HANDLING OF IKONOS-IMAGES from ORIENTATION UP TO DEM GENERATION

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ABSTRACT:

SpaceImaging is not distributing the original IKONOS-images, only a rectification to a plane with constant height is available – the so called CARTERRA-GEO. In addition the sensor model is not published. For the image orientation rational polynomial coefficients (RPC) are available from SpaceImaging, giving the relation of the Geo-images to the ground coordinate system in form of geographic coordinates and the height. The RPCs have to be improved by means of control points. Another possibility is the reconstruction of the imaging geometry based on the available view direction from the scene centre to the satellite (nominal collection elevation and azimuth). If the view ,direction will not be improved, with both methods as well as with the PCI-software using the satellite modelling, approximately the same, but not in any case satisfying accuracy has been achieved. The precise results can be reached if the view directions also will be introduced as unknowns. The orientation methods just based on control points and handling the geometric relation by rational polynomial functions or a 3D-affine transformation (PCI terrain dependent solution) requires a higher number of well distributed control points. Extrapolations out of the volume of the control points may lead to not acceptable discrepancies.

A DEM generation based on 2 IKONOS-images taken with a time interval of two month failed. Only in very limited areas a matching was possible because of quite different shadows and changing of the vegetation. On the other hand a stereo model taken with 12 seconds time interval was leading to excellent results.

The main problem for the generation of orthoimages is caused by the digital elevation models (DEM). DEMs are often not accurate enough, causing a limitation of the possible range of nadir angles.

1. INTRODUCTION

The very high resolution space images are now in a real competition to aerial images. Especially IKONOS images do have a wide spread use for applications formerly reserved to aerial photos.

From an elevation of 680km, the Kodak Space Remote Sensing Camera, Model 1000 of the IKONOS satellite is imaging the object area in the panchromatic band with 13 680 pixels, each covering 0.82m on the ground in the case of a nadir view. Like the pixel size the swatch width of at least 11.2 km is depending upon the view direction which can be changed very fast by rotating the whole satellite. Not the original images are distributed, only derived products are available. SpaceImaging has not published the information about the sensor model.

2. SENSOR GEOMETRY

2.1 Basic Information

The lowest level of an IKONOS image product is the CARTERRA Geo, a rectification of the image to a plane with constant height. It is re-sampled to 1m pixel size independent upon the physical pixel size. Different high level products up to precise orthoimages are also available, but for this, the customer has to deliver also the control point information and the digital elevation model. The precise orthoimages are approximately 6000 US$ up to 14 000 US$ more expensive like the Geo-product. By this reason, usually only the Geo-images are ordered and the customer are producing the higher level products themselves.

IKONOS is a highly agile satellite, it can change the view direction very fast into any direction, but usually the nadir angle is limited to in maximum 45°. If a larger area shall be covered from one orbit, the first strip will be imaged with the movement of the satellite like this will be done by standard line scanner sensors (figure 1, left hand side), after this, the view direction will be rotated to the side and the neighboured strip will be scanned against the satellite movement by continuously rotating the whole satellite (figure centre). It is also possible to rotate the satellite and to scan across the orbit direction.

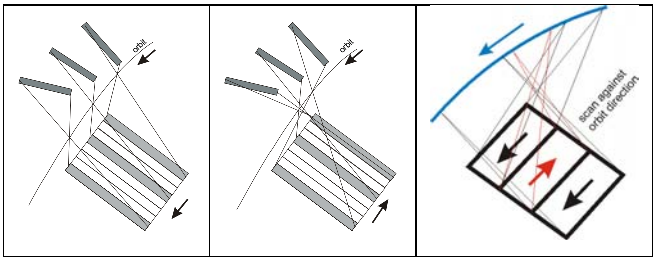


Figure 1: principle of imaging - scan direction with orbit and scan direction against orbit

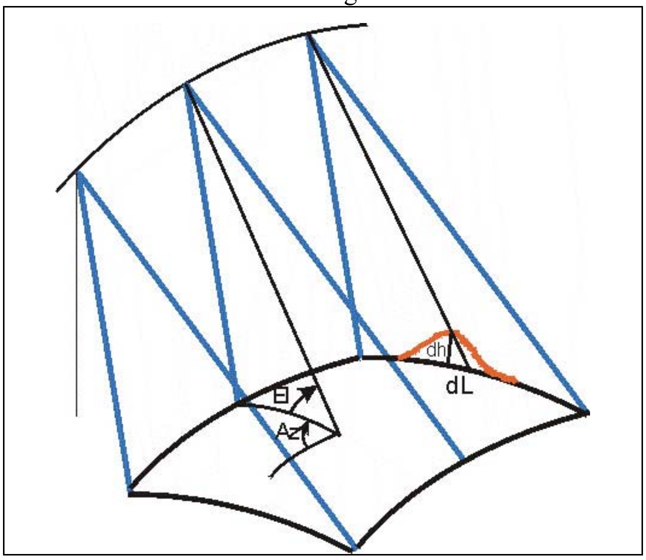


Figure 2: geometric condition of Geo-images

The CARTERRA-Geo images are influenced by the local terrain elevation. A height difference dh against the height level of rectification is causing a dislocation dL.

dL = dh * tan (local nadir angle) **Formula 1**

In addition the geo-reference of the Geo-scene has to be improved by means of control points. The geo-reference is based on the direct sensor orientation of the IKONOS satellite based on GPS-positioning and a combination of an inertial measurement system together with star sensors. The absolute geo-reference without control points is claimed in the specifications with a standard deviation of 12m. Dial and Grodecki (2002) from SpaceImaging are reporting about a higher accuracy in the range of 4m, but it is not normal distributed. This range can be confirmed, but under operational conditions it is very often difficult to get information about the local datum of the national coordinate systems.

The sensor model for the IKONOS-images is not available but SpaceImaging is distributing the relation of the Geo-Image to the national coordinate system in form of rational functions. They do describe the scene position as the relation of a polynomial as function of the three-dimensional ground coordinates divided by another (formula 2).

$$x_{ij} = \frac{P_{i1}(X,Y,Z)_j}{P_{i2}(X,Y,Z)_j} \qquad y_{ij} = \frac{P_{i3}(X,Y,Z)_j}{P_{i4}(X,Y,Z)_j}$$

Formula 2: rational functions

$$P_{i1}(X,Y,Z)_j = a_1 + a_2\cdot Y + a_3\cdot X + a_4\cdot Z + a_5\cdot Y\cdot X + a_6\cdot Y\cdot Z + a_7\cdot X\cdot Z + a_8\cdot Y^2$$
$$+ a_9\cdot X^2 + a_{10}\cdot Z^2 + a_{11}\cdot X\cdot Y\cdot Z + a_{12}\cdot Y^3 + a_{13}\cdot Y\cdot X^2 + a_{14}\cdot Y\cdot Z^2 + a_{15}\cdot Y^2 X + a_{16}\cdot X^3$$
$$+ a_{17}\cdot X\cdot Z^2 + a_{18}\cdot Y^2\cdot Z + a_{19}\cdot X^2\cdot Z + a_{20}\cdot Z^3$$

Formula 3: cubic polynomial

The horizontal ground coordinates are handled as geographic coordinates. Third order polynomials are used. So with 80 coefficients the relation between ground coordinates and the Geo-image can be described. SpaceImaging is adjusting the rational functions based on the not published sensor model. With such parameters a totally sufficient internal accuracy can be reached (Grodecki 2001).

The rational functions are a three-dimensional interpolation. They do have an advantage for the transfer of the image orientation to photogrammetric workstations. The workstations must not have the actual sensor geometry available.

Another possibility of the geometric handling of IKONOS Geo images is the reconstruction of the imaging geometry – this will be done in the Hannover program CORIKON. In the header data, belonging to the images, the view direction from the scene centre to the satellite is available as nominal collection azimuth and elevation (Az and El in figure 2). Based on this view direction the actual location of the satellite orbit can be reconstructed with the general information about the orbit which has been published. So the location of the individual projection centre for any image position can be calculated. This of course has to respect the imaging principle shown in figure 1. The required information is available as “scan azimuth” in the header data, where scan azimuth 180° means the scan with the satellite motion and scan azimuth 0° means the imaging against the satellite motion. The influence of the scan direction to the adjusted ground coordinates is limited. In the mountainous area of Zonguldak, the root mean square difference of the adjusted control point ground coordinates handled once with the scan direction 180° and the next time just with 0°, is limited to 0.17m with extreme values up to 0.61m.

Of course it is also possible to reconstruct the imaging geometry just based on control points without taking care about the available information. But for such a reconstruction the control points must be well distributed three-dimensional and a higher number of control points are required. This method will be used with the affine projection model (Hanley et al 2002) which is identical to the rational function shown in formula 2 and 3, but is limited to the linear coefficients (a1 up to a4). The affine projection model is not respecting the perspective geometry in the CCD-line. It is causing 1m error in the horizontal position for points with just 120m difference in height against the location of the control points for points at both ends of the CCD-line. In the case of the mountainous scene Zonguldak described later, positional errors up to 5m can be caused by this method. By this reason, the affine projective model is limited to flat terrain. The determination of a higher number of polynomial coefficients just based on control points requires a high number of control points and is not a save method.

2.1 Results of IKONOS Image Orientation

In the area of Zonguldak, Turkey two IKONOS Geo scenes have been analysed with different methods. 39 control points are determined by GPS, they are located in an elevation between 217m and 652m above sea level. The mountainous area goes from the Black Sea up to 850m elevation.

For one scene also the rational polynomial coefficients (RPC) are available. This scene has been adjusted with the Hannover program CORIKON, reconstructing the imaging geometry, with the Hannover program RAPORI, based on the RPC and with the PCI satellite modelling, which is also based on RPC.

	RMSX	RMSY
RAPORI, RPC + 6 unknowns	5.20	1.04
CORIKON, reconstruction of geometry + 6 affine parameters	5.33	0.86
PCI satellite modelling	5.85	0.82
CORIKON, 8 unknowns	1.01	0.80

Table 1: root mean square discrepancies at the 39 control points of the IKONOS orientation in Zonguldak, Turkey

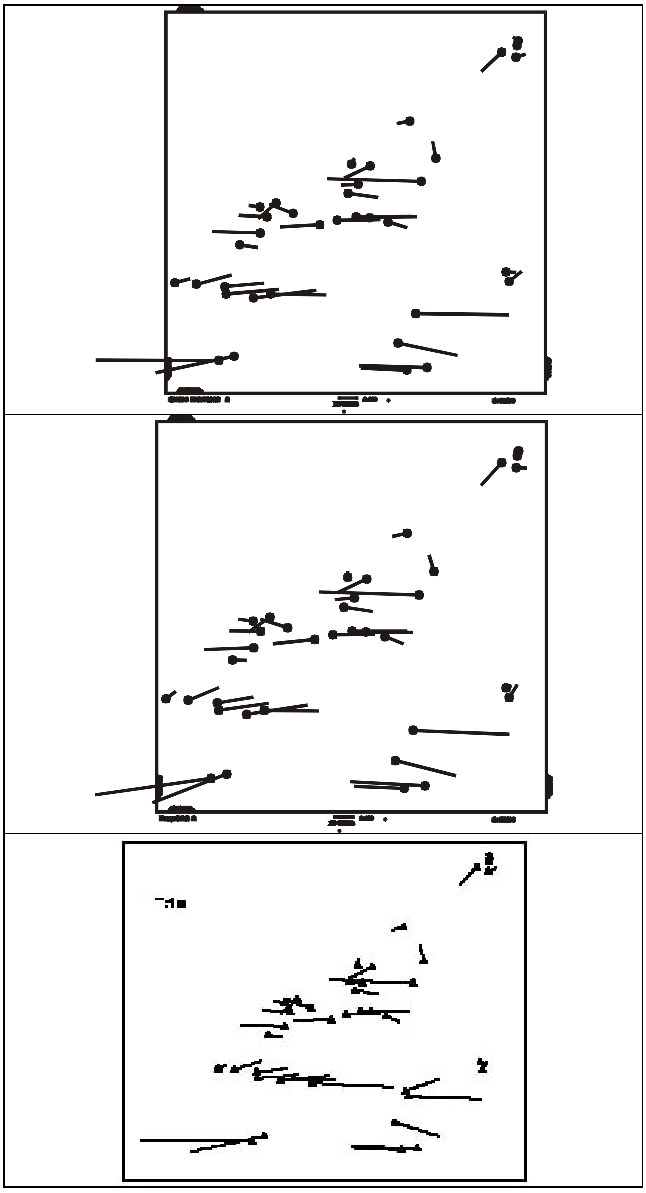


Figure 3: IKONOS Geo, Zonguldak, Turkey discrepancies at control points:
up: RAPORI - based on rational polynomial coefficients
center: CORIKON - reconstruction of image geometry without improvement of view direction
down: PCI - satellite orbital modelling

As it can be seen in figure 3 and in table 1, the results of all three solutions are similar. The slightly larger value for the PCI solution is based on an independent point measurement which cannot be compared directly with both other solutions. The large discrepancies in the X-direction are quite above the possible accuracy level. They are strongly correlated with the point elevation and are oriented perpendicular to the view direction (nominal collection azimuth). This obvious problem has been solved with the Hannover program CORIKON by adjusting also the view direction.

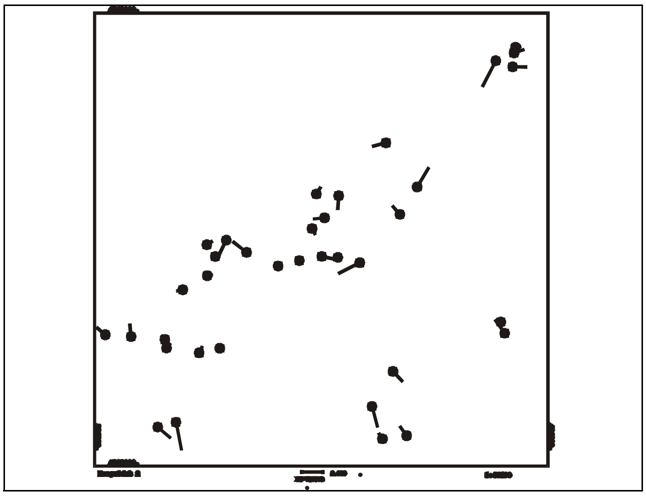


Figure 4: IKONOS Geo, Zonguldak, Turkey, discrepancies at control points – image orientation with adjusted view direction (CORIKON)

The adjustment of the view direction resulted in a change of the nominal collection azimuth of 8.6° which is with a Student test value of 31 highly significant. The nominal collection elevation has only changed 0.4°, this is also significant but not on a so high level. Such a problem has been seen also with a scene in Saudi Arabia, but not in other areas. In the named scene in Saudi Arabia, based on 21 control points with differences in the elevation up to 338m, the azimuth has changed 4.3°, reducing the root mean square differences from 3.22m to 1.48m.

All unknowns in program CORIKON, 6 affine parameters and the horizontal and vertical view direction are checked for their significance and correlation. Not significant parameters are marked and can be taken out of the adjustment. Both unknown view directions are taken automatically out of the solution if they are highly correlated and / or not significant. This may happen if all control points are located in approximately the same height level. In the Zonguldak area the adjustment of the view direction has drastically improved the results even to values slightly below the pixel size of 1m. (figure 4 and table 1, lowest line).

A1	SHIFT X	JUSTIFIED	56.031	****
A2	SCALE X	JUSTIFIED	14.369	****
	A3	NOT JUSTIFIED	.055	
A4	SHIFT Y	JUSTIFIED	245.618	****
	A5	JUSTIFIED	2.153	*
A6	SCALE Y	JUSTIFIED	12.122	****
	KAPPA	JUSTIFIED	30.650	****
	NADIR	JUSTIFIED	6.298	***

Table 2: unknowns in program CORIKON with the Student test values

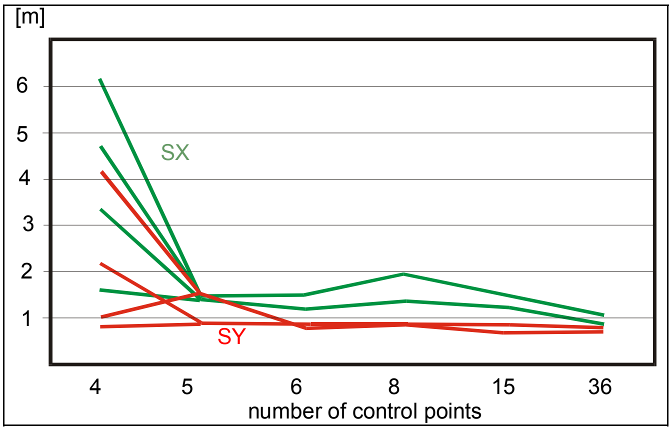


Figure 5: accuracy at independent check points depending upon different number of control points, data set: Zonguldak 1 and 2

A similar orientation quality like in the first Zonguldak scene has been reached also with the second scene in the same area. If all possible 8 unknowns are introduced into the adjustment, by theory 4 control points are required. An orientation with just 4 control points is leading to not save results. The accuracy tested at the not used control points, which are in this case independent check points, showed an accuracy quite depending upon the selected control points. With 5 control points or more, this problem was solved (figure 5). The accuracy will only be slightly improved by a higher number of control points. In areas without the special problem of the view direction also with 4 control points satisfying results have been achieved.

By testing the unknowns in CORIKON for significance and against high correlations, save results have been reached. This is not the case with some commercial programs with solutions just based on control points and no test of the unknowns.

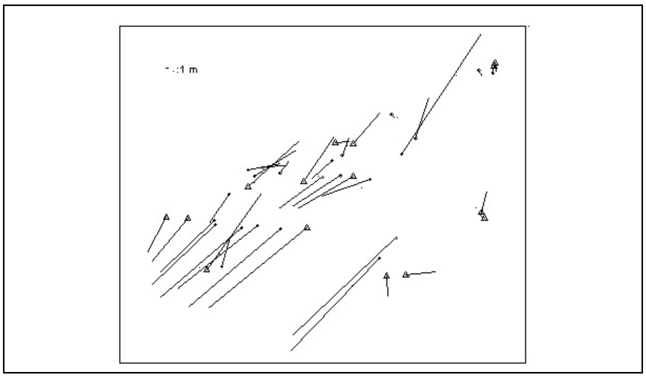


Figure 6: PCI terrain dependent rational functions – not optimal selection of control points

With rational functions just determined by means of control points, large discrepancies outside the volume of the control points may appear like shown in figure 6. Such a solution should not be used. Also SpaceImaging is warning about the use of such a solution.

3. DETERMINATION OF DIGITAL ELEVATION MODELS

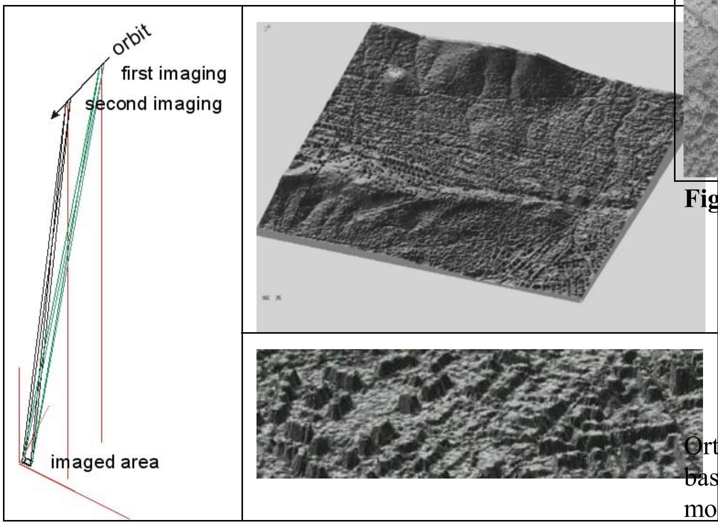
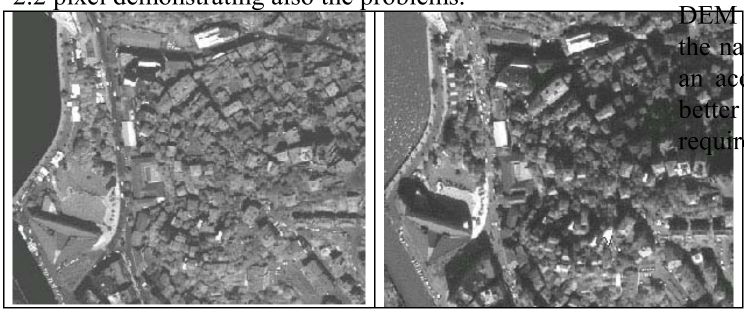


Figure 7: left: configuration of IKONOS stereo model right: generated DEM – lower part: detail in city area showing buildings in the DEM

With a stereo combination digital elevation models can be generated. But only few IKONOS stereo combinations taken from the same orbit are available in the archive.

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 of 0.2 pixel for the x-parallax excellent results have been reached, corresponding to a vertical accuracy of 1.7m (see figure 7).

Quite different results have been achieved in the area of Zonguldak where one scene was taken in July and the other in October. The radiometric change in the area, mainly caused by a quite different illumination (figure 8), together with the very high resolution has caused large problems for the automatic image matching. Without low pass filtering the matching was not possible. But also with filtering, the matching failed in the forest areas totally. The matched points do have an accuracy of just +/-5.8m With the height to base relation of 3.9 this corresponds to a standard deviation for the x-parallax of Spx=+/-1.5 pixel. The y-parallax of the matching has reached Spy=+/-2.2 pixel demonstrating also the problems.



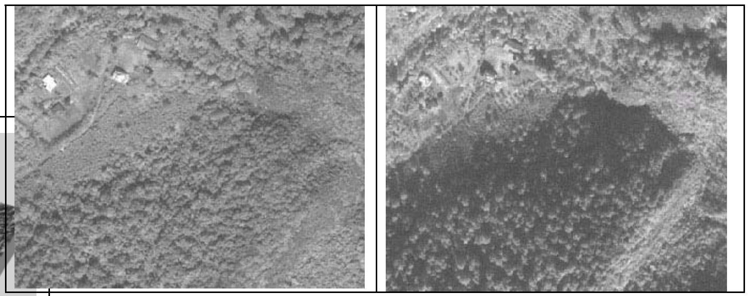


Figure 8: corresponding IKONOS sub-scenes
left: 07/09/02, sun elevation 67.2°
right: 10/11/02, sun elevation 41.5°

4. GENERATION OF ORTHOIMAGES

Orthoimages can be generated with IKONOS Geo scenes based on the scene orientations and digital elevation models for example with the Hannover program IKORTHO. The DEM must not be created by IKONOS images. Under usual condition an orthoimage should have at least 2 pixels per mm. For a printed version an accuracy of 0.25mm is sufficient. This leads to a requirement of 2m for the positioning. The image orientation can be made with 1m accuracy, so the major error component can be allowed for the DEM. IKONOS scenes are not only taken with a vertical view, a local nadir angle up to 45° is possible depending upon the placed order.

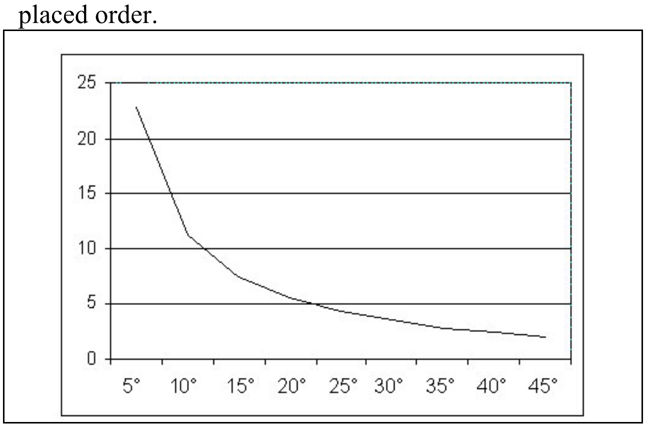


Figure 9: requested accuracy of the DEM for a required position accuracy of 2m as a function of the local nadir angle

As shown in figure 9, for a local nadir angle of 5° the DEM must have only a standard deviation of 23m, but for the nadir angle of 45° an SZ=2m is required. DEMs with an accuracy of just 2m are not often available, so it is better to restrict the view angle depending upon the required accuracy and the quality of the available DEM.

CONCLUSION

With the high resolution of the IKONOS images and the possible geometric quality, a competition to aerial images exists and the use of the different products is only a question of economy. With the correct mathematical model orientation an accuracy in the range of a pixel can be reached under operational conditions just with few control points.

IKONOS stereo models, taken from the same orbit do allow an excellent image matching with sub-pixel accuracy. The optimal conditions for matching will not be reached with a height to base relation of 1.0 – such a relation is causing always some problems with the matching, so it is better to go to a height to base relation in the range of 2.0.

The major problem for the orthoimage generation is caused by the very often not sufficient digital elevation models. For reaching a specified accuracy, very often the nadir angle has to be reduced.

ACKNOLEDGEMENT

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