Very high resolution satellite images - competition to aerial images

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Introduction:

Very high resolution images taken from optical satellites today reach a ground sampling distance (GSD) up to 0.41m, distributed with 0.50m. Such a resolution also belongs to the domain of aerial images, leading to a competition between space and aerial images. Under operational conditions the decision for the source of images for a project is not only determined by technical parameters, it depends upon the availability of images. Here also the aspect of classification is important – if the use of aerial images is restricted, even a higher price is paid for comparable space images. Nevertheless it should be clear, where are the limits for the use of different image products to avoid unnecessary problems with project specifications.

High and very high resolution space images:

The grouping of high and very high resolution space images is not generally accepted; within this presentation very high resolution are images with 1m or smaller GSD for the panchromatic or highest resolution channel of the satellite.

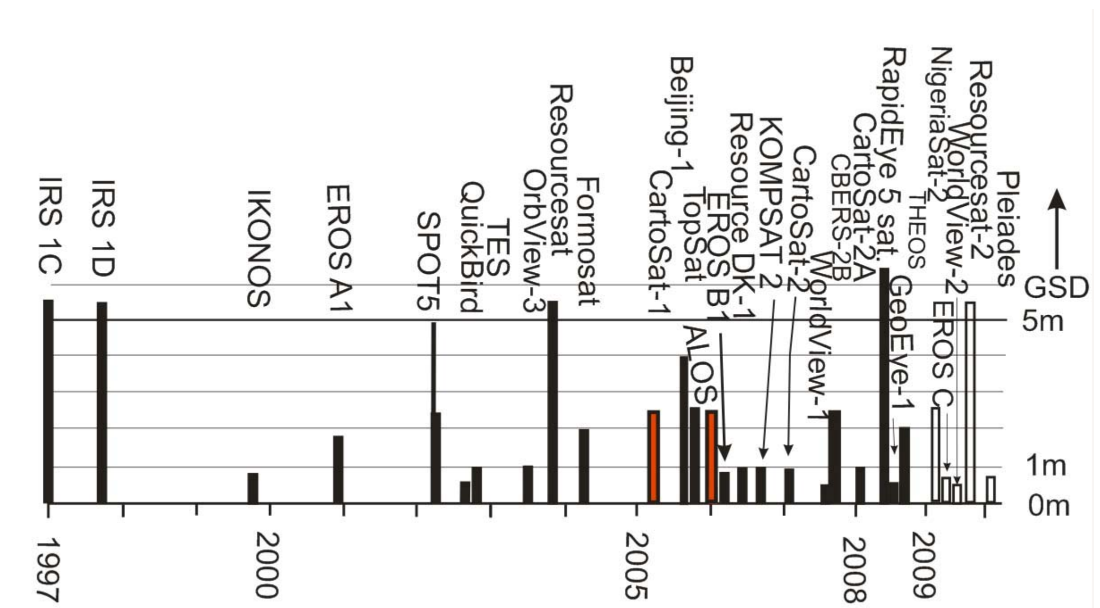


Figure 1: Overview over high and very high resolution optical satellites as function of launch time and GSD of highest resolution channel

As visible in figure 1, the number of high and very high resolution satellites is growing fast. In figure 1 in total 11 existing satellites with 1m GSD and below are shown and for 2009 more are proposed. In this overview only systems available for civilian use are included; the not accessible military systems are not respected here. Of course most of these systems are fore dual use – military and civilian, but the free satellite capacity can be used for civilian purposes.

Most very high and very high resolution satellites have a combination between higher resolution panchromatic channel and lower resolution multispectral channels. This combination is satisfying for interpretation and mapping purposes, here the colour must not have the same high resolution as the panchromatic band. Large differences exist for the data acquisition capacity. For example EROS-B is operating in asynchronous imaging mode with a slow down factor in the range of 8 (8 times longer orbit segment as scene size on the ground) and has limited storing and transmission capacity, so only individual scenes are taken, while WorldView-1 has an imaging capacity of 750 000 km²/day.

Geometric Potential:

The orientation of satellite images is supported by direct sensor orientation – the satellites are equipped with a positioning system like GPS, giros for getting attitude information, supported by star sensors. The direct sensor orientation without support by control points today has reached a high accuracy level. IKONOS can determine ground positions with a standard deviation of approximately 4m for X and Y and WorldView-1 and GeoEye-1 are specified with 2.5m up to 3m. Similar techniques are available for aerial images with accuracy for the coordinate components in the range of 0.15m. If the accuracy of the direct geo-referencing is not satisfying, the national datum is not known accurate enough or reliable positions have to be guaranteed, ground control points are required.

The precise geo-reference is possible by reconstruction of the imaging geometry, replacement models like sensor oriented rational polynomial coefficients (RPC) or approximations. By bias corrected, sensor oriented RPC-solution the same accuracy as with geometric reconstruction is possible (Jacobsen 2008b), while approximations for the scene orientation strongly depend upon the number and three-dimensional distribution of ground control points. The approximations as 3D-affine transformation, direct linear transformation and terrain dependent RPC-solution, computing a limited number of polynomial coefficients by means of ground control points, cannot be recommended, partially they are leading to poor results and in general they require a high number of ground control points.

For most sensors the geo-reference accuracy is limited by the identification of the ground control points in the images. Even if it is not optimal, control points mostly are located at edges, causing an uncertainty of the image position by at least 0.5 pixels. With large symmetric control points clear sub-pixel accuracy is possible (Hanley et al 2004) with most sensors.

Today most space images are delivered together with sensor oriented RPCs, which are based on direct sensor orientation. They have to be improved by control points, named as bias correction. The handling of the orientation by bias corrected RPCs and by geometric reconstruction depends also upon the image type. There is a tendency to level 1B-type images – images projected to a surface with constant height above geoid like IKONOS Geo or QuickBird OR Standard. The use of close to original images (level 1A-type), only improved by radiometry and inner sensor orientation, is reduced for mapping purposes, but they are still preferred for generation of height models. As visible in table 1, with level 1A and level 1B-type images similar accuracy can be reached in relation to GSD. Only with KOMPSAT-1 and OrbView-3 no sub-pixel accuracy is shown. In the case of KOMPSAT-1 the accuracy is limited by the quality of the control points. OrbView-3 seems to be limited by the inner sensor stability; also other authors are reporting about similar results.

Sensor, test area	level type	GSD	SX/SY	SX / SY [GSD]
ASTER, Zonguldak	A	15 m	10.8 m	0.7
KOMPSAT-1, Zonguldak	A	6.6 m	8.5 m	1.3
SPOT, Hannover	A	10 m	4.6 m	0.5
SPOT 5, Zonguldak	A	5 m	5.1 m	1.0
SPOT 5, Zonguldak	B	5 m	5.1 m	1.0
SPOT HRS, Bavaria	A	5m x 10m	6.1 m	0.7 / 1.1
IRS-1C, Hannover	A	5.7 m	5.1 m	0.9
Resourcesat, Hannover	B	5.9 m	5.3 m	0.9
Cartosat-1, Warsaw	B	2.5 m	1.4 m	0.6
OrbView-3, Zonguldak	A	1m (2m pixel)	1.3 m	1.3 *
IKONOS, Zonguldak	B	1.0 m	0.7 m	0.7
QuickBird, Zonguldak	B	0.61m	0.5 m	0.8
WorldView-1, Istanbul	B	0.50 m	0.45 m	0.9

Table 1: root mean square discrepancies at independent check points determined by scene orientation * OrbView-3 1m GSD, 2m projected pixel size

In comparison the orientation of digital aerial images also is possible with sub-pixel accuracy (Jacobsen 2009). For precise point determination aerial images are oriented by means of targeted control points, enabling a quite better pointing as for usual space image control points. But in general the orientation accuracy of space and aerial images is accurate enough for generation of topographic data sets. The limitation for map scales comes from the side of information contents.

Generation of height models:

Height models are a basic requirement for geo information systems (GIS). They have to be used for the most often generated product, the orthoimage. If the available height models are not accurate enough, have no sufficient point spacing or if existing height models are too expensive or not distributed, height models have to be generated. One possibility is the generation of height models by automatic image matching. This requires stereo models where both images have to be taken under similar conditions. Optimal is the imaging of both used scenes during the same path, avoiding changes of the object and different illumination conditions. With the today dominating flexible satellites in most cases the acquisition of a stereo pair from the same orbit is possible. Nevertheless only a limited number of stereo pairs are available in the image archives because of economic reasons; this is different for the stereo systems like ASTER, SPOT-5 HRS, Cartosat-1 and ALOS/PRISM. Based on 2 or 3 optics, they are generating permanently stereo models. The images taken by SPOT-5 HRS cannot be ordered, SPOT Image only likes to distribute height models based on it. The SPOT-5 HRS height models over forest areas should be handled with care because of the limited spectral range of the images between

0.48µm and 0.70µm. This is not leading to sufficient image contrast in forest areas (Büyüksalih et al 2008). By this reason the Reference 3D height models based on SPOT HRS are supported by a gap filling in some forest regions with the SRTM height model. ASTER stereo pairs are taken in the near infrared spectral range, optimal for matching in forest areas, but the 15m GSD limits the vertical accuracy to approximately 15m (Sefercik et al 2007). ASTER/PRISM images have some problems with the image quality, but this seems not to influence the results of image matching. In addition the orientation of PRISM based on sub-images requires more control points than the orientation of a full scene. Very good results have been achieved with Cartosat-1 stereo pairs. The images are covering a spectral range from 0.50 up to 0.85µm, including the near infrared, leading to good contrast also in forest regions. Even in difficult regions a good coverage by matched points has been reached (Jacobsen, 2007, Büyüksalih et al 2008). Gaps in matching Cartosat-1 scenes are caused in the case of test area Mausanne by missing contrast in fields without vegetation, in Warsaw by areas covered by snow, in Istiranca by clouds and in Jordan by lakes and fields without vegetation. No other optical satellite could lead to completer matching results. The automatic image matching leads to the height of the visible objects, that means to digital surface model. If a mixture of points located on the ground and located on objects, like trees and buildings, is given, the points not belonging to the bare surface can be filtered. By filtering the standard deviations of the height values have been improved in any case (table 2).

		SZ	bias	SZ as F(terrain inclination α)
Mausanne January	open areas	4.02	-0.51	$3.91 + 1.64 \tan\alpha$
	open areas filtered	3.30	0.48	$3.17 + 3.14 \tan\alpha$
Mausanne February	open areas	4.13	-1.16	$3.96 + 3.06 \tan\alpha$
	open areas filtered	3.39	-0.58	$3.22 + 1.97 \tan\alpha$
Warsaw	open areas	3.23	-0.54	$3.16 + 1.19 \tan\alpha$
	open areas filtered	2.43	0.44	$2.39 + 8.80 \tan\alpha$

Table 2: accuracy of Cartosat-1 height models checked by precise reference DEMs

As it can be seen in table 2, the height accuracy depends upon the terrain inclination. For flat and open terrain after filtering root mean square differences of the DEMs based on Cartosat-1 against reference height models are 3.17m, 3.22m and 2.39m. For 2.5m GSD and the base to height relation of 1.6 this corresponds in the average to a standard deviation of the x-parallax of 0.7 GSD, this is a very good result for DEMs. If a DEM is analysed against check points, the results would be too optimistic because check points have usually a good object contrast and are not so much affected by terrain inclination. For getting realistic information about the accuracy of height models, reference height models have to be used. As point spacing 3 GSD, identical to 7.5m, are justified; so detailed and precise DEMs can be generated by automatic image matching of Cartosat-1 images.

Of course with aerial images quite more accurate height models can be achieved as with space images, but finally this is a question of economy, required accuracy and point spacing. Instead of aerial images in some countries airborne laser scanning is used for height models. This is still more expensive, but includes the advantage of a better description of the bare surface.

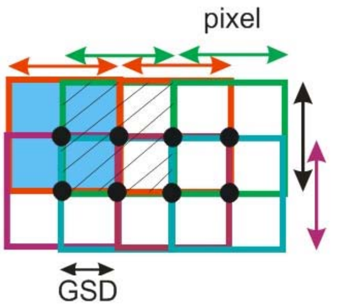
Information Contents - Mapping:

Mapping today is data acquisition for a geo information system (GIS). The geo-reference is stored with the national coordinates, so we do not have the former fixed map scale. Geo-information are visualised with a presentation scale – this has replaced the former map scale. The visualisation scale depends upon the details included in the data base. For a satisfying visual impression there is only a very limited scale range for the presentation, so the presentation scale is still also named as map scale. For a larger map scale the data acquisition has to be based on images with smaller GSD to enable the identification of the required details. The relation between the required GSD and the map scale is a key point for economic data acquisition. This has nothing to do with the misleading information of some satellite image distributors which is just based on accuracy relations. For such a relation at first it has to be checked if the nominal value of the GSD really corresponds to the image quality. By edge analysis a factor for the effective resolution can be determined. A sudden change of the brightness in the object space leads to a continuous grey value change in the image. The grey value profile perpendicular to the edge can be differentiated, leading to the point spread function. The width of the point spread function can be used for the determination of the factor for the effective resolution (Jacobsen 2008a).

sensor	nominal GSD	factor for effective GSD	effective GSD
TK-350	10 m	1.30	13 m
KVR-1000	1.6 m	1.37	2.2 m
ASTER	15 m	1.0	15 m
Kompsat-1	6.6 m	1.0	6.6 m
IRS-1C	5.0 m	1.16	5.8 m
SPOT-5	5 m	1.0	5 m
IKONOS	1 m	1.0	1 m
QuickBird	0.6 m	1.0	0.6 m
OrbView-3	1 m	1.20	1.2 m
Resourcesat	5.9 m	1.12	6.6 m
Cartosat-1	2.5 m	1.12 / 1.28	2.8 m / 3.2 m
ALOS Prism	2.5 m	1.08	2.7 m
WorldView-1	0.5 m	1.02	0.5 m

Table 2: effective image resolution determined by edge analysis

Of course the actual image quality is not only dependent upon the sensor quality, also atmospheric conditions and the sun elevation play an important role, so a variation of the factors listed in table 2 may occur. The edge analysis is also sensitive against edge enhancement, causing too optimistic results. The largest factors we have for the Russian space photos TK-350 and KVR-1000. Here too optimistic information about the real image content came together with the photos. Even the computed effective GSD is affected by the film grain, making the use of the space photos difficult. The major influence to the factor for effective GSD seems to be based on staggered CCD-lines. Caused by the over-sampling of 50% staggered CCD-lines are reducing the GSD by the factor 2 against the projected pixel size (figure 2). Staggered CCD-lines are improving the ground resolution, but not by the factor 2 as the numerical improvement of the GSD against the projected pixel size – this can be seen with the factor for effective GSD.



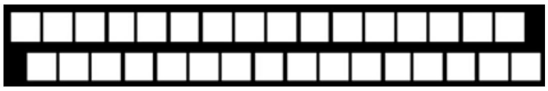


Figure 2: above: staggered CCD-lines

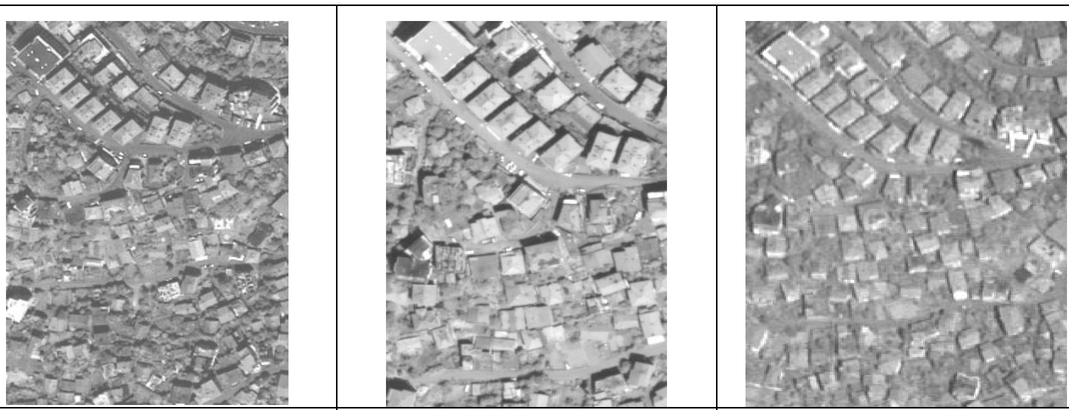
left: difference between projected pixel size and GSD caused by staggered CCD-lines, leading to 50% over-sampling

The real relation between map scale and required effective GSD only can be determined by experimental mapping. The information contents important for topographic mapping of the used very high resolution space images is dominated by the GSD and the imaging conditions. For the interpretation the colour information is helpful, it is simplifying the object recognition and interpretation, but only very few elements could be mapped in addition with colour images against a mapping with panchromatic images.

The mapping is possible by on-screen digitizing of orthoimages or in a stereo model. For the use of orthoimages only a single image and a height model is sufficient. The stereo data acquisition requires better trained operators. A comparison of on-screen digitizing against stereo mapping showed only limited advantages of the stereo mapping. In one case a dump was not identified without stereo support and very few buildings, affected by shadow and trees could not be identified by on-screen digitizing. In general this did not justify the data acquisition with more expensive stereo models against on-screen digitizing of orthoimages.

The mapping is strongly dependent the image quality, dominated by the imaging conditions. In shadow regions of build up areas nearly no objects can be identified, so high sun elevation has advantages. On the other side in central and northern Europe topographic mapping for rural areas should be based on images taken before the leaves are starting to grow in the spring and at that time of the year the sun elevation is limited. A compromise for the dominating regions is required. Images taken under vaporous atmospheric conditions are reducing the object contrast, but they are improving the visibility in shadow regions, but usually clear atmospheric conditions are preferred.

The mapping also depends upon the area itself. Figure 3 shows a combination of planned and unplanned build up areas. In the planned area the buildings are large and regular, while in the unplanned area the buildings are smaller and have varying orientation. The planned part without problems can be mapped with IKONOS, QuickBird and OrbView-3 images, while the higher resolution of Quickbird has an advantage in the unplanned area. Caused by over-sampling of staggered lines Orbview-3 has some blurring effect, reducing the contrast. In the unplanned areas the mapping is quite more difficult. The problem is caused by not sharp edges of roads and southern building edges having less contrast than northern edges showing good contrast against the shadow on the northern side.



IKONOS 1m GSD	Quickbird 0.62m GSD	OrbView-3 1m GSD

Figure 3: comparison of different space images, planned (upper part) and unplanned (lower part) build up area

Panchromatic and pan-sharpened IKONOS and QuickBird images and panchromatic OrbView-3 scenes have been vectorized in the test area Zonguldak, Turkey. 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 there is no shadow 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 can not be extracted since they are coverage by shadow, buildings and trees and not in any case there is a clear side line in nature. In fact 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 in addition with pan-sharpened images. 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. 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, also the morphologic details are better. The rule of thumb also has been checked and confirmed with images having a lower resolution as SPOT, IRS-1C and space photos. A data acquisition of buildings in the city area of Istanbul has been made with WorldView-1 images, having 0.5m GSD. Nearly all buildings could be mapped. A check against a topographic map 1:5000 showed only very few not recognised buildings, which only have been forgotten during data acquisition.

For topographic mapping a standard deviation of the elements of 0.2mm up to 0.3mm in the map scale is sufficient. In relation to the information contents, requiring 0.1mm GSD in the map scale, this corresponds to a standard deviation of 2 up to 3 GSD. Such accuracy is absolutely not a problem, so the limiting parameter is the information contents.

With the today available GSD of 0,5m or 0.6m topographic maps 1:5000 can be generated with space images. This before was a domain of aerial images. Also in aerial images not 100% of the required elements can be identified, which has been solved by a field check. In this relation maps with a scale 1:5000 and smaller can be made with similar results with space images instead of aerial images.

Conclusion:

With the today available optical space images a real alternative for generation of topographic maps in the scale range of 1:5000 and smaller exists. Similar information content can be reached and the accuracy is not the limiting factor. Reverse the required map accuracy together with the geometric data acquisition accuracy cannot be used for specifying the possible mapping scale – this would lead to too optimistic map scales. Under usual conditions the scene orientation is accurate enough and not causing problems.

Detailed digital elevation models can be generated especially with images taken by stereo sensors. This only should be done if the free of charge available SRTM height model is not accurate enough or has no satisfying point density. In near future with the German TanDEM-X mission by interferometric SAR a competing world wide height model with 2m vertical standard deviation will be available.

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