Mapping with IKONOS images

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ABSTRACT: Caused by the price structure of Space Imaging, IKONOS-images are usually available as CARTERRA-Geo-product, that means rectified to a surface with constant height difference against the earth ellipsoid. Based on the "nominal view direction" and "nominal azimuth", available in the header data and the rough orbit information from literature, it is possible to create an orthophoto without knowledge of the full sensor information. The steps of transformation are described in detail. The required digital height model can be created by automatic image matching if stereo models are available. In spite of a not optimal height to base relation of just 7.5 in a sample area a vertical accuracy of +/-1.7m has been reached. Based on a data set of the OEEPE, line maps have been created and compared with line maps produced by mono plotting with Swiss digital orthophotos having a pixel size of 30cm. This resulted in the conclusion, that the information contents of IKONOS-images is corresponding to a map scale of 1 : 10 000.

1 INTRODUCTION

The very high resolution space images available now from IKONOS and Quick Bird do have a resolution which is partially in competition to aerial images. For a comparison, the geometric potential and also the information contents is important as well as the required information about the imaging situation. The very large price range for the same image product sold by Space Imaging has slowed down the use of IKONOS-images especially in countries where no restriction for the use of aerial images is existing. Nevertheless the very high resolution space images are very important especially in regions where by political reasons restrictions for the use of aerial images are existing. In using space images instead of this, the required development especially of underdeveloped countries can be supported.
The extreme difference in price between the rectified IKONOS-images, sold as CARTERRA Geo and the ortho-images sold as CARTERRA precision of US\$ 37.-/km² (North America) up to US\$ 146.-/km² (Japan) has caused a dominating use of the Geo-images. But in not flat areas, the terrain height is affecting the geometric location, so orthoimages should be used for a correct georeferencing.

2 GEOMETRIC RELATION OF GEO-IMAGES

SpaceImaging is not distributing the sensor model of the IKONOS-images, but in the metadata-file, coming together with the images, the "nominal collection elevation" and the "nominal collection azimuth" are included. Based on this horizontal and vertical view direction in relation to the scene centre, together with the general knowledge of the satellite orbit, the view direction for every point in the scene can be computed (see figure 1).

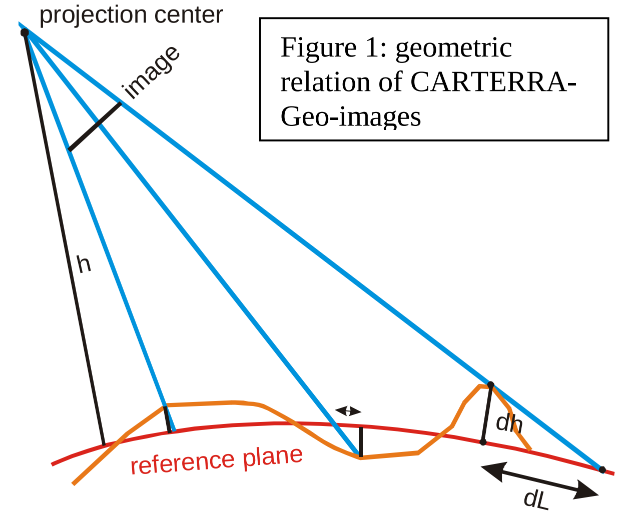

Figure 1: geometric relation of CARTERRA-Geo-images

The Geo-product is rectified to a specified plane parallel to the earth ellipsoid using the direct sensor orientation of the satellite which is based on GPS, inertial measurement units and star sensors. Beside the remaining errors of the image orientation, the geometry of such rectified images is influenced by the local height difference dh against the rectification plane, causing a displacement dL as shown in figure 1, the geoid undulation and also the relation of the national coordinate system to WGS84 (datum).

The dislocations of the Geo-images caused by the simple rectification to a reference plane can be improved by a digital elevation model (DEM), changing it to the geometry of a CARTERRA-Map-product.

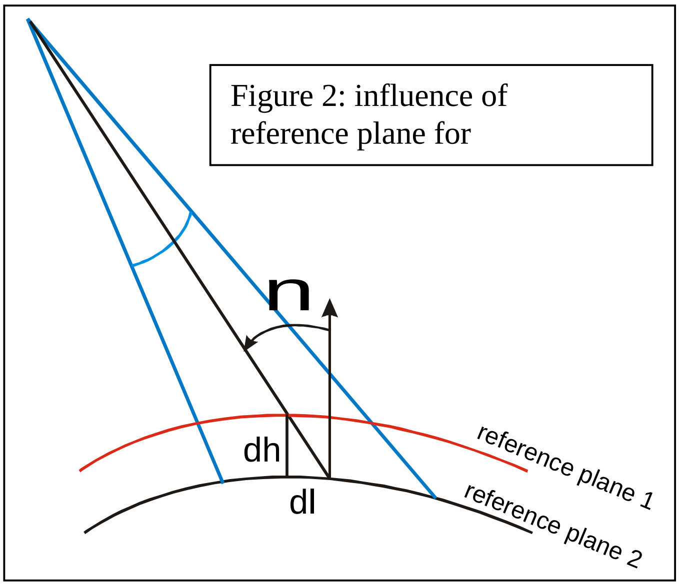

Figure 2: influence of reference plane for

The height level of the reference plane is not available for Geo-images. A deviation of the reference plane from the correct value is causing an error in the location of dl =dh•tanν (see figure 2). Together with the remaining deviation of the sensor orientation this can be determined by means of control points. At first a height correction is required followed by a transformation to the control points.

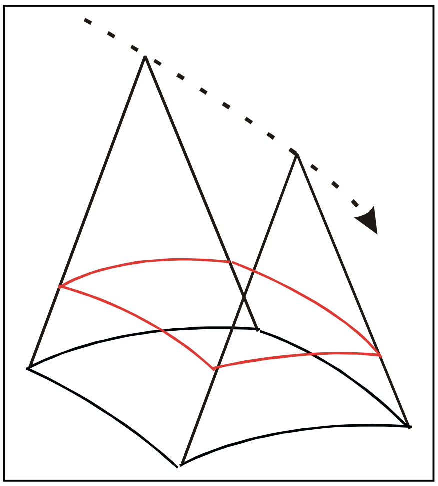

Figure 3: influence of the height level to the required type of transformation

As visible in figure 3, an error in the reference height is causing an affine deformation of the ortho rectified image, so at least an affine transformation is required for the improvement to the location of control points.

The required digital elevation model can be generated by automatic image matching from an IKONOS-stereo-pair. Based on the geometric relation determined by means of control points, from corresponding image points in the georeferenced Geo-image the three-dimensional position can be computed.

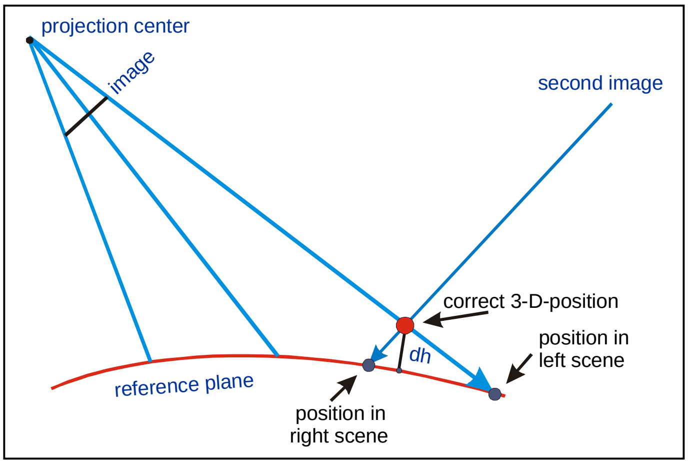

Figure 4: geometric relation between CARTERRA Geo-images and the three-dimensional location of the imaged points

3 ACCURACY OF GEOMETRIC POINT DETERMINATION

As extreme case for the determination of the correct ground location based on CARTERRA-Geo-images, the OEEPE-data set from Lucerne has been used. The altitude in the mountainous scene goes from 415m to 2197m above mean sea level (figure 5).

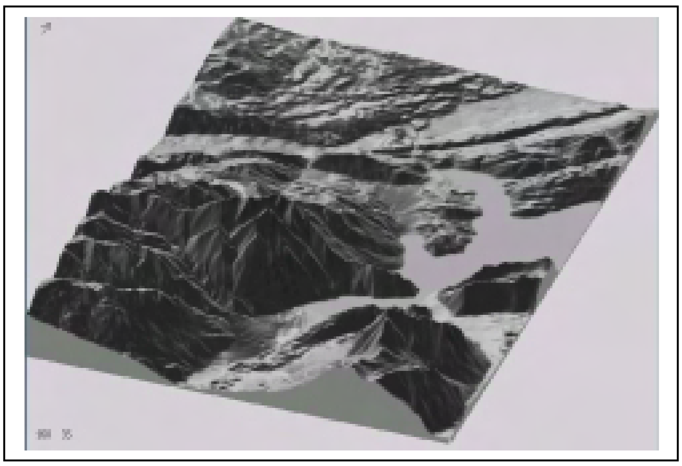

Figure 5: DEM of the Swiss test field

As reference Swiss digital orthoimages and the Swiss digital elevation model with a spacing of 25m was available. 128 control points have been digitised in the Swiss orthoimage and the Geo-image. The height values of the control points are achieved by interpolation with the Swiss DEM (Hannover program DEMINT).

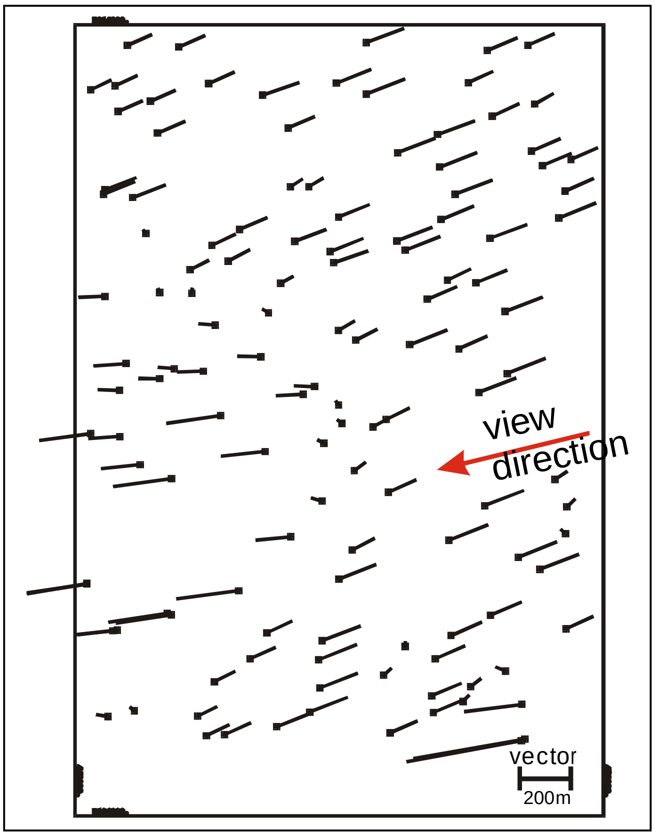

Figure 6: discrepancies CARTERRA-Geo against control points

The root mean square discrepancies between the Geo-image and control points are RMSX=+/-124m and RMSY=+/- 40m with extreme values up to 420m (see figure 6). The sign and the size of the differences are clearly correlated to the altitude. After height correction to a level of 800m above mean sea level, but without use of control points, the discrepancies are reduced to RMSX=+/-7.5m and RMSY=+/-18.5m with a clear systematic component. The shift of -6.8m in X and 18.3m in Y is showing the accuracy of the direct sensor orientation - it is within the specification of SpaceImaging of 25m. After a simple shift to the control points, the mean square differences are reduced to RMSE X=+/-3.5m and RMSE Y = +/- 2.3m but still showing clear systematic errors, mainly a rotation of the scene of 0.4°. No more systematic effects can be seen after an affine transformation to the control points. This is reducing the discrepancies at the 128 control points to RMSX=+/-2.52m and RMSY=+/-1.72m (see figure 7).

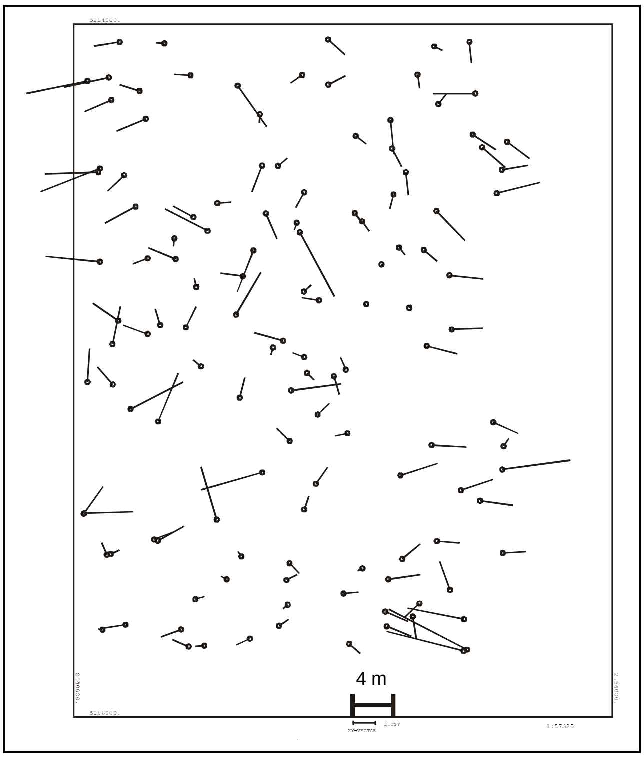

Figure 7: differences after correction by the relief displacement + affine transformation to control points

In figure 7 still some larger discrepancies up to 9.8m can be seen. Especially in the higher part randomly distributed differences are available. An explanation may be the limited spacing of the DEM of 25m, which is not sufficient in the steep mountains. In addition the identification of topographic control points is not corresponding to the identification of man made features in the lower parts. A computation limited to 79 control points which have been specified in advance as very clear points, is reducing the discrepancies to RMSX=+/-1.67m and RMSY=+/-1.60m.

area	SX	SY
Switzerland	2.52m	1.72m
New Jersey DEM 1	3.66m	3,98m
New Jersey DEM 2	2.65m	2.95m
Turkey (left scene)	0.52m	1.40m
Turkey (right scene)	1.73m	1.52m

Table 1: root mean square differences after correction by the relief displacement + affine transformation to control points (Hannover program CORIKON)

The good values of both scenes in Turkey can be explained by the quality of the control points which have been determined by GPS. In the case of the area New Jersey, the main limitation came from the digital elevation models. 2 different DEM's have been available with mean square differences in Z of +/-9.4m. By this reason, the discrepancies have been analysed for the component in the view direction and across. The across direction is not affected by the altitude and it shows only +/- 1.1m and +/- 1.2m mean square differences.

4 ACCURACY WITHOUT CONTROL POINTS

If no control points, but a digital height model is available, orthoimages corresponding to the CARTERRA-Reference or the –Map-product can be produced. SpaceImaging specifies the Reference-image with +/-25m accuracy and the Map-image with +/-12m. A mayor problem is the height of the reference plane for the rectification (see also figure 2). By this reason it has been analysed more in detail.

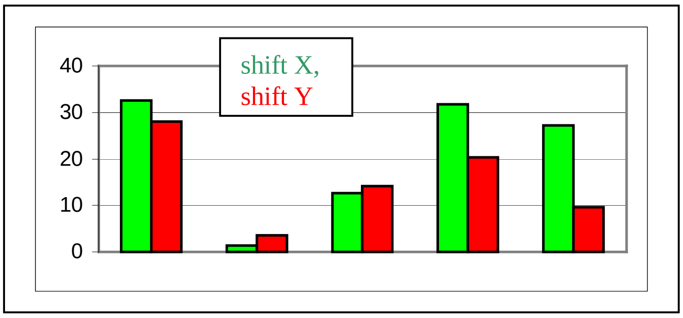

Figure 8: shift of the orthoimages after height correction against control points – Z-reference = mean height of control points (areas: Switzerland, USA, Malaysia, 2x Turkey)

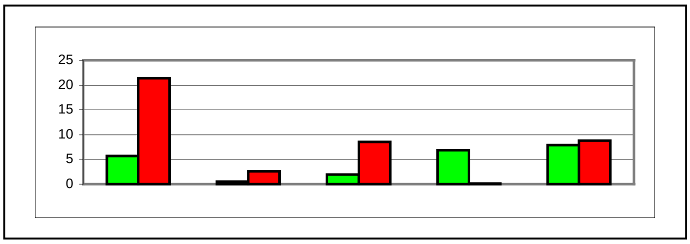

Figure 9: shift of the orthoimages after height correction against control points – Z-reference = mean height of DEM (areas: Switzerland, USA, Malaysia, 2x Turkey)

The result of the analysis is very obvious. In each case better results have been achieved with orthoimages related to a reference plane with a height corresponding to the mean height of the DEM. The mean square shift of the orthoimages is +/-20.4m for a reference plane with the mean height of the control points and just +/-9.1m in the case of the mean height of the DEM. In general this shows the very good accuracy of the direct sensor orientation of IKONOS which is in these 5 cases better than the specification for the CARTERRA-Map-image.

5 GENERATION OF DEM

The number of stereo models taken by IKONOS is limited up to now, but the system has a good potential for the generation of DEM's. A test area in Turkey has been imaged from the same orbit two times with a time interval of 12 seconds, corresponding to a base of 90km. The nominal collection elevation of the first scene is 78.3°, for the second scene 82.9°. This does not mean that the base to height relation is identical to tangent (82.9° - 78.3°) = 0.08; because of the three-dimensional situation we do have in this case a relation of 0.13 or 1:7.5.

The automatic image matching has been made with the Hannover program DPCOR in the image space. The matching in the image space is independent against the image geometry, only the following computation of the ground coordinates has to respect the real geometry. DPCOR is based on seed points for the start of the region growing method. At first an image correlation will be used, followed by a least squares matching, the highest accurate possibility of automatic matching. The contrast and image quality in the working area was very good, which is not the case for every IKONOS image. In the project area a city with usually separated buildings and the surroundings are included.

Caused by the image quality and the very structured area, the correlation coefficients have been very high, 81% of the points do have a correlation coefficient larger than 0.95 and only 4.8% a coefficient below the used tolerance limit of 0.80. The resulting corresponding pixel positions of both scenes have been used by the Hannover program IKONDEM for the computation of the ground coordinates. The misfit of the 2 rays used for the intersection is +/-0.3 pixel, indicating a high point accuracy.

In the used project area no accurate reference height values have been available, but it is possible to determine the building heights independent by means of the shadow. The sun elevation also included in the metadata of the Geo-product can be used together with the length of the shadow. In the imaged city area several buildings with a height in the range of 30m are available. Under the condition of the very good contrast, these height values could be determined with an accuracy of approximately +/-0.5m. Compared with the results of the automatic image matching, a root mean square difference of the building heights of +/-1.7m has been reached corresponding to a standard deviation of the x-parallax of +/-0.22 m = 0.22 pixel. This high accuracy only can be reached under good contrast conditions, that means for rural area and a lower sun elevation which is usually causing a not so good image quality, the result may not be the same.

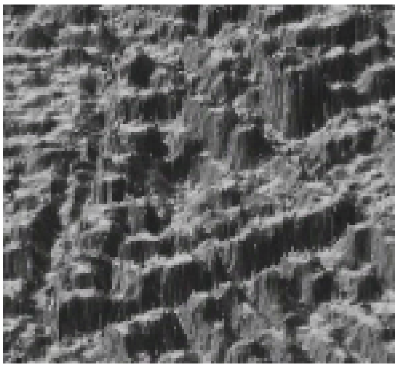

Figure 10: 3D-view of a DEM generated by image matching, sub-area in the city

Figure 11: IKONOS-image corresponding to figure 10

The discrepancy between the DEM and a control point in the matched area was just 1.1m, confirming the high quality of the DEM.

6 MAPPING WITH IKONOS IMAGES

For mapping not only the geometric quality is important, very often the information contents of the images has the priority. By this reason, line maps have been made in the OEEPE test area in Switzerland at first with an orthoimage based on the CARTERRA-Geo-image by means of the Hannover program IKORTHO and later with the Swiss orthophotos having 0.3m pixel size.

Figure 12: sub-area of IKONOS-image used for mapping

Figure 13: Swiss topographic map 1 : 25 000

A first comparison of the IKONOS-image (figure 12) with the Swiss topographic map 1 : 25 000 (figure 13) shows very clear the higher information contents of the panchromatic IKONOS-image.

The Swiss orthoimages do have a better image quality like the IKONOS-images. Even down sampled to 1m pixel size, the Swiss orthoimages do have a quite contrast and the identification of details is more easy.

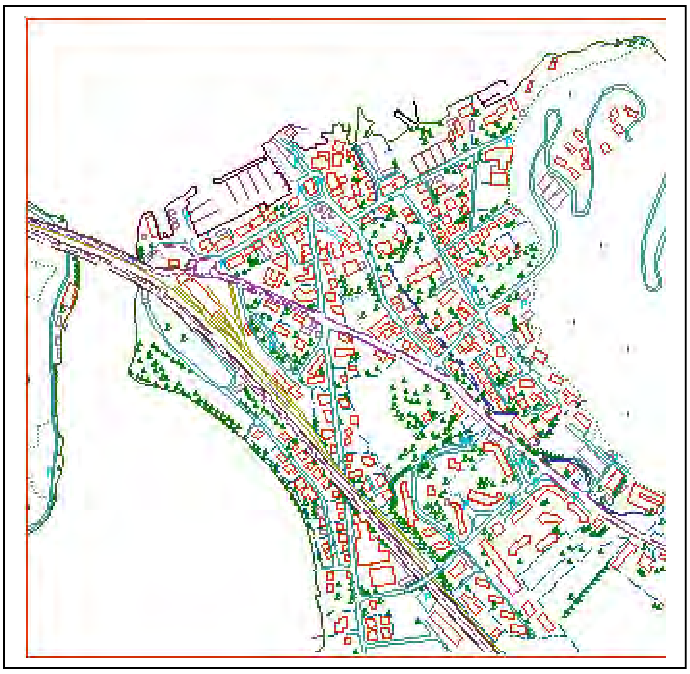

Figure 14: map based on panchromatic IKONOS-image

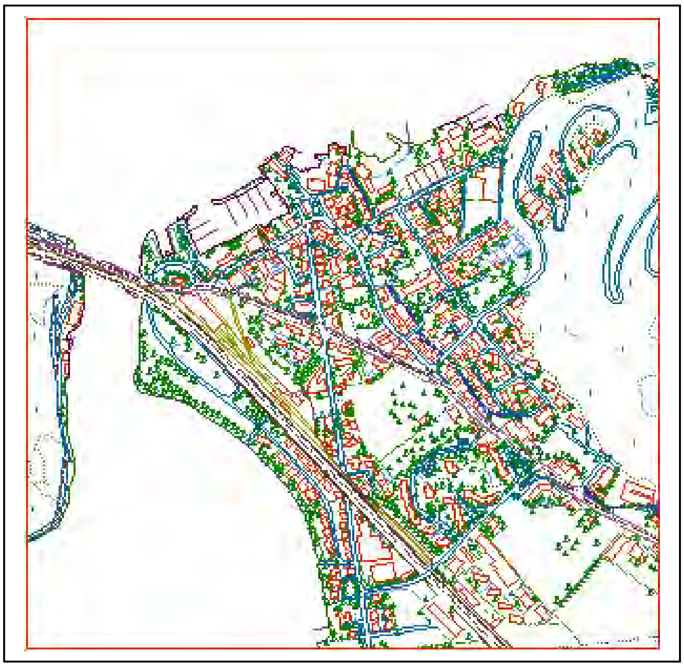

Figure 15: map based on Swiss orthoimage with 0.3m pixel size

On the first view, the information contents of the maps based on the IKONOS-PAN-image (figure 14) and the Swiss orthophotos (figure 15) is similar, but a more accurate view shows more details at the buildings based on the Swiss orthophotos and few misidentifications and not recognised buildings in the map based on the IKONOS-image. Figure 16 shows the typical problems of mapping with the IKONOS-image: the limited contrast, the shadow and neighboured trees are caused the failure of the identification of the encircled buildings. In comparison to the mapping with the Swiss orthoimage (figure 17) also not so many details could be identified.

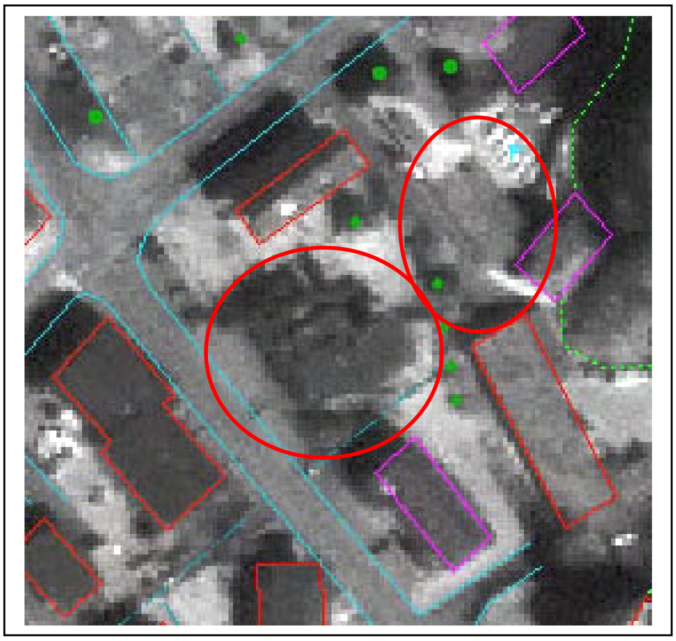

Figure 16: details of the line mapping with IKONOS image, encircled building not recognised

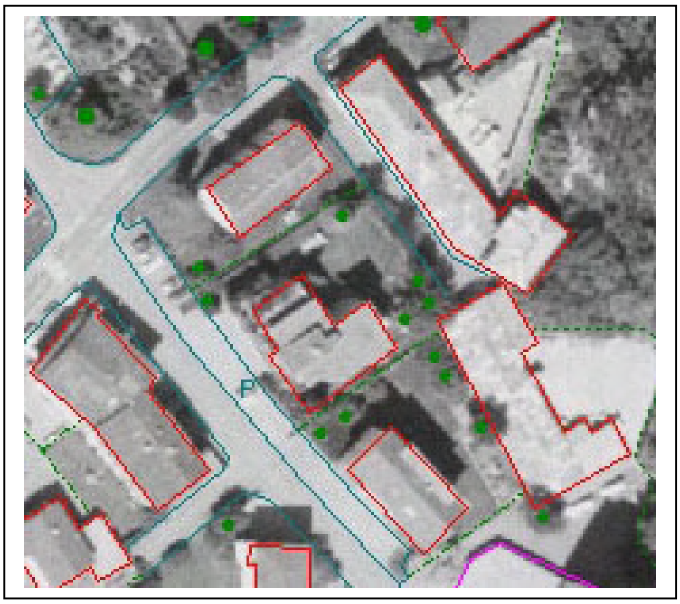

Figure 17: details of mapping with Swiss orthoimage (0.3m pixel size)

In another area building parts located in shadow could not be seen (figure 18) like a small building with a dark roof. One small street has been misidentified and few other buildings have not been mapped correctly. In general these are only minor details, important for a map in the scale 1 : 5000. In a map scale 1 : 10 000 not so many details are shown, corresponding to the result based on the IKONOS-image.

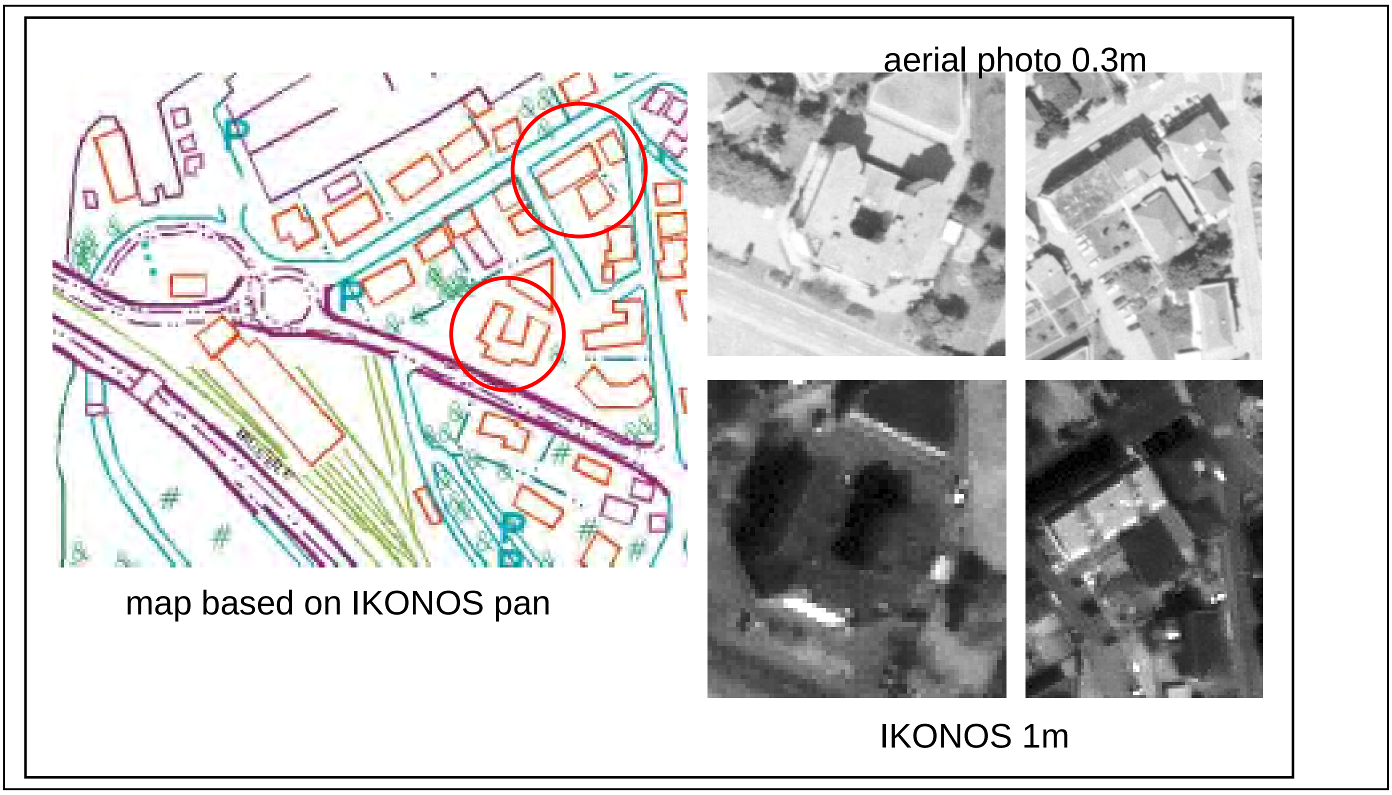

Figure 18: details of mapping

The main information achieved by the mapping with the IKONOS-images corresponds to a map scale 1:10 000. This confirms the **rule of thumb for the required pixel size for a map scale that 0.05 up to 0.1mm pixel size in the map scale are required**. For the panchromatic IKONOS-image with 1m pixel size this means a map scale number of : 1m / 0.1mm = 10 000 should be possible and this has been confirmed.

The line map has been made at first with the IKONOS-image and after this with the Swiss orthophoto to avoid a pre-knowledge of the area. Based on the identification of the Swiss orthoimage, also the not recognised buildings in the IKONOS-image could be seen. That means, with support of a field check the missing elements can be mapped, but not the details of the buildings. Also a local improvement of the grey values supported the object identification.

7 CONCLUSION

The generation of orthoimages based on the CARTERRA-Geo-product, which is a rectification to a plane with constant height, can be made by means of a DEM and control points. Even if the nominal collection elevation and azimuth from the IKONOS metadata-file are not available, with control points in different altitude this can be computed. Only few control points are required for reaching the full accuracy potential. The DEM's can be created based on IKONOS-stereo models available as Geo-images with high accuracy, which is in any case sufficient for the creation of orthoimages in the scale 1 : 10 000.

The information contents of the IKONOS-PAN-images corresponds to topographic maps 1 : 10 000. Only few details could not be recognised. The reached accuracy is also sufficient for this scale.

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