Mapping from space for developing countries

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ABSTRACT: Mapping today is a data acquisition for Geo Information Systems (GIS). Maps are just one form of the output of the geoinformation. Geoinformation are important as basic information for any planning purpose, nevertheless the term mapping is used for such data acquisition. Without such information no modern administration of a country is possible. In several developing countries no actual geoinformation and no regular update exists. Classical, the data acquisition is based on aerial images, but not in all countries photo flight equipment is available and foreign photo flight companies can enter some countries only with extreme bureaucratic effort, causing a delay of photo flights and raising the price. The problem of control point determination for mapping purposes today is solved by GPS-positioning, which can be improved by world wide satellite reference systems like Omnistar to absolute accuracy up to 30cm. With the high and very high resolution optical satellites a competition to aerial images exist. The highest resolution system operational now is WorldView-1 with 50cm distributed ground sampling distance (GSD) corresponding to a photo scale of approximately 1 : 20 000.

For topographic maps not in every case the highest resolution is required. Based on long time experience, satellite images with 5m GSD can be used for mapping in the scale 1:50 000 or approximately 0.1mm GSD is required in the map scale. For three-dimensional point determination stereo pairs are required. From the very high resolution satellites only few stereo pairs, taken from the same orbit, are available, but this is partially solved by the stereo systems Cartosat-1 and ALOS-PRISM. The image quality of ALOS-PRISM is still not optimal, but the images can be used for the generation of digital elevation models (DEM). The geoinformation also can be generated by on-screen digitizing of orthoimages if a DEM exists. Beside the possibility of the generation of height models by automatic image matching, DEMs can be bought also based on the stereo system SPOT-5 HRS, but for several purposes the nearly world wide available SRTM height model can be used free of charge.

An overview about available imaging systems, the possibility of DEM generation as well as detailed description about the possibilities and limitations of the SRTM height models will be given as well as an overview about the experimental relation between GSD and possible map scale. The geometric and information potential of the serious of high and very high optical satellite images is demonstrated.

1 INTRODUCTION

Geometric correct and actual geo-information is required for any planning process. In several developing countries no up to date mapping information is available. Especially metropolitan areas are affected by emigration to cities, so cities having a population in the range of 100 000 thirty years ago, today have millions. Infrastructure problems and especially ecologic difficulties are caused. Under such conditions slums

arise, affecting the whole cities and even countries. The only possibility to control or reduce such problems is an optimal planning, which has to be started by data acquisition.
Mapping by ground survey is too time consuming and sometimes the access to some areas is dangerous up to impossible. So for example in the Brazil slums, the so called favelas, the access for governmental authorities is so risky, that they do not try any ground survey. Aerial survey of course can be used, but if there is no photo flight plane available in the country, it is time consuming and expensive. In addition in several countries restrictions for the use of aerial images exist, even if today this is not any more justified. With the very high resolution space images, now available with up to 50 cm GSD, a topographic mapping up to the map scale 1:5000 is possible. Geoinformation systems (GIS) of course are based directly on the ground coordinates, so no scale of mapping is fixed, but the accuracy and especially the information details determine a representation scale of a GIS. Of course some flexibility for the representation scale exists, but if the expected accuracy and information quality is respected, the variation is very limited. Also a smaller representation scale is difficult because of required generalisation.

2 SENSORS

A serious topographic mapping requires a GSD of 5m or smaller. Of course also with images of SPOT-1 up to SPOT-4, having 10m GSD for the panchromatic channel, topographic maps have been generated, but in such maps often important details are missing and the effort for the identification of visible objects required an intensive ground check. So the real generation of topographic maps started with approximately 5m GSD. The boom in mapping with space images came with the 1m GSD of IKONOS, now followed by several also very high resolution optical space systems.

sensor	pixel size (nadir) [m] pan / multi spectral	swath [km]	pointing in-track	pointing across
SPOT 1-4	10 / 20	60	-	+/-27°
SPOT 5	5 (2.5) / 10	60	-	+/-27°
SPOT 5 HRS	5 x 10	120	+20°, -20°	-
MOMS-02 / -P	5.8 / 16.5	37 / 78	-27°,0°,27°	
IRS-1C/1D,	5.8 / 23.5	70 / (142)	-	+/-26°
Resourcesat	5.8 / 5.8	70 / (142)	-	+/-26°
EROS A	1.8	12.6	free view direction	
FORMOSAT 2	2 / 8	24	free view direction	

Table 1: High resolution optical space systems without very high (> 1m GSD)

sensor	GSD (nadir) [m] pan / multi spectral	swath [km]	remark
IKONOS	0.82 / 3.2	11.3	
QuickBird	0.61 / 2.44	16.4	
OrbView-3	1 / 4	8	colour and pan not together
EROS B	0.7 / -	14	
KOMPSAT-2	1 / 4	14	
Resource DK1	1 / 3	28	elliptical orbit
Cartosat-2	1 / -	10	
Worldview-1	0.45 / -	16	distributed with 0.5m GSD, no colour

Table 2: very high resolution optical space images

sensor	GSD (nadir) [m]	swath [km]	pointing in-track
SPOT 5 HRS	5 x 10	120	+20°, -20°
Terra ASTER	15 / (30, 90)	60	0°, 27.2°
Cartosat 1	2.5	30	26° fore, 5° after
ALOS PRISM	2.5	35 (70)	-24°, 0°, +24°

Table 3: optical stereo space systems

	IKONOS	QuickBird	WorldView-1	*GeoEye*	*WorldView-2*
company	GeoEye	DigitalGlobe	DigitalGlobe	*GeoEye*	*DigitalGlobe*
launch	24.9.1999	18.10.2001	18.9.2007	*1st quarter 2008* planned	*2008 planned*
GSD [m]	0.82/ 3.28	0.61/2.44	0.45 / -	*0.41/1.64*	*0.45/1.80*
Agility – slew 300km	25 sec	62 sec	10 sec	*42 sec*	*9 sec*
remark		asynchronous	only pan		*8 colour bands*

Table 4: comparison of highest resolution optical systems

The tables 1 up to 4 also illustrate the development of optical space systems. At first a stereoscopic coverage was only possible by changing the view direction across the orbit by rotating a mirror or the camera. This now has been replaced by agile satellites, equipped with reaction wheels or control moment gyros, able to change the view direction of the satellites fast and very precise, so that a continuous change within imaging is possible without loss of accuracy; so stereo images can be taken from the orbit with a time delay of only few seconds, avoiding a change of the object during taking both images. The agility of the satellites is different, QuickBird is relatively slow so a stereo imaging within the orbit is not economic, leading to the situation, that only few QuickBird stereo pairs from the same orbit are available. This has changed with WorldView-1, able to generate more than one stereo pair from the same orbit (table 4). The limitation of available stereo pairs caused the appearance of stereo systems (table 3), generating with 2 or 3 cameras always stereo coverage's. The number of high resolution systems will grow in near future. Also smaller systems with approximately 2m will be operated by countries, not active in imaging from space up to now.

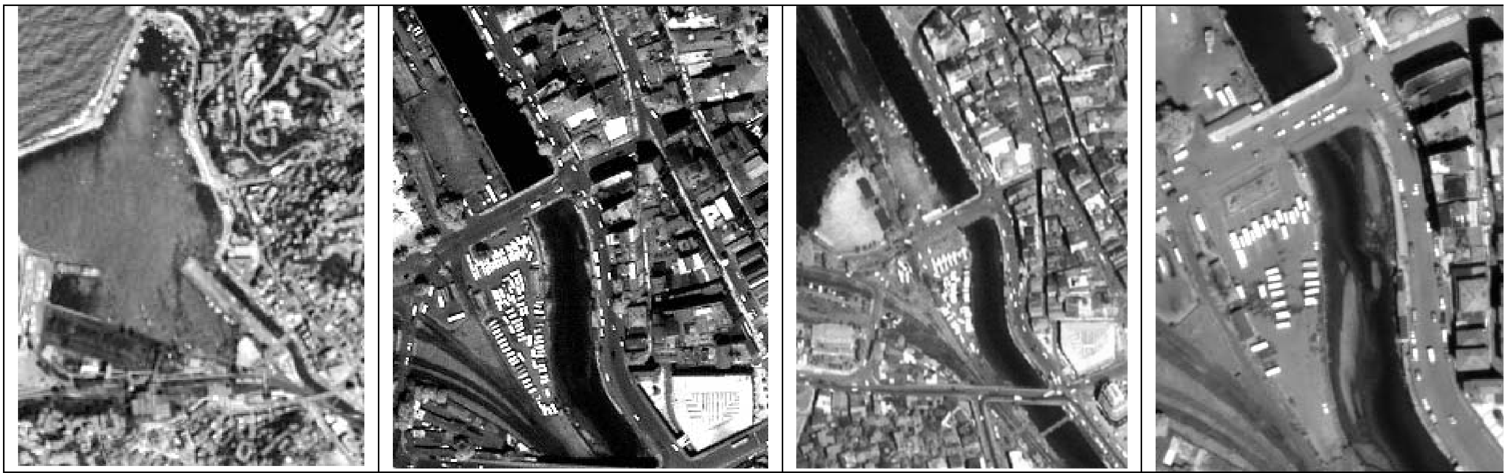
3 INFORMATION CONTENTS OF IMAGES

Landsat-5, 30m GSD	ASTER, 15m GSD	KOMPSAT-1, 6.6m	IRS-1C, 5.7m GSD

Fig. 1: comparison of space images

As it is obvious in figure 1, Landsat TM and ASTER with its resolution of 30m and 15m cannot be used for topographic mapping. Landsat is specialised for land classification, but the road network cannot be identified like with ASTER. This becomes better with KOMPSAT-1 and IRS-1C, where the mayor road network can be identified.

The information content must not agree in any case with the nominal GSD. The effective resolution has been checked by edge analysis. A sudden change of brightness in object space (e.g. bright roof beside dark shadow) is causing a continuous change of grey value profiles in the images. A differentiation of the grey value profile leads to the point spread function. The width of the point spread function includes the effective resolution, corresponding to the information content. IRS-1C is only a 6 bit-image, this may explain the effective resolution of only 6.9m. Of course this may be influenced by the atmospheric conditions during imaging. In fact in the KOMPSAT-1 image, more details could be identified like in the IRS-1C image. The slightly better resolution of SPOT-5 leads also to a slightly better possibility of object identification.



SPOT-5, 5m GSD	IKONOS, 1m GSD	OrbView-3, 1m GSD	QuickBird, 0.6m GSD

Fig. 2: comparison of very high resolution space images

With higher resolution more details can be identified in the space images. OrbView-3 has a pixel size of 2m; neighboured pixels are over-sampled by 50%, so the distance from one projected pixel centre to the next (the GSD) is 1m. Of course with such a technique the image quality cannot be the same like in the case where the pixel size is identical to the GSD. By this reason more details can be identified in an IKONOS image like in an OrbView-3-image. Of course the better resolution of QuickBird leads to more visible details.

4 GENERATION OF TOPOGRAPHIC MAPS

For most space images also colour channels are available with lower resolution. By pan-sharpening the lower resolution colour can be mixed with the higher resolution panchromatic channel to a colour image with the same resolution like the panchromatic image. A comparison of mapping with very high resolution pan-sharpened images against mapping with panchromatic images showed no remarkable advantage of the colour. Colour only simplifies the object identification, making it faster, but only very few additional objects have been identified (figure 3).

Figure 3: panchromatic and pan-sharpened IKONOS image in difficult area

Figure 4: IKONOS-images Zonguldak taken with different sun elevation of
46° 41° 61°

A more important fact is the imaging condition. Like shown in figure 4, the information content may dependent upon the sun elevation. In the IKONOS image taken under 41° sun elevation, the streets are mainly in the shadows, so only few details of the streets, like the limits of the footpath, could be seen. The same importance has the cloud coverage. In cloud shadows a mapping is very difficult. Also close to the clouds in most cases too much haze is available, avoiding the object identification.

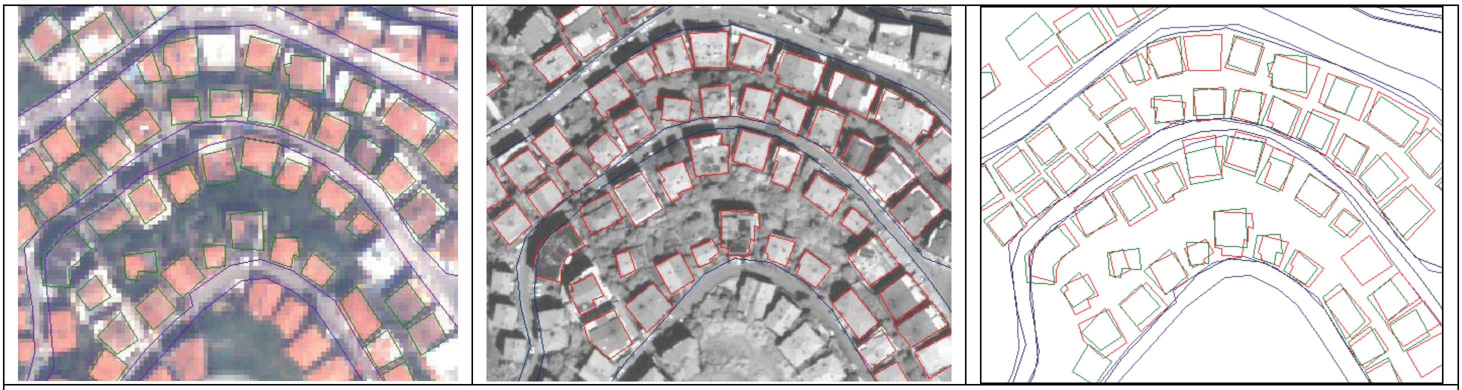
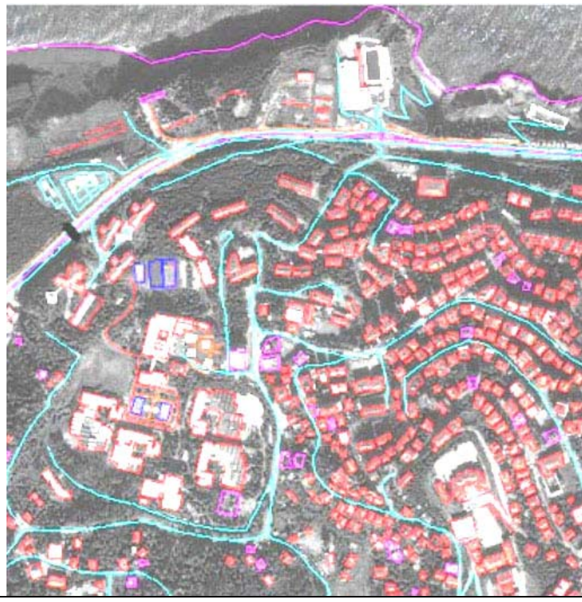


Figure 5: Mapping of buildings with original QuickBird colour images (2.4m GSD) and with QuickBird panchromatic images (0.62m GSD), on right hand side overlay of mapped buildings

In figure 5 a mapping based on QuickBird images with the original colour, having 2.4m GSD, and the panchromatic image (0.62m GSD) has been compared. Any building could be identified also with 2.4m GSD, but the details of the buildings, corresponding approximately to the information details of a map 1:5000, could only be identified with 0.62m GSD.

Topographic maps shall have a standard deviation of the coordinate components of 0.2mm up to 0.3mm in the map, corresponding to 1m up to 1.5m in the map 1:5000. For QuickBird this corresponds to 1.6 up to 2.4 GSD. This is not a problem for well defined objects, because in general an accuracy of approximately 1 GSD can be reached with nearly all very high resolution space images. In most cases the mapping is based just on one image; that means, orthoimages have to be generated and the mapping is an on-screen digitizing of orthoimages. This is a simple type of mapping, where the operator must have experience only with the object interpretation and the effect of displacement by height differences against the surface of the digital elevation model (DEM). Opposite a stereoscopic mapping requires quite more training of the operator. The generation of orthoimages requires a DEM. The SRTM DEM (see chapter 5) has a standard deviation of approximately 4.5m in open and flat areas. That means the influence to the location is in the range of 1m if the nadir angle does not exceed 12.5°. So very often this DEM can be used. For larger nadir angles and rough terrain a better DEM may be required, like it is possible for example with Cartosat-1 (Jacobsen 2006).



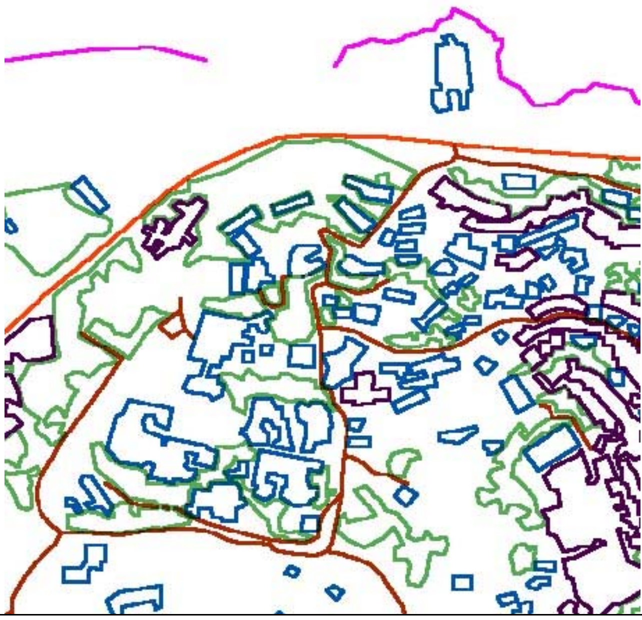
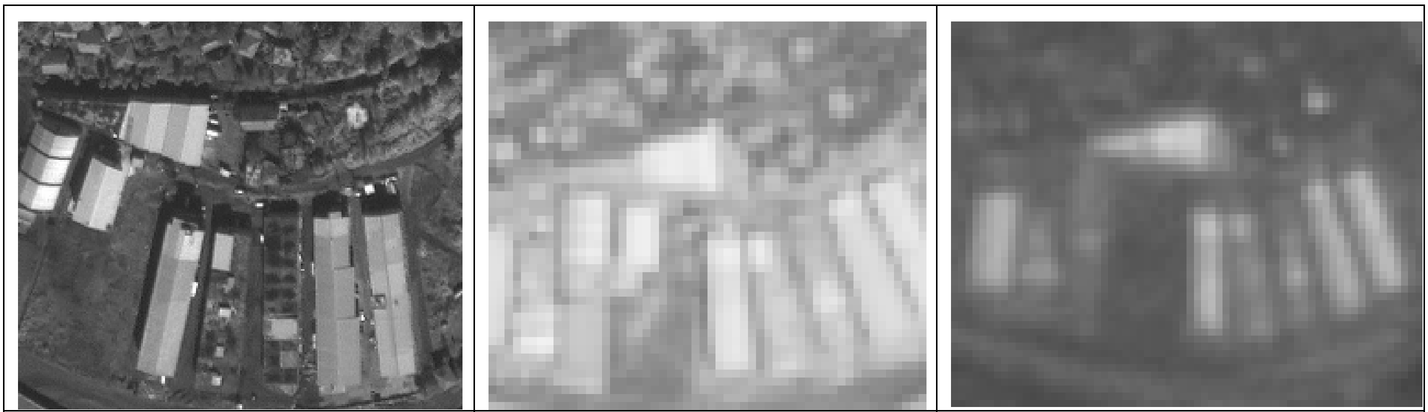


Figure 6: mapping with OrbView-3 (upper left), IKONOS (upper right) and QuickBird (centre left) in comparison to topographic map 1 : 5000 from survey administration (centre right)

mapping with SPOT-5 (lower left)

In the area of Zonguldak, Turkey, OrbView-3, IKONOS and QuickBird images have been used for mapping (figure 6). For medium and larger buildings with regular roof-shape, the mapping is easy with all images. Sometimes concrete roofs cannot be separated from the surrounding garden if no shadow is increasing the contrast. Even in the very high resolution QuickBird images sometimes the contrast of buildings is not sufficient for a precise mapping. The side-line of roads cannot be extracted since they are located in the shadow of building and trees and not in any case there is a clear side line in nature. Of course such problems exist also for aerial photos with corresponding GSD. There is only a limited difference between mapping results based on panchromatic and pan-sharpened images. Especially few additional smaller buildings in unplanned areas have been mapped only with pan-sharpened images. But the color is helpful for object interpretation and speeds up the data acquisition. The higher resolution of QuickBird allows the plot of few additional unpaved paths and shorter streets located in shadows or hidden by buildings. The results based on IKONOS and OrbView-3 are not too different, only very few details have not be mapped with OrbView-3 (see also Topan et al 2006).

Using the images from SPOT-5, IRS-1C and KOMPSAT-1, with GSD between 6.6m and 5m, is quite different than using the images with 1m or better GSD. With approximately 5m GSD building blocks can be identified and the mapping is only possible for very large buildings (figures 6 and 7). This corresponds to the rule of topographic mapping, that approximately 0.1mm GSD in the map scale is required. Corresponding to this, a topographic map 1 : 50 000 could be generated with 5m GSD. In such a topographic map usual buildings are only included as symbol and in cities only building blocks are shown. Important for this scale is the completeness of the road network. In the Zonguldak area not all roads could be identified correctly, but the city of Zonguldak is a difficult area for data acquisition – the roads are narrow, the buildings are high and the terrain even in the city has an inclination up to 30%.



IKONOS, 1m GSD	SPOT-5, 5m GSD	IRS-1C, 5.7m GSD

Figure 7: identification of buildings in very high and high resolution space images

A topographic mapping with images having 10m GSD and larger is not possible. If the GSD exceeds clearly 5m several elements, important also for smaller map scales, cannot be identified.

5 DIGITAL ELEVATION MODELS

DEMs are a basic part of any GIS. They are required for the generation of orthoimages and several planning purposes. The worldwide lack of qualified and accessible DEMs has been improved with the Shuttle Radar Topography Mission (SRTM) in February 2000. It was an international project from USA and Germany/Italy. Based on the German/Italian SRTM X-band, DEMs have been generated by the German DLR. They can be bought with a point spacing of 1 arcsec, corresponding to 31 m at the equator. The SRTM X-band has not used a scan-SAR mode, so the area between 56° southern up to 60.25° northern latitude is covered only partially. This is different for the US SRTM C-band DEM, it only has gaps in steep mountains, on water bodies without waves and very dry sand desserts. The US SRTM C-band DEM is available free of charge in the internet with 3arcsec spacing, corresponding to 92m at the equator.
Some SRTM DEMs have been compared with precise reference DEMs (table 5). In general the accuracy of the SRTM C-band DEM is on the same level like the SRTM X-band DEM. The spacing of 1arcsec instead of 3arcsec for the X-band DEM has special advantages in mountainous areas, where an interpolation over 92m leads to a loss of accuracy. X- and C-band radar cannot penetrate the vegetation; that means they are representing the visible surface and not the bare ground. Of course this is the same for DEMs generated by automatic image matching of optical space images.

	RMSZ [m]	bias [m]	RMSZ F(terrain inclination) [m]
Arizona, open area (flat – smooth mountains)	3.9	1.3	2.9 + 22.5 ∗ tan α
Williamsburg NJ, open area (flat)	4.7	-3.2	4.7 + 2.4 ∗tan α
Atlantic City NJ, open area (flat)	4.7	-3.6	4.9 + 7.6 ∗ tan α
Bavaria, open area (rolling)	4.6	-1.1	2.7 + 8.8 ∗ tan α
Bavaria, open area (steep mountain)	8.0	-2.4	4.4 + 33.4 ∗ tan α
Zonguldak, open area (rough mountain)	7.0	-4.4	5.9 + 5.6 ∗ tan α
West-Virginia, forest (mountainous)	11.6	-7.7	7.3 + 7.2 ∗ tan α
Atlantic County, open area (flat)	4.4	-3.4	4.4
Pennsylvania, open area (flat – rolling)	5.4	-0.2	5.3 + 9.4 ∗ tan α
Pennsylvania, forest (mountainous)	7.9	-4.3	7.0 + 6.4 ∗ tan α
Philadelphia, city area, filtered (flat)	3.2	-1.3	3.2

Table 5: root mean square Z-discrepancies of SRTM C-band height models [m]
α = terrain inclination (Jacobsen 2005, Passini et al 2007, Sefercik et al 2006)

CartoSat-1 always generates a stereo coverage. In the frame of the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme 3 Cartosat stereo pairs have been used for DEM generation and could be compared with precise reference DEMs (table 6) (Jacobsen 2006). The surprising result of matching was that there are only negligible gaps. This was confirmed in a mountainous area north of Istanbul, nearly totally covered by forest. Also in this difficult area, with the exception of small cloud coverage, only negligible gaps appeared. This was different for SPOT-5 HRS, where it was quite more difficult in forest areas (Jacobsen 2003). The different behaviour of SPOT-5 HRS and Cartosat-1 in forest areas can be explained by the spectral range of the sensors. Cartosat-1 is also sensitive for the near infrared, generating better contrast in forests.

The vertical accuracy of a height model in general is depending upon the terrain inclination, so a complete analysis has to be made as a function of the tangent of the terrain inclination. A different accuracy for open areas and forest has to be expected. The elements not belonging to the bare ground can be filtered if there are some elements representing the ground are available in the neighbourhood. The filtering works in open areas, where only few points are not belonging to the ground, but it has problems in closed forest areas, where no ground can be seen. The forest in the Cartosat test areas has several clear cuts, so an improvement of the height model was possible.

	Mausanne January			Mausanne February			Warsaw		
	SZ	bias	SZ as F(inclination)	SZ	bias	SZ as F(inclination)	SZ	bias	SZ as F(inclination)
open areas	4.02	-0.51	3.91 + 1.64∗tan α	4.13	-1.16	3.96 + 3.06∗tan α	3.23	-0.54	3.16 + 1.19∗tan α
forest	3.55	0.92	3.33 + 0.33∗tan α	3.59	0.58	2.82 + 1.70∗tan α	4.37	0.64	4.11 + 0.34∗tan α
open areas filtered	3.30	0.48	3.17 + 3.14∗tan α	3.39	-0.58	3.22 + 1.97∗tan α	2.43	0.44	2.39 + 8.80∗tan α
forest filtered	3.47	1,49	2.93 + 1.81∗tan α	3.42	1.43	2.69 + 1.97∗tan α	3.13	0.81	3.11 + 6.50∗tan α

Table 6: accuracy of Cartosat-1 height models

6 CONCLUSON

Very high resolution space images can be used for the generation of large scale topographic maps in urban areas. The geometric accuracy is not the limiting factor for the map scale; it is limited by the information contents of the images; that means the possibility of object identification. However, in relation to a topographic map 1 : 5000 not all objects could be mapped. This confirms the rule of thumb, that a GSD of at least 0.1mm in the map scale is required or reverse that IKONOS and OrbView-3 images can be used for the topographic map scale 1 : 10 000. With the 0.6m GSD of QuickBird images more details can be seen like with 1m GSD, but the details of the reference map has not been reached. This is also the case for aerial images having a similar GSD – also for aerial images additional ground information is generated. Of course this is also influenced by not so experienced operators and the extreme difficult test area. In not so mountainous terrain and in planned build up areas it is quite easier to generate topographic maps and QuickBird images can be used without problems up to the map scale 1 : 5000.

Not only the GSD; also the imaging conditions are important. The sun elevation plays a major role because mapping in the shadow is quite difficult. The colour is helpful for object identification, speeds up the mapping but does not lead to more details and higher accuracy.

The mapping usually will be made by on-screen digitizing of orthoimages. For the generation of orthoimages height models are required. For space images with limited nadir angle, the free of charge available SRTM C-band height model can be used. If this is not sufficient, height models have to be generated by automatic image matching. Optimal conditions today are available with the stereo sensors Cartosat-1 and ALOS-PRISM, or the height models from SPOT-5 HRS can be bought.

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