Information Contents of High Resolution Satellite Images

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ABSTRACT: Large scale topographic maps do include more details like small scale maps. Corresponding to this, the required details have to be visible in the used images. Not only the pixel size, also the image quality, the spectral range and the number of spectral bands and the sensor type are important for the object identification. Even if space photos are scanned with a small pixel size, this must not correspond to the information contents; the photo grain may limit the information contents of digitized photos. Today the majority of space images are based on CCD line or array sensors, so the ground pixel size is better defined like for photos. The ground sampling distance (GSD) – the distance of the pixel centres on the ground – must not be the same like the size of the physical pixels projected to the ground. We do have the influence of the optics, the actual situation of the atmosphere and a numerical over or under sampling. In addition the image quality, especially the contrast, is depending upon the grey value range which goes from 6 bit or 64 different grey values to 12 bit or 4096 different grey values. Very high resolution images must be equipped with a time delay and integration (TDI) technology or the image motion has to be reduced by a permanent rotation of the satellite during imaging. Both techniques can influence the image quality.

In the test area Zonguldak, Turkey, the effective information contents of several sensors like TK350, KVR1000, ASTER, SPOT V, IRS-1C, KOMPSAT-1, IKONOS and QuickBird have been analysed for the generation of topographic maps.

1 INTRODUCTION

The information contents and the geometric accuracy are important for the generation of qualified topographic maps with the required contents and geometry. Even if maps today are usually only graphic representations of geo information systems, a GIS is related with the accuracy specification, the contents and the degree of generalization to a representation scale. There is only a very limited range of scale for the graphic output. Maps shall have a horizontal standard deviation of approximately 0.25mm in the representation scale. For the information contents based on experience there is the rule of thumb of 0.05 up to 0.1mm GSD in the representation scale (Doyle 1984). That means with 1m GSD of IKONOS images a map with a scale 1:10 000 can be generated (1m / 0.1mm = 10 000). For this scale a horizontal accuracy of 2.5m (10 000 ∗ 0.25mm = 2.5m) is required. Under operational conditions accuracy in the range of 1 GSD can be reached corresponding to 1m. Because of this relation the bottle neck for mapping is the information contents and not the horizontal accuracy. The information contents are not a very precise defined topic. At first some countries do show more details in the maps like others and the mapped object may be also different. It is easier to map a US city with straight, perpendicular and wide roads like an unplanned city with narrow and not regular roads with small buildings. In addition there are some side effects of the used images like sun elevation (length of shadow), incidence angle and image contrast.

For the vertical accuracy no fixed relation to the map scale is defined because it is more depending upon the terrain. For flat terrain a quite higher vertical accuracy is required like for mountainous areas. The height information may come also from another source like for example the shuttle radar topography mission (SRTM) which generated a homogenous digital elevation model (DEM) for the area from 56° southern up to 60.25° northern latitude (Jacobsen 2005).

2 GROUND SAMPLING DISTANCE

Ground sampling distance is the distance of the centres of neighboured pixels projected to the ground. The pixel size on the ground is the physical size of the projected pixels. Neighboured pixels may be over-sampled (the projected pixels are overlapping) or under-sampled (there is a gap between neighboured pixels). The user will not see something about over- or under-sampling; this is only influencing the image contrast, for the user the GSD looks like the pixel size on the ground. For example SPOT 5 generates in the supermode images with 2.5m GSD, but the neighboured pixels are overlapping 50%, so the pixel size on the ground is 5m.
The effective GSD must not be identical to the nominal. By theory the information contents of the SPOT 5 supermode corresponds to an effective GSD of 3m. Similar this may be the case also for other images. Especially digitized photos may have differences between the nominal and the effective GSD. The effective GSD can be analysed by edge detection. An object with a sudden change of the grey values will not have the same sudden change in the image.

GSD	TK350	KVR1000	ASTER	KOMPSAT-1	IRS-1C	SPOT 5	IKONOS	QuickBird
nominal	10m	1.6m	15m	6.6m	5.7m	5m	1m	0.6m
effective	13m	2.2m	15m	6.6m	6.9m	5m	1m	0.6m

Table 1: effective GSD determined by edge detection

All used images have been analyzed for the effective GSD. For the photos TK350 and KVR1000 available with 10m respective 1.6m GSD from the beginning a difference between the nominal and the effective GSD was expected. From the digital images of the Zonguldak test area only the IRS-1C has an effective GSD larger than the nominal value. For IRS-1C this may be caused by the limited radiometric resolution of just 6 bit. But the effective GSD may be influenced also the actual situation of the atmosphere. In other areas EROS A1 and OrbView-3 has been tested. For EROS A1 the effective GSD was 2.4m instead of the nominal value of 1.8m. For OrbView-3 the effective and the nominal GSD have been identical. Landsat images do have a too large GSD for topographic mapping, nevertheless Landsat 7 panchromatic is with nominal 15m GSD not far away, but as effective GSD only 17m has been seen.
The synthetic aperture radar (SAR) image from JERS of the Zonguldak test area cannot be compared directly with optical images. The physical conditions of SAR imaging are quite different from optical image generation. Speckle is disturbing the object identification. The test of the effective GSD of a SAR image is a little difficult. For the JERS SAR scene the nominal GSD is 12m and by edge analysis an effective GSD of 15m has been determined.

3 COMPARISON OF IMAGES

In figure 1 windows of space images with approximately the same number of pixels from the city area of Zonguldak can be compared. The dominating figure for the object identification is the GSD, but the colour simplifies the interpretation. Landsat 7 MSS with 30m GSD and a good spectral resolution can be used for classification. It is possible to differentiate the object classes, but for topographic mapping it cannot be used. The panchromatic Landsat 7 image with 15m nominal and 17m effective GSD has only limited contrast. With ASTER images more details can be seen. The contrast of ASTER is quite better; in addition the multispectral presentation has advantages. With 15m GSD always some structures in the city and the major roads can be identified. Not only the edge analysis, also a simple comparison with ASTER and panchromatic Landsat indicates that TK350 does not have the information contents corresponding to 10m GSD, it is not better like panchromatic Landsat. In addition the original photo includes a high number of scratches and visible film grain which had to be filtered.

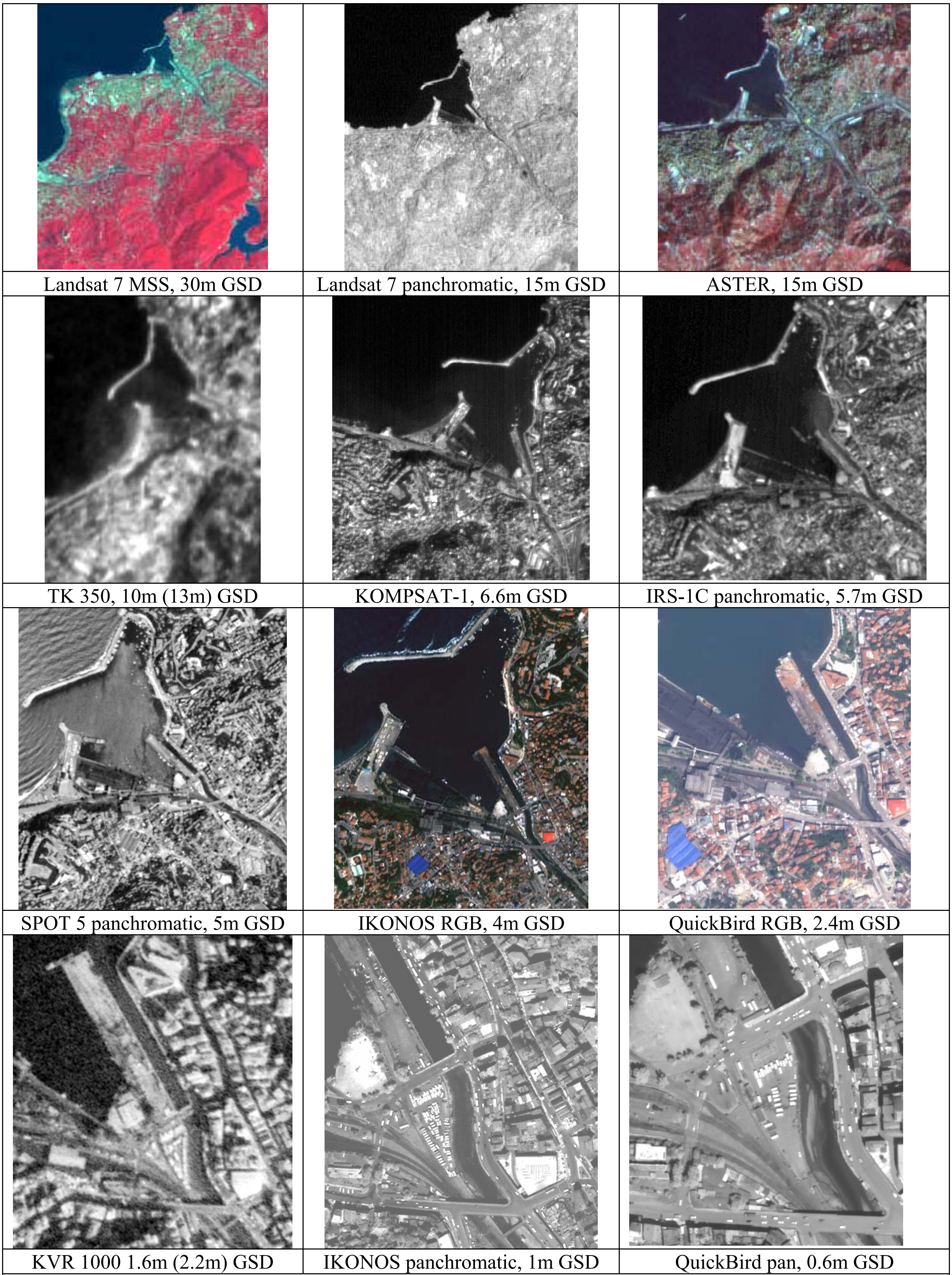


Figure 1: space images available in Zonguldak test area, shown with full resolution

A comparison of Landsat and ASTER with the JERS synthetic aperture radar (SAR) image having a similar GSD demonstrates the lower information contents of SAR in relation to optical images. SAR is disturbed by speckle and especially in build up areas individual strong reflections occur by buildings acting as corner reflectors. A comparison within a EuroSDR test (Lohmann et al 2004) of aerial SAR and optical images having the same GSD in the range of 1m up to 4m resulted in information contents of SAR images in relation to optical images in the range of 60% to 100%. This result may be important for the announced high resolution space born SAR systems; images like JERS with a nominal GSD of 12m are not useful for topographic mapping.
Starting with 6.6m GSD of KOMPSAT-1 it is becoming more important for mapping purposes. KOMPSAT-1 and SPOT 5 are very close together with the GSD and also the general object identification. The major road structures within the city can be identified. In general the city of Zonguldak is a difficult area – the buildings are close together, so sometimes it is not easy to decide on which side of a building row the street is located, also backyards have been identified by mistake as roads. In addition within the build up area is very steep and on the northern slope the streets have been totally in the shadow. It is not possible to digitize individual buildings. Only large ones and industrial complexes or building blocks can be mapped. This is sufficient for 1:50 000, larger map scales cannot be generated (figure 2).

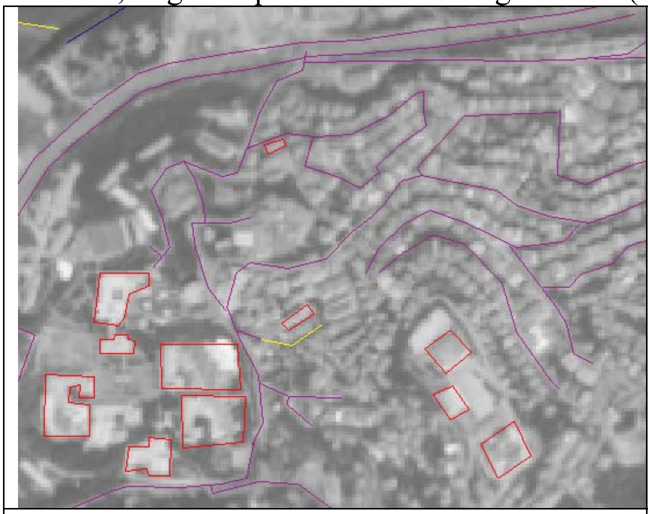


Figure 2a: SPOT 5 with digitized elements

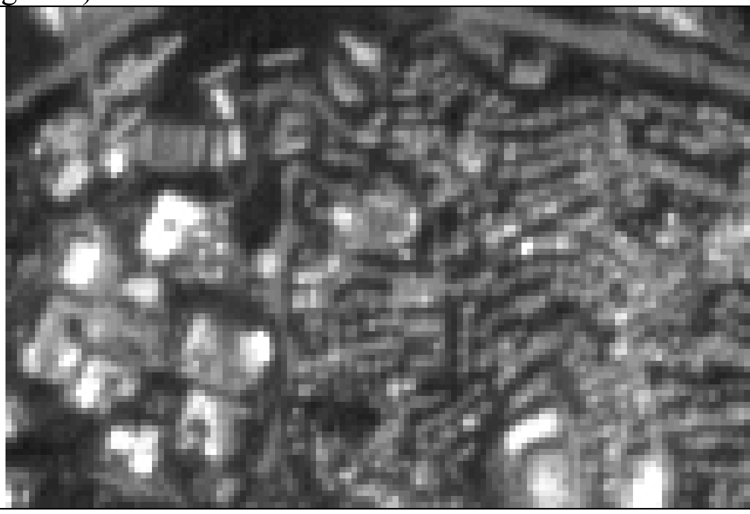


Figure 2b: KOMPSAT 1

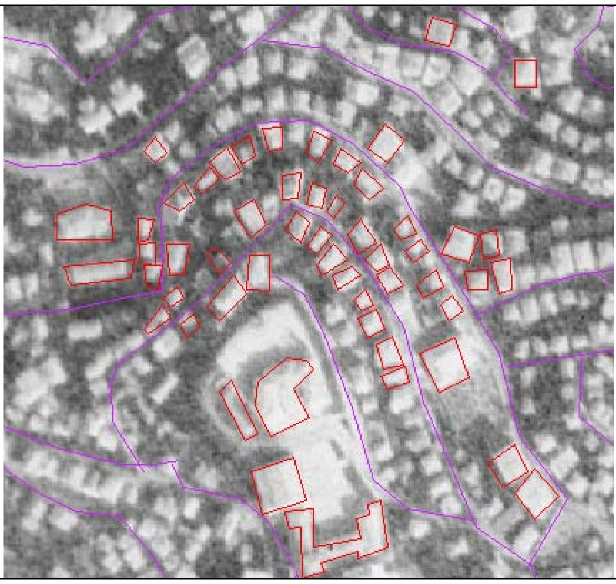


Figure 3a: KVR1000 with digitized elements

Figure 3b: IRS-1C

A comparison of the panchromatic images from KOMPSAT-1, SPOT 5 and IRS-1C (figures 2a, 2b and 3b) shows the disadvantage of the 6 bit grey value resolution of IRS-1C. Especially the details of the large buildings shown on the lower left hand side cannot be seen. The general object identification corresponds to the effective GSD of 6.9m for the IRS-1C.

The identification of individual buildings starts with 2m GSD in panchromatic images which can be seen at the example of the KVR1000 (figure 3a). Colour is supporting the object identification. The original colour image of IKONOS with 4m GSD shows the individual buildings because of the dominating red roofs in the city of Zonguldak, but the buildings are too small for individual plotting (figure 1). In general the manual classification of the different objects is supported by the colour and the mapping is easier like with panchromatic images. The mayor roads can be identified in IKONOS colour images.

sun elevation 67° azimuth 138°	sun elevation 41° azimuth 166°	sun elevation 46° azimuth 144°

Figure 4: IKONOS images with different sun elevation

Figure 4 shows the strong influence of the sun elevation to the object identification. With a sun elevation of 41° it is difficult to identify the streets located in the building shadows. The building roofs are still in sun shine, so the mapping of the buildings is not a problem, but in Zonguldak the building rows are close together, so sometimes it is difficult to decide if within between it is a street or backyards. Not only the sun elevation is important - the third image has just 46° sun elevation against 41° for the second, also the sun azimuth plays a roll in relation to the street azimuth like visible in the third image in relation to the second. With the third image the mapping of streets was quite easier.
The pan-sharpening simplifies the identification of buildings, but the advantage of the colour is limited for 1m GSD. The IKONOS image shown in figure 5a has been taken with an incidence angle of 30° causing a shift of the building roofs in the orthoimage by 57% of the building heights. Such a shift of up to 10m in the shown image cannot be neglected. It is difficult to map the building at the level of the bare ground – in the shadow there is no good contrast and 50% is hidden by the building itself. The simplest method is the mapping of the roof followed by a shift of the polygon to the visible parts at the ground level.

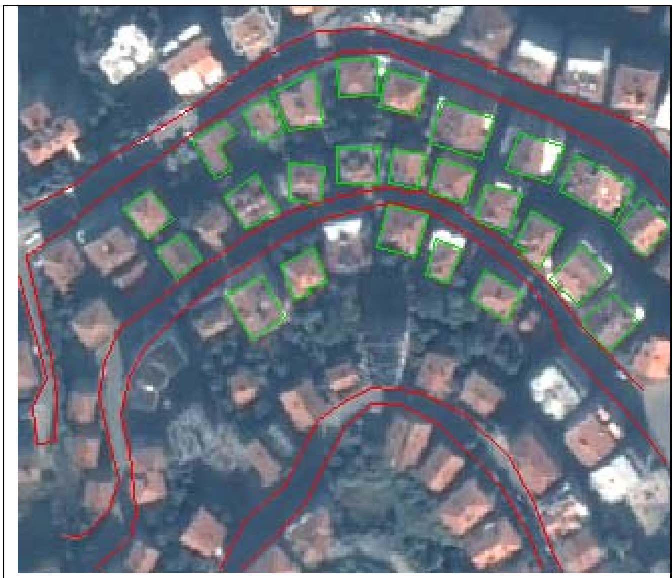
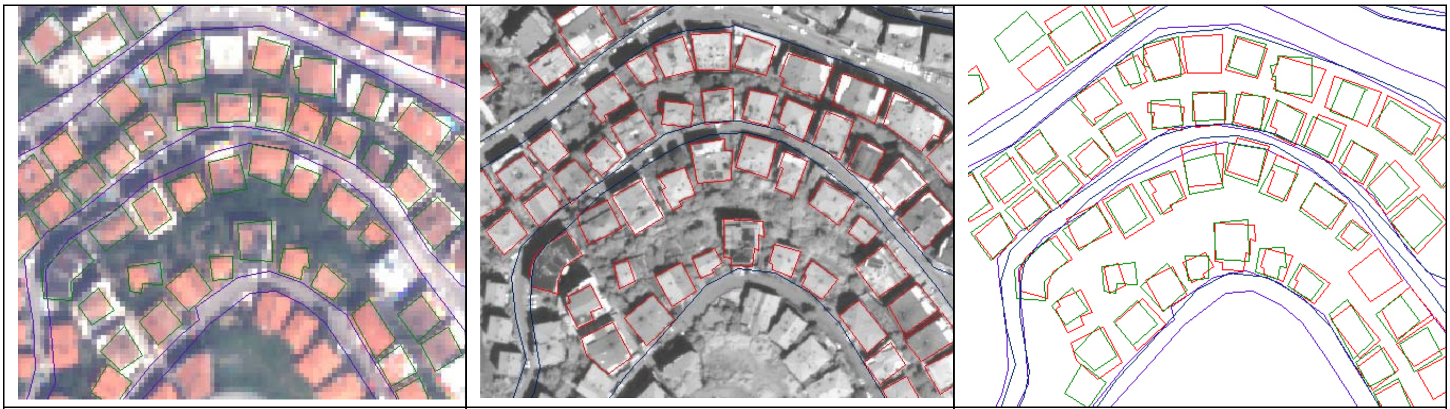


Figure 5a: IKONOS pan-sharpened

Figure 5b: mapping based on QuickBird

With the 2.4m GSD of QuickBird colour images it is difficult to map the correct shape of the buildings which are not in any case right-angled and not having the front parallel to the street (figure 6 left). With 60cm GSD it is not a problem to plot the building details (figure 6, centre). Caused by the object, the mapping of the street lines is not so simple even in the panchromatic QuickBird image. Partially curb stones exists, partially not and partially parking areas are going without clear limits up to the buildings. Also with high resolution aerial images this would not be easier. Under this condition there is a sufficient fit of the street lines. The contents of the map based on the 0.6m GSD corresponds to a map scale 1:5000. Also the required accuracy of 0.25mm in the map corresponding to 1.25m is not a problem; it is only limited by the definition of the objects.



QuickBird colour, 2.4m GSD	QuickBird pan, 0.6mGSD	overlay plot with colour and pan

Figure 6: comparison of mapping with QuickBird colour image (2.4m GSD) and panchromatic (0.6m GSD)

4 CONCLUSION

The major limitation for mapping purposes is the image resolution. The required accuracy of 0.25mm in the publishing scale can be reached without problems, if the following rule for the image interpretation is respected. As major factor for the location accuracy is the identification of the objects in the images; the system accuracy is clearly higher. Orthoimages generated with existing DEMs may have a dominating location accuracy caused by the DEM spacing and accuracy. The standard deviation of the interpolated height multiplied with the tangent of the incidence angle is leading to the accuracy component caused by the DEM.
The general rule for the required ground sampling distance of 0.05 up to 0.1mm in the publishing scale has been confirmed, but it is not totally fixed. We do have an influence of the shadows – also cloud shadows are causing large problems. The identification of objects is depending upon the objects itself. Under the difficult conditions of Zonguldak with strongly curved and often not parallel streets, building rows close together and large terrain inclination, it is quite more difficult to identify the objects like in flat areas with regular scheme. Even with the 1m GSD of IKONOS not in any case it was possible to see small streets and foot paths located in shadow areas. With larger nadir angles in the build up areas several objects are hidden by larger buildings, so mapping in cities is easier with close to nadir images. As well as for the accuracy also for the object identification a small incidence angle has advantages, but the condition of close to nadir images is influencing the repetition time of imaging and it may be difficult to get such images in time especially for areas with high percentage of cloud coverage. In some cases the image quality may be influenced by the atmospheric conditions. The effective GSD should be determined by edge detection because for the space photos and IRS-1C it was not identical to the nominal size.

	required GSD
urban buildings	2m
foot path	2m
minor road network	5m
rail road	5m
fine hydrology	5m
major road network	10m
building blocks	10m

Table 2: required GSD for object identification in panchromatic images under usual conditions

Based on the tests in the Zonguldak area and some previous ones, the rule for object classification listed in table 2 has been found. Colour images do improve the object classification, so in the case of colour the required GSD may be 1.5 times as much. Images having a GSD exceeding 10m are not sufficient for the generation of topographic maps. The TK 350 photos from Zonguldak do have only an effective GSD of 13m; they cannot be used for topographic mapping purposes even for the map scale 1: 100 000. With a GSD in the range of 5m to 7m not all important objects can be seen if the contrast is not sufficient. In addition no actual space photos taken with TK350 or KVR1000 are available. The good contrast of SPOT images was leading to quite better results like with IRS-1C; KOMPSAT-1 was within between. The KVR 1000 image with an effective GSD of 2.2m shows all details required for the map scale 1 : 25 000 and even more, but it is not sufficient for the map scale 1 : 10 000. With IKONOS having 1m GSD a mapping in the scale 1:10 000 and with QuickBird a mapping in 1:5000 is possible. Now IKONOS images can be ordered also with the original GSD of 0.8m, such images have not been investigated in the Zonguldak area.

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REFERENCES

Doyle, F.-J., 1984: Surveying and Mapping with Space Data, ITC Journal 1984

Jacobsen, K., 2005: High Resolution Imaging Satellite Systems, 3D-Remote Sensing Workshop, Porto, on CD

Lohmann, P., Jacobsen, K., Pakzad, K., Koch, A., 2004: Comparative Information Extraction from SAR and Optical Imagery, Istanbul 2004, Vol XXXV, B3. pp 535-540

Topan, H., Büyüksalih, G.,Jacobsen, K., 2004: Comparison of Information Contents of High Resolution Space Images, ISPRS Congress, Istanbul 2004, IntArchPhRS. Vol XXXV, B4. pp 583-588

Wegmann, H., Beutner, S., Jacobsen, K., 1999: Topographic Information System by Satellite and Digital Airborne Images, Joint Workshop of ISPRS Working Groups I/1, I/3 and IV/4 – Sensors and Mapping from Space, Hannover 1999, on CD + http://www.ipi.uni-hannover.de