Remote Sensing in Transition, Goossens (ed.)
 ISBN 90 5966 007 2

Orthoimages and DEMs by QuickBird and IKONOS

K. Jacobsen
University of Hannover, Germany

Keywords: orthoimage, DEM, image matching, IKONOS, QuickBird

ABSTRACT: The very high resolution space images from IKONOS and QuickBird are today in a competition to aerial images. The resolution is sufficient for the generation of orthoimages at a scale of approximately 1 : 8000 up to 1 : 5000. Also the geometric potential is satisfying, but it is necessary to use a strict geometric model. Rational functions for the relation of the image to the ground coordinates should not be determined directly based on control points, because this will hide discrepancies at the control points and do not guarantee the correct geometry for areas with poor control point distribution. The geometric models used for CARTERRA Geo-images (IKONOS) and QuickBird Basic Imagery are explained together with the existing problems, especially the problems of the IKONOS images with the information about the view direction which is included also in the rational functions.
The mayor geometric limitation for the production of orthoimages is not the stable geometry of the space images; it is caused by the used existing digital elevation models (DEMs) from the national mapping agencies or from published DEMs like the GTOPO30 or based on SRTM. DEMs also can be generated by automatic image matching of IKONOS and QuickBird Images. Stereo pairs taken in the same orbit do not cause any problem with the generation of DEM's; this is different if images taken with a larger time interval from different orbits shall be handled. The change of the vegetation, but also the change of the length of shadows and other radiometric differences can lead to problems with the image matching.

1 INTRODUCTION

Orthoimages and digital elevation models (DEM) are a basic requirement for several applications. Orthoimages do have the full information contents like the original data and a geometry corresponding to maps. By this reason the economic generation of orthoimages is replacing very often the quite more expensive map production or it is used as a supplement for maps because it is not generalised like the maps. In addition the space images do have the advantage of not being classified like aerial photos in several countries. With the absolute sensor orientation of the IKONOS and QuickBird images for some applications with limited accuracy requirement, no control points have to be used.

DEMs for the generation of orthoimages may be generated by automatic image matching of stereo combinations. The images of a stereo combination must not come from the same orbit, but the imaging conditions should be similar, like the length of the shadows and the situation of the vegetation. But the DEMs may come also from other sources like from other available stereo pairs or from the national map agencies or other general available sources like the GTOPO30 or from SRTM.

2 ORIENTATION OF IKONOS IMAGES

From SpaceImaging (SI) different image products are available, starting with the CARTERRA Geo which is corresponding to a level 1B-product and orthoimages with different accuracy specifications. There is a wide price range for the different products depending upon the type of product, the distributor and if the data are from archive or if they have to be taken. Between the less expensive CARTERRA Geo and the precise orthoimages there is a financial difference in the range of 50 to 120 US$/km² or for a scene of 121km² a difference of 6000 US$ up to 14000 US$.

Table 1. price for IKONOS products per km²

product: CARTERRA	price for North America	price for international	price SI Eurasia
Georectification	7 – 35 $	29 $	18 $
Reference - ortho without control	29 $	73 $	36 $
Map - ortho without control	39 $	98 $	47 $
Pro - ortho with control points	49 $	122 $	59 $
Precision – ortho with control	66 $	149 $	99 $

Caused by the large difference in price, mainly CARTERRA Geo-images are used. A Geo-image is a rectification of the image to a plane with constant height. In the metadata belonging to the image, the view direction for the scene centre is available as nominal collection elevation and azimuth. In the Hannover program CORIKON this is used together with the general information about the satellite orbit to reconstruct the image geometry, that means the view direction for any image position. With the local view direction and a DEM orthoimages or in the case of a stereo pair, a DEM can be created. The absolute sensor orientation has an accuracy in the range of +/-4m up to +/-12m. This may be sufficient for some applications, but very often also a problem with unknown national datum (relation of national coordinate system to WGS84, ITRF) is existing. Especially in developing countries the national datum is not known very precise, it is not published or it may differ from location to location. So very often the datum problem is causing more discrepancies like the absolute sensor orientation itself.

For reaching a higher precision corresponding to the pixel size of 1m, also independent from the knowledge of the national datum, control points are required. An affine transformation of the image positions improved by the height displacement to the control points should be used (Jacobsen 2002b).

Instead of the reconstruction of the Geo-image geometry, rational polynomial coefficients (RPC) distributed by SI can be used. The RPC do describe the relation between the ground coordinates in form of geographic coordinates to the image positions as a relation of a third order polynomial divided by another third order polynomial. So with 80 coefficients the geometric relation can be expressed (Grodecki 2001, 2002). In addition control points have to be used for the exact location of the scene.

RPC can be computed also based on a higher number of control points without information about the sensor model, which is not distributed by SI, but this requires a higher number of well distributed control points. If ground points are computed outside of the area of control points, the RPC based on control points may lead to large errors. This method should be avoided even if it is implemented in some commercial software packages.

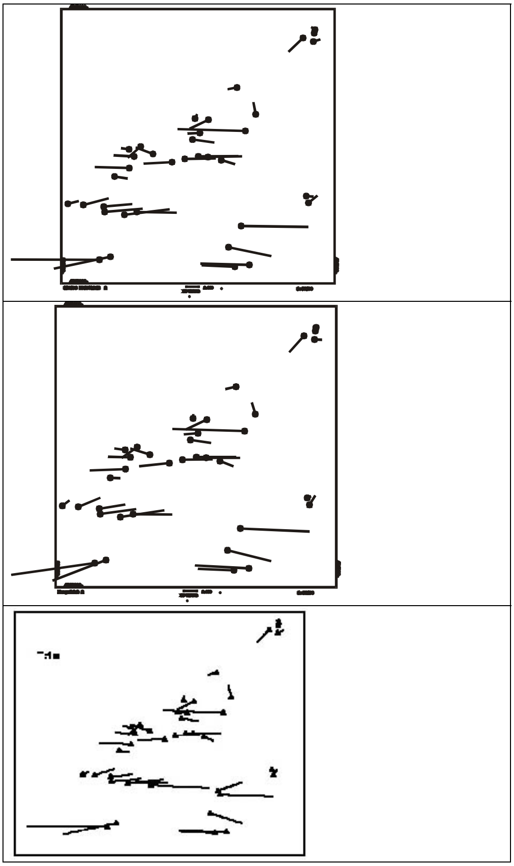

Figure 1. IKONOS Geo, Zonguldak, Turkey, discrepancies at control points:
upper: based on rational polynomial coefficients
center: based on view direction without improvement
lower: PCI satellite modelling

In the area of Zonguldak, Turkey two IKONOS-scenes have been oriented with control points determined by GPS ground survey. For one data set RPC from SI are available, so they could be used for the image orientation with the Hannover program RAPORI. The distribution of the discrepancies can be seen in the upper part of figure 1. A domination of the vectors in the X-direction is obvious. In addition there is a very clear correlation to the point elevation. The same data set has been handled also with the Hannover program CORIKON (see center part of figure 1). If CORIKON is limited to an improvement based on the relief displacement and an affine transformation to the control points, very similar results

Table 2. root mean square discrepancies at the 39 control points of an IKONOS orientation in Zonguldak, Turkey

	RMSX	RMSY
RAPORI, RPC + 6 unknowns	5.20	1.04
CORIKON, reconstruction of geometry + 6 unknowns	5.33	0.86
PCI satellite modelling	5.85	0.82
CORIKON, 8 unknowns	0.85	1.04

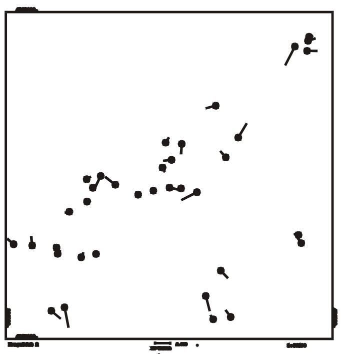

Figure 2. IKONOS Geo, Zonguldak, Turkey, discrepancies at control points – image orientation with adjusted view direction

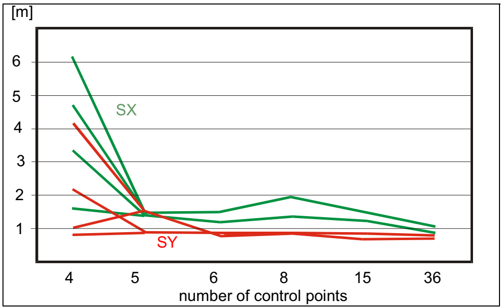

Figure 3. accuracy at independent check points depending upon different number of control points data set: Zonguldak 1 and 2

are achieved. The same discrepancies can be seen at the orientation with the PCI software (Toutin et al 2001) using the satellite modelling.

Quite better results can be reached if also the view direction will be adjusted (last line in table 2 and figure 2 and 3). That means, in this case there is something not OK with the nominal collection azimuth and elevation. Such a clear effect could not be seen with other scenes.

In the case of the data set Williamstown, where the control points have been digitised from the orthophotos of the USGS, no problems with the nominal collection elevation and azimuth could be seen. In addition to the relief displacement even just with a shift to the control points, nearly the same accuracy

Table 3. root mean square differences at 33 control points – data set Williamstown, NJ

	RMSX	RMSY
8 unknowns	1.45 m	0.97 m
5 unknowns	1.47 m	0.99 m
affine transformation	1.51 m	1.00 m
shift (2 unknowns)	1.57 m	1.14 m

could be reached like with 8 unknowns in the orientation. 3 unknowns (collection azimuth and 2 affine coefficients) have had Student test values below 1.0 (see table 3, adjustment with 5 unknowns) and only the shift parameters have been significant. But also the shift has reached just 1.54m in X and –3.69m in Y, that means, the absolute sensor orientation without control points was excellent in this case.

Also with other data sets (Jacobsen 2002 b) similar results have been reached with IKONOS Geo-data, so in general there are no problems with the orientation of the Geo-data. The RPC-information from SI is not required for the precise georeferencing.

3 ORIENTATION OF QUICKBIRD IMAGES

Opposite to SI, from DigitalGlobe (DG) also the level 1A-images from QuickBird are available as "Basic Imagery". They are corrected by the internal calibration and do correspond to distortion free images taken with a CCD-line of 27 552 pixel. The "Standard Imagery" is corresponding to the IKONOS-Geo with the difference that they are not related to a surface with constant height but to the digital elevation model (DEM) GTOPO30 (WEB-location see under references). The GTOPO30 is a world wide DEM of the USGS with a spacing of usually 30" corresponding to a little less than 1km. The accuracy differs depending upon the area. Caused by the rough ortho-rectification to the GTOPO30, the relief displacements of the Standard Imagery is smaller like for the IKONOS Geo. But it makes the reconstruction of the geometry a little more difficult like for IKONOS.

The orientation of the Basic Imagery can be determined with programs handling satellite line scanner images like SPOT, MOMS, IRS, ASTER or others. The image orientation based on the direct sensor orientation (GPS + inertial system + star cameras) are available in an ephemeris and an attitude file. Especially the attitude data, available as quaternions, do give a good overview about a not regular change of the attitudes during the imaging of a scene. Like for IKONOS and SPOT5, the view direction of QuickBird is changing during imaging of a scene – at least a yaw correction will be made to compensate the effect of the earth rotation and the orbit direction

Table 4. root mean square differences of QuickBird orientation at control points

scene	control points	RMSX	RMSY
12450	48	1.08 m	1.22 m
12450	207	1.24 m	1.34 m
12451	55	1.26 m	1.22 m

to reach a scene with lines nearly parallel to the co-ordinate system. IKONOS and QuickBird do have also the possibility to scan the object area against or across the satellite orbit.

With the Hannover program BLASPO, without use of the ephemeris and attitude information, just based on the given "inTrackViewAngle" and "crossTrackViewAngle" together with few additional parameters QuickBird-scenes have been oriented with discrepancies at the control points shown in table 4. The accuracy in the range of 2 pixel is mainly limited by the quality of the control points, digitised from USGS orthophotos and the height information of the USGS DEM

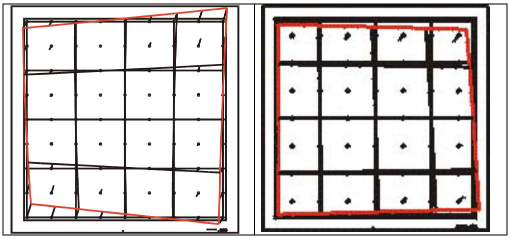

Figure 4. effect of the additional parameters to the scene ("systematic image errors") – QuickBird scenes Phoenix and Atlantic City

The systematic image errors (figure 4) do show the rotation of the sensor during imaging a scene.

4 GENERATION OF DEMS

With a stereo combination digital elevation models can be generated (Jacobsen 2003). But only few IKONOS stereo combinations taken from the same orbit are available in the archive. DigitalGlobe does not achieve stereo models in the standard program.

An IKONOS stereo combination taken with just 12 seconds difference in time, corresponding to a height to base relation of 7.5, has been analysed. The small angle of convergence leads to very similar images, an optimal condition for automatic image matching. So with a standard deviation for the x-parallax of 0.2 pixel excellent results have been reached, corresponding to a vertical accuracy of 1.7m.

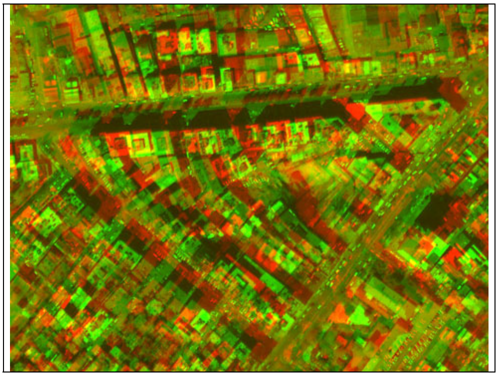

Figure 5. anaglyphic IKONOS stereo sub-scene - has to be looked trough anaglyphic glasses

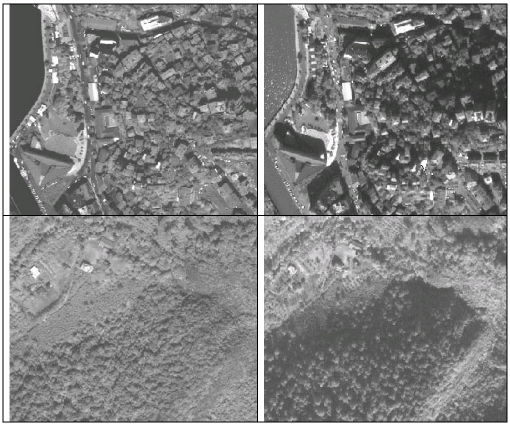

Figure 6. corresponding IKONOS sub-scenes
left: 07/09/02, sun elevation 67.2°
right: 10/11/02, sun elevation 41.5°

In another area two IKONOS scenes imaged at 07/09/2002 and 10/11/2002 have been used for a DEM generation. The results were disappointing. The matching failed totally in the forest area, but also in other parts it was not optimal. Only after strong low pass filtering some results could be achieved. The reason for the problems with the automatic image matching can be seen in figure 6. The change of the sun elevation has caused large differences of the grey values in the mountainous area.

From QuickBird two overlapping scenes taken with 10 days difference in time over suburbs of Phoenix, Arizona have been used. The change of the sun elevation and the vegetation is negligible, so good conditions for the image matching do exist.

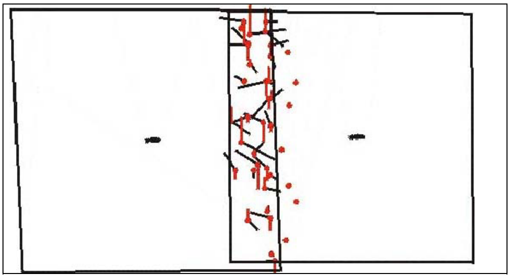

Figure 7. combination of QuickBird images with a height to base relation of 9.1

The automatic image matching was excellent, leading to a vertical accuracy of 4.8m in relation to the USGS DEM, which is also not free of error. This corresponds to a standard deviation of the x-parallax of 0.8 pixel. The average correlation coefficient was in the range of 0.95 and the matching failed only in few limited areas with very low contrast like on roads, sandy areas and few roofs.

5 ORTHOIMAGES

For the generation of orthoimages the image orientation and a DEM is required. As mentioned before, in general there are no problems with the quality of the image orientation. The DEM may come also from other sources.

The human eye cannot see a difference between a photo and a digital image if at least 8 pixel / mm are available. In the case of a smaller number of pixel per millimetre, the image quality is reduced. Corresponding to this, based on the 1m pixel of IKONOS images, orthoimages up to a scale 1 : 8000 and from QuickBird Basic Imagery with 0.6m pixel and a close to nadir view a scale of 1 : 4800 can be generated. Maps and orthoimages should have an accuracy of approximately 0.25mm or for 8 pixel/mm an accuracy of 2 pixel. So for IKONOS 2m is required and for the higher resolution of QuickBird 1.2m.

A discrepancy Δh in the height information of a DEM is influencing the position in an orthoimage ΔL by the relation: $\Delta L = \Delta h * \tan$ (local nadir angle).

In addition to the geometry also the radiometry is important for the orthoimage generation. IKONOS and QuickBird do have the same spectral range (both optics and sensors are produced by Kodak) of 0.45µm – 0.90µm wavelength for the panchromatic images. This is an extended panchromatic range including also the near infrared. Caused by this, a better image contrasts can be reached. In addition both sensors do have a radiometric resolution of 11 bit, allowing an optimal fit to the existing range of grey values.

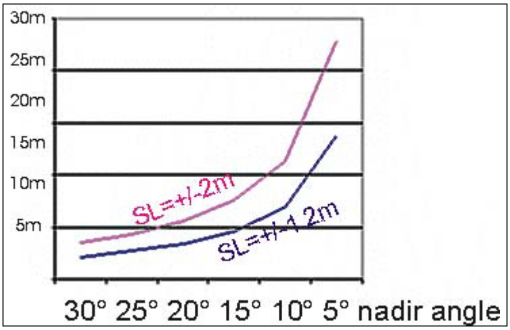

Figure 8. required vertical accuracy depending upon the nadir angle and the standard deviation in location

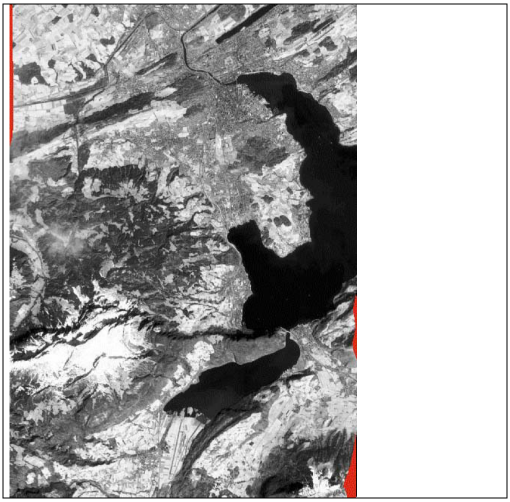

Figure 9. IKONOS-orthoimage red area = shift of corner caused by elevation - upper left = low = shift to right, lower right = high elevation = shift to left

Digital orthophotos from the USGS have been compared with IKONOS- and QuickBird images. In every case the radiometric quality of the high resolution space images was better like for the USGS orthophotos.

Figure 10. left: IKONOS (pixel size 1m
right: USGS DOQQ (pixel size 1m)

Figure 11. left: QuickBird (pixel size 0.64m)
right: USGS DOQQ (pixel size 1m)

6 CONCLUSION

The high resolution space images from IKONOS and QuickBird can be used for the orthoimage generation up to a scale 1:8000 / 1:4800. The image geometry does not cause any problems. For the orientation no special orientation information like rational polynomial coefficients is required from SpaceImaging or DigitalGlobe. Also the generation of orthoimages can be done by the user itself with appropriate software.

The radiometric quality of the space images is usually better like of traditional aerial photos. It is better to order images from the archive with the real information about cloud coverage like to order an individual image acquisition without guarantee of cloud free images. Not only the clouds are creating problems, also the cloud shadows and the haze around clouds.

ACKNOWLEDGEMENTS

Thanks are going to Dr. Gürcan Büyüksalih, Karaelmas University Zonguldak, for the support of the use of IKONOS images in the area of Zonguldak and the Jülich Research Centre, Germany, and TUBITAK, Turkey, for the financial support of the investigation in this area. Thanks are also going to Dr. Ricardo Passini, BAE Systems ADR, Pensauken, NJ, for the cooperation with the IKONOS- and QuickBird-images in the USA.

REFERENCES

Grodecki, J. 2001: Ikonos Stereo Feature Extraction - RPC Approach, ASPRS annual convention, St Louis 2001, on CD

Grodecki, J., Dial, G., 2002. Ikonos geometric accuracy validation. PECORA / ISPRS Commission I, Denver, CO 2002, on CD.

Jacobsen, K., 2001. Automatic matching and generation of orthophotos from airborne and spaceborne line scanner images, Proc. Joint ISPRS Workshop "High Resolution Mapping from Space 2001", University of Hannover, (on CD).*

Jacobsen, K. 2002a: Generation of Orthophotos with CARTERRA Geo Images without Orientation Information, ASPRS annual convention, Washington 2002 *

Jacobsen, K. 2002b: Mapping with IKONOS images, EARSeL 2002, Prague

Jacobsen, K. 2003: DEM generation from satellite data, EARSeL 2003, Ghent

Toutin, Th., Chenier, R., Carbonneau, Y., 2001. 3D geometric modelling of Ikonos Geo images, Proc. Joint ISPRS Workshop "High Resolution Mapping from Space 2001" University of Hannover (on CD).

GTOPO30: http://edcdaac.usgs.gov/gtopo30

Literature marked by * is available at:
http.//www.ipi.uni-hannover.de