COMPARISON OF QUICKBIRD AND IKONOS FOR THE GENERATION OF ORTHOIMAGES

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ABSTRACT

The very high resolution space data from IKONOS and QuickBird are in a competition to aerial images today. The resolution is sufficient for the generation of Digital Orthophoto Quarter Quads (DOQQ's). 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 (DEM's). The results of the DOQQ's generation based on IKONOS and QuickBird images with different DEM's are shown.

1. INTRODUCTION

With a pixel size of 1m, IKONOS-images do have the same resolution like the USGS DOQQ's. QuickBird images even do have a higher resolution. The original pixel size for nadir images is 61cm and this is enlarged influenced by the nadir angle by the factor 1/cos (nadir angle) across the view direction and $1/\cos^2$ (nadir angle) in the view direction. The original image resolution is available with the "Basic Imagery", but also the "Standard Imagery" is available without loss of radiometric information with 60cm or 70cm pixel size. So the resolution is not any more a reason for the use of aerial photos. The next aspects are the radiometric quality and the geometric accuracy. The radiometric quality of the very high resolution space images is very often still better than in the case of the existing DOQQ's. The geometric conditions are following.

2. GEOMETRY OF IKONOS IMAGERY

With the CARTERRA "Geo", "Reference", "Pro", "Precision" and "Precision Plus", IKONOS image products with different geometry are available, reaching from a rectification without control points up to precise orthoimages. Caused by the extreme differences in the price usually only the CARTERRA "Geo" are used and upgraded to orthoimages. The Geo-product is a geo-referenced rectification to a plane with constant height. The geo-reference is based on the direct sensor orientation, using the satellite position and view direction for each line.

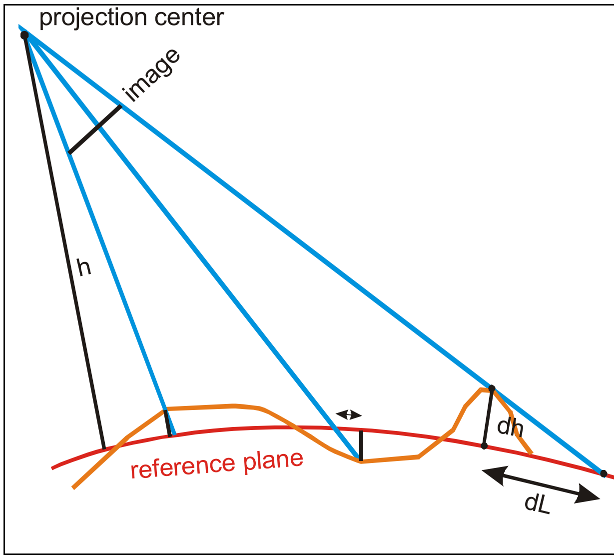

Figure 1: geometric model of the CARTERRA Geo-product

- rectification to a plane with constant height, geo-location influenced by the point altitude
- dislocation depending upon height differences to the reference plane:

$$dL = dh * \tan(\text{nadir angle})$$

The change of the Geo-product into an orthoimage requires a digital elevation model (DEM) and the information about the view direction for each point. The relation between image and 3D-ground points can be ordered together with the images from SpaceImaging as rational functions. The rational functions do describe the position in the scene (line, sample) as a relation of 2 polynomials depending upon the ground coordinates (see Grodecki 2001). 40 unknowns are used as rational polynomial coefficients (RPC's) for the latitude and 40 for the longitude, so any type of geometry can be described. The RPC's have to be calculated based on a strict mathematical model – an adjustment directly based on control points has to be avoided, it would hide errors of control points and it would have only a sufficient accuracy within the volume of the control points. The advantage of the RPC's is the transfer of the image orientation to digital workstations. Any type of different image geometry can be used without change of the workstation software. The RPC's are determined by the direct sensor orientation of the IKONOS satellite. This has an accuracy of few meters on the ground and has to be improved by means of control points.

With the Hannover program RAPORI the relation between the Geo-product and the control points is determined by the RPC's, improved by an affine transformation to the control points. In the area of Zonguldak this was leading to root mean square differences at GPS check points of SX=5.33m and SY=0.86m (figure 2, left hand side). An independent solution is available with the Hannover program CORIKON; it is using just the general information about the orbit and the nominal collection elevation and azimuth which is included in the metadata-file. CORIKON adjusts the shift of the location of the Geo-scene after height correction by 6 affine parameters; in addition also an improvement of the nominal collection elevation and azimuth can be included. The up to 8 unknowns can be selected individually and they are checked for significance by a Student test and the correlation value. So only the justified unknowns are introduced. If CORIKON is limited to the affine parameters, for the data set in the area of Zonguldak with SX=5.20m and SY=1.04m (figure 2, right hand side) approximately the same result has been achieved like based on the RPC's. The adjusted ground coordinates of both solutions are with +/- 0.35m close together (compare figure 2 – left and right hand side); this is confirming the correct data handling. But the figure 2 indicates a strong dependency of the discrepancies at the control points from the view direction. An adjustment of CORIKON with the nominal collection elevation and azimuth as unknowns is reducing the discrepancies to SX=1,00m and SY=1.03m (figure 3). Not only the strong improvement, also the significance test shows the requirement for an improvement of the view direction. Similar problems have been seen also at other, but not at all Geo-scenes.

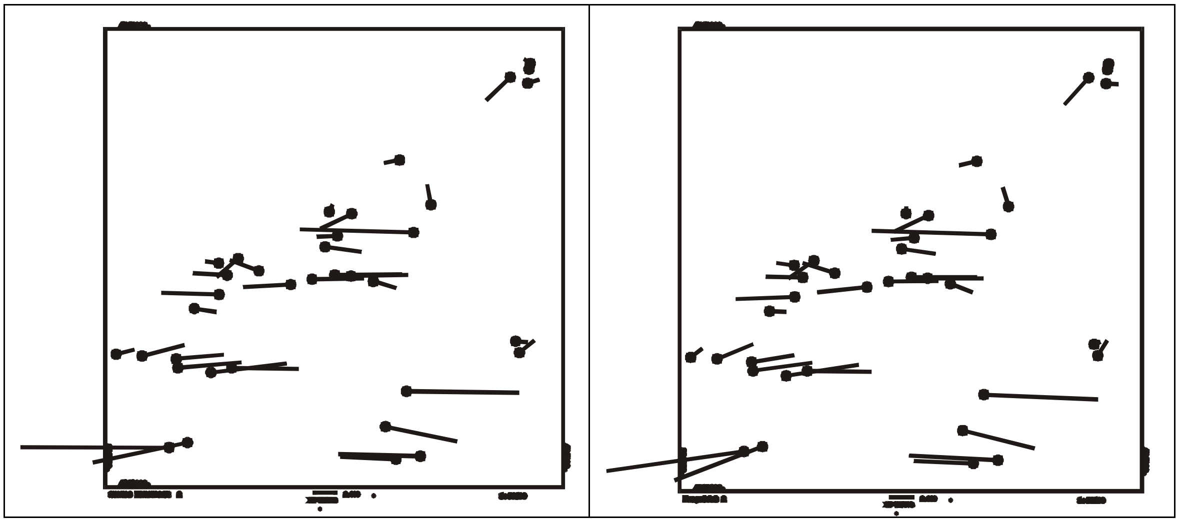

Figure 2: IKONOS Geo, Zonguldak, Turkey, discrepancies at control points:
left: based on rational functions right: based on view direction without improvement

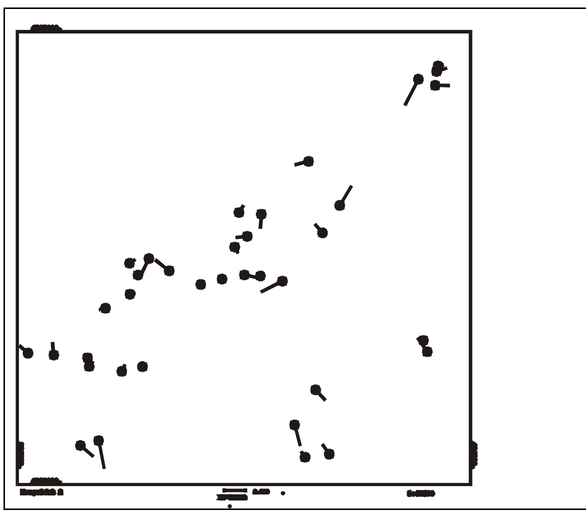

Figure 3: discrepancies at control points

based on view direction (program CORIKON) with adjustment of the nominal collection elevation and azimuth

same vector scale like figure 2

unfavourable point distribution caused by the Black Sea in the upper left part

In the area of New Jersey a Geo-scene has been oriented using control points achieved from the Digital Orthophoto Quarter Quads (DOQQ's) of the USGS and the corresponding 7.5'-DEM. Here the same problem exists like in the area of Zonguldak. Without adjustment of the nominal collection elevation at the check points root mean square discrepancies of SX=3.66m and SY=3.97 are given with +/-5.04m in the view direction and 1.02m across the view direction. An adjustment of the nominal collection azimuth was not required. With an improvement of the nominal collection elevation the discrepancies have been reduced to SX=1.66m and SY=1,08m or in the view direction +/-1.66m and across +/-1.07m. The higher value in the view direction is caused by the limited accuracy of the DEM. For the quality of the USGS DOQQ's and the corresponding DEM this is a satisfying result. In general there is the question, which data source is influencing more the discrepancies – the internal accuracy of the IKONOS Geo-scene seems to be better than the USGS data used as reference. This is indicated also with the Zonguldak data set, where the control and check points have been determined by GPS ground survey. A second scene from the Zonguldak area, where we do not have the RPC's, was leading to SX=0.80m and Sy=0.71m. Here the dominating effect is the point identification in the IKONOS image and not the internal accuracy of the scene.

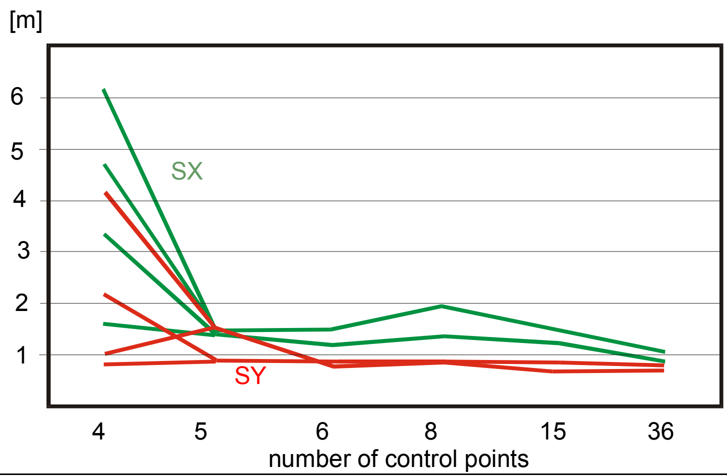

Figure 4: IKONOS Geo

accuracy at independent check points depending upon different number of control points

data set: Zonguldak 1 and 2

With the 2 data sets from the Zonguldak area, the required number of control points has been analysed. For both data sets it is necessary to adjust the nominal collection elevation and azimuth. Together with these both unknowns and the 6 elements of the affine transformation, 8 unknowns have to be determined, so at least 4 control points are required. Program CORIKON checks the significance and correlation of the unknowns and allows an individual specification of the unknowns. Depending upon the number of control points up to 3 unknowns, including also the collection elevation in one case, have not been justified. The best results (see figure 4) have been achieved if just the justified unknowns have been introduced into the adjustment. With only 4 control points, the result is strongly depending upon the used control points – 2 different selections are shown in figure 4 for both data sets. Starting with 5 control points the results are stable. The Y-component is across the view direction, not influenced by the collection elevation and also the vertical accuracy of the control and check points. In general the point distribution for this data set is not optimal caused by the Black Sea located in the upper left part.

3. GEOMETRY OF QUICKBIRD BASIC IMAGERY

Opposite to IKONOS, for QuickBird the so called “Basic Imagery” is available which is close to the original sensor image. The Basic Imagery is a sensor corrected merged image of the individual CCD-lines. It corresponds to the geometry taken by a unique CCD-line with 27 552 elements without geometric distortion. The ephemeris are delivered together with the images. Also other products like the “Standard Imagery”, having a geometry similar to the CARTERRA Geo, are available.

Two Basic Images have been handled in the area of Arizona with DOQQ’s and the 7.5’-DEM of the USGS as reference. The Hannover Program BLASPO for the handling of satellite line scanner images has been upgraded for the QuickBird Basic Images. The ephemeris have not been used for the adjustment, only the required rough orbit information has been checked and improved by the ephemeris. BLASPO together with the pre-program SATRAC computes the actual orbit as inertial ellipse by means of the orbit inclination, semi-major axis and numerical eccentricity together with the view direction, focal length, scene positions and control points. The view direction in relation to the orbit, available as “in track view angle” and “cross track view angle”, at first will not be changed and kept as the same for all scene lines. As unknowns in the adjustment the rotation of the whole scene and the semi-major will be changed. In addition to these 4 unknowns a scale factor in the orbit direction, and an angular affinity, corresponding to a change of the CCD-line orientation not perpendicular to the orbit has to be included. These 6 unknowns are sufficient for SPOT, ASTER, MOMS and IRS images. QuickBird is changing the horizontal angle of the CCD-line in relation to the orbit to cover an area on the ground oriented to the geographic coordinate system. This requires special additional parameters if the ephemeris are not used.

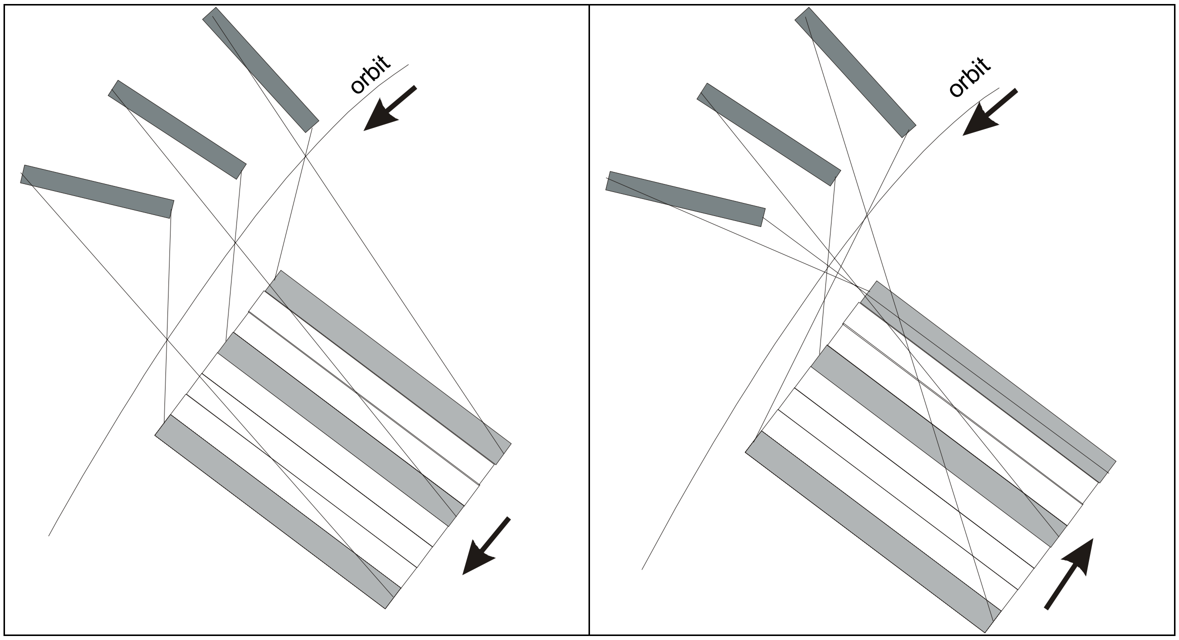

Figure 5: principle of imaging and mathematical model of BLASPO
scan direction 0 degrees scan direction reverse (180 degrees)

The CCD-line orientation can be changed like shown in figure 5. A reverse scan direction like shown on the right hand side of figure 5 is also possible. Such a reverse scan will be made if from one orbit also a second scene east or west of the first scene is requested. This has to be respected in the mathematical model of CORIKON and BLASPO, but the influence is still limited because of the very long focal length.

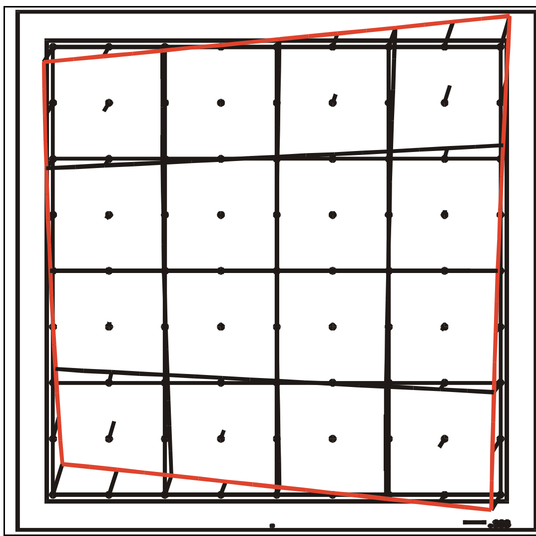

Figure 6: effect of the additional parameters to the scene ("systematic image errors") – QuickBird scene 1450

The orientation angle of the CCD-line has been changed within the scene

vectors enlarged

The reference, that means control points, has been determined from DOQQ's. The USGS orthoimages do have a pixel size of 1m - this is larger than the 0.64m of the used QuickBird scenes. So the DOQQ's are not optimal for the control point generation. From the DOQQ's only the horizontal coordinates can be achieved. The required height has been interpolated at the X-Y-position of the control points in the USGS 7.5'-DEM. Neighboured DOQQ's are overlapping; in the overlapping area 112 corresponding points have been measured. The root mean square difference is +/-1.43m leading to an individual horizontal coordinate accuracy of +/-1.01m. In addition we do have the influence of the vertical accuracy. For some parts 2 different DEM's have been available from the USGS. Shaded 3D-views of the DEM's showed a poor quality of some of the DEM's (see figure 7). In the extreme case the differences in Z have exceeded 100m. The visual inspection shows in some of the DEM's an extreme stripping, these DEM's have not been used.

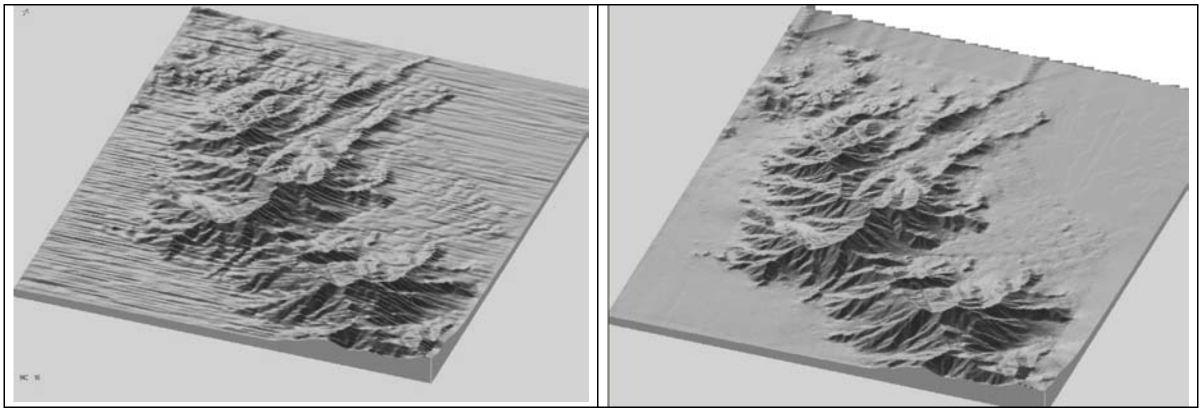

Figure 7: different USGS 7.5'-DEM's of the same area

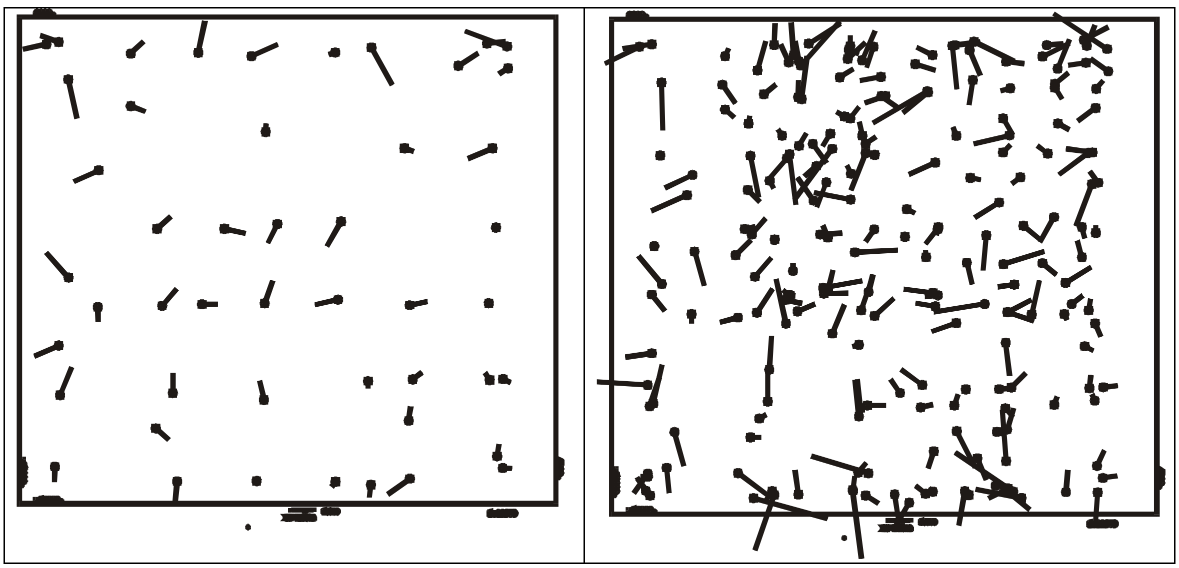

Figure 8: QuickBird scene 12450 – discrepancies at control points
48 control points (symmetric objects) 207 control points (several points at corners)

At first in the scene 12450 at symmetric objects 48 control points have been identified. An adjustment was leading to root mean square differences of SX=1.03m and SY=1.04m (figure 8, left hand). This is very close to the determined accuracy of the DOQQ's, so the influence caused by the internal QuickBird accuracy is quite smaller. Of course the estimated accuracy of the DOQQ's is pessimistic because only points at the border have been used for the investigation and they are not so accurate like the center of an orthoimage. Later another person has measured 159 additional control points, but these control points are mainly at grey value corners like the intersection of drives and road sides (see figure 9). Such corners in general are shifted from the bright side to the dark side. Corresponding to this, a common adjustment with all 207 control points resulted in SX=1.24m and SY=1.34m. Based on this common adjustment, the 48 symmetric points do have mean square differences of SX=1.08m and SY=1.22m. In spite of the not optimal point selection, in general this is a quite sufficient result for the generation of actual orthoimages based on QuickBird Basic images.

Figure 9: control point at a grey value corner
- intersection drive and road side

a shift from the bright drive to the dark road cannot be avoided

The continuing scene 12451 with an overlap of approximately 6000 lines to the scene 12450 has also been used. With 55 control points an accuracy of SX=1.26m and SY=1.22m has been reached, which is similar to the preceding scene. Both scenes are from the same data take and the separation into scenes is only artificial. So it is possible to join both scenes together to an area covering approximately 17.5km x 30.5km. An adjustment was leading to mean square differences at 90 control points of SX=1.48m and SY=1.70m. Over such a long scene higher degree changes of the CCD-sensor line can be expected which is enlarging the discrepancies. Here it is better to respect the recorded sensor line orientation.

Of course such a high number of control points will not be used under operational conditions. By this reason different control point configurations have been analysed (figure 10). The increase of the accuracy with a higher number of control points can be explained just by the influence of the individual control point accuracy. 9 control points are sufficient for the sensor orientation and do have enough redundancy for reliable results. Even if the accuracy of the control points is limited by the geometric quality of the used DOQQ's, the achieved accuracy is totally sufficient for the generation of new DOQQ's. Also because of the source of the control points not less than 9 control points should be used. If the data sets have been prepared for the image measurement, it does not matter if some more control points are measured.

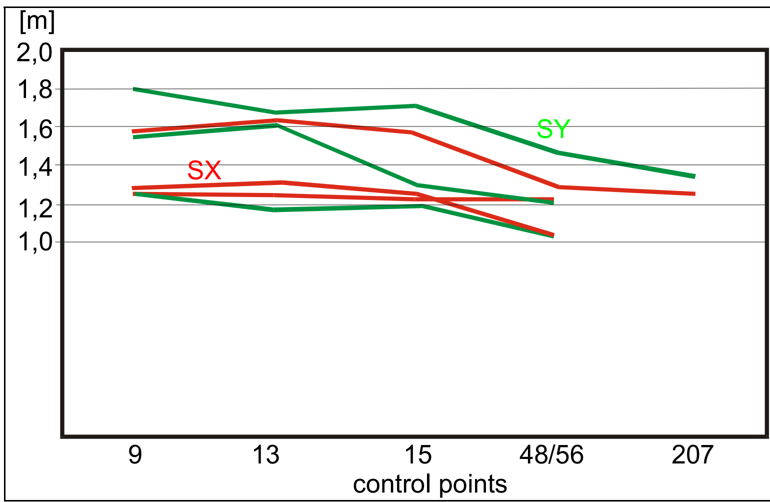

Figure 10: QuickBird, Basic Imagery:
accuracy at independent check points depending upon different number of control points

scene 12450 and 12451

4. RADIOMETRIC QUALITY

The radiometric quality of the used DOQQ's is not the same like the quality of the used very high resolution space images. Especially the contrast of the orthoimages in the Arizona area (figure 12, right hand side) is poor. The band width for the panchromatic space images is going into the near infrared up to 900nm wavelength. This improves the contrast of the vegetation and the water bodies. But in general the contrast of the used space images is quite better. Of course the smaller pixel size of the QuickBird images is improving the identification of details, but if these images are used for the generation of orthoimages with 1m pixel size, this advantage will be lost. Nevertheless, usually the quality of down sampled images is better like the quality of images achieved with just this pixel size. Not all very high resolution space images do have the same quality like the used examples. Especially in more northern areas with lower sun altitude the radiometric quality may be lower.

Figure 11: IKONOS (pixel size 1m) DOQQ (pixel size 1m)

Figure 12: QuickBird (pixel size 0.64m) DOQQ (pixel size 1m)

5. CONCLUSION

The geometric quality of orthoimages made with IKONOS and QuickBird images is directly depending upon the orientation accuracy shown with the discrepancies at the independent check points. The used control and check points generated by means of the DOQQ's and the USGS 7.5'-DEM are not free of errors, so the geometric potential is better like shown with these data sets. With control and check points determined by GPS-positioning with IKONOS images an accuracy in the range of 1 pixel has been reached.

The limitation for this is more the point identification than the internal scene accuracy. The orientation of IKONOS images should include at least a check, better the adjustment, of the nominal collection elevation and azimuth. Also the rational functions, distributed by SpaceImaging, are influenced by the sometimes limited accuracy of the view direction. The QuickBird scenes can be oriented without use of the detailed ephemeris; only connected scenes should be improved by these data.

In addition to the sufficient orientation accuracy, the use of existing USGS 7.5'-DEM's is influencing the geometry of orthoimages made by the very high resolution space images. Not all of these DEM's are satisfying, at least a graphical check with a shaded 3D-view should be made. Errors in the DEM multiplied with the tangent of the nadir angle are giving the horizontal displacement of an orthoimage. A wide angle aerial image has in the corner a tangent of 1:1, so in this location the displacement in the position is identical to the displacement in the height. The very high resolution space images usually do have quite smaller nadir angles that mean also a smaller influence of the DEM errors to the horizontal component of an orthoimage.

The radiometric quality of the space images is usually better than the radiometric quality of aerial images. Problems still exist with the cloud coverage; even a small percentage of clouds should not be accepted for the creation of orthoimages.

For the generation of DOQQ's there is no clear advantage of QuickBird against IKONOS images or reverse. Both space image types do guarantee the geometric quality if satisfying control points and DEM's are available. The handling of the 1.6 Gb QuickBird images is not a problem on modern PC's.

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