BLAN. This includes a covariance analysis – the computation of the correlation depending upon the distance between the control points. Neighbouring points have been identified as correlated with a correlation coefficient 0.2 up to 0.3. This is also leading to a higher accuracy of one point in relation to the neighbouring one. In table 1 the relative accuracy for points having a

distance below 600m is shown as relative accuracy. A larger discrepancy between the relative and the absolute accuracy indicates remaining systematic errors – identical to a not complete mathematical model.

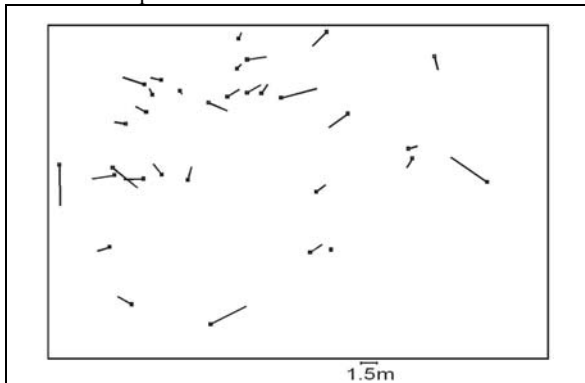


fig. 5: discrepancies at control points – scene 471890 after bias corrected RPC orientation with affine transformation, RMSX=1.54m RMSY=1.26m

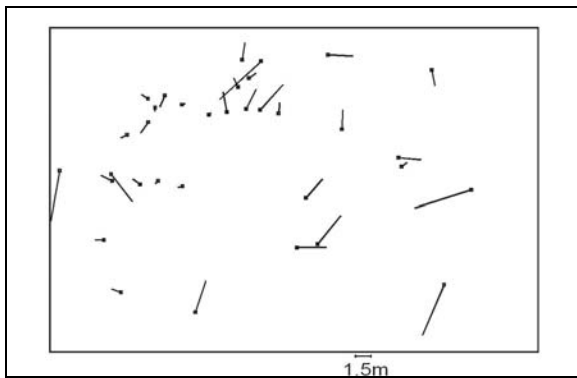


fig. 6: discrepancies at control points – scene 443940 after bias corrected RPC orientation with affine transformation, RMSX=1.68m RMSY=1.89m

The discrepancies at the control points for both OrbView-3 scenes in Zonguldak (figures 5 and 6) do show the same characteristic. On the extreme left and extreme right hand side larger discrepancies are available. A second measurement did not change the result; the control points are well defined and have been checked with IKONOS and QuickBird scenes not justifying the deletion of these points. That means there are still some remaining systematic effects.

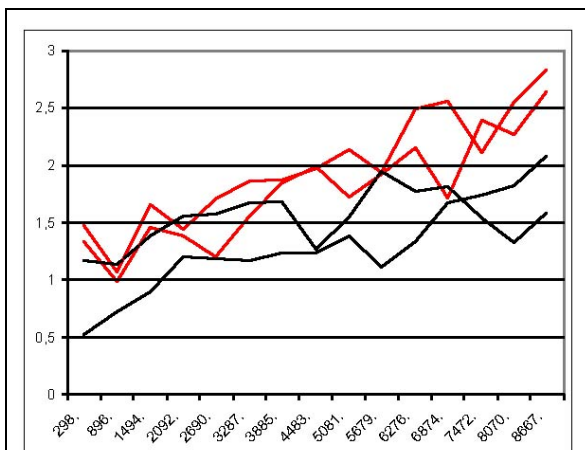


fig. 7: relative standard deviation (vertical) of both scenes for X and Y as F (distance – horizontal) [m]

The relative standard deviation (figure 7) shows for both scenes and both coordinate components a clear trend caused by the systematic part. The remaining systematic effect cannot be removed with a simple improvement; that means it is finally limiting the results.

4. CONCLUSION

The geometry of the original OrbView-3 images does not allow a simplified orientation with the approximate solutions of the 3D-affine transformation and DLT. Even with an extended 3D-affine transformation with 14 parameters it is not possible to reach the same accuracy like with the bias corrected rational polynomial coefficients. But also with the RPCs a sub-pixel accuracy has not been reached. The relative accuracy of short distances is independent upon the remaining systematic effects, but in the average it is also exceeding a pixel. This is caused by the image quality, slightly lower than for IKONOS, resulted by the over-sampling of the staggered CCD lines. A GSD of 1m allows usually a topographic mapping up to a map scale of 1 : 10 000. For this scale a mapping accuracy of 2.5m is sufficient. This requirement is fulfilled with the achieved result.

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