Very High Resolution Optical Space Sensors – Overview, Accuracy and Information Contents

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Abstract

Very high resolution optical space sensors available for public use like IKONOS, QuickBird and OrbView-3 do have a geometric resolution and information contents comparable with medium scale aerial images. In the near future more similar systems will be available from countries like India, South Korea and France supplemented by imaging radar systems from Germany and Italy having also up to 1m ground sampling distance (GSD). With WorldView-1 and –2 as well as OrbView-5 the GSD will be reduced to 0.45m respectively 0.41m. But also some systems with 2m and 2.5m GSD like Formosat, Cartosat-1, ALOS-PRISM and SPOT 5 supermode exists can be used.

The geometric accuracy of these sensors can be investigated by image orientation which may be based on the strict solutions geometric reconstruction and sensor oriented rational polynomial coefficients (RPC) and the approximations 3D-affine transformation, DLT and terrain dependent RPCs. The different orientation methods are described and compared for limitations, accuracy and required number and distribution of control points. An extended 3D affine transformation is shown, allowing the use also for large scenes and with some restrictions also for original images. Under operational conditions at least the strict solutions are leading to an accuracy of 1 GSD.

The image information contents are depending upon the GSD. As a rule of thumb for topographic mapping a GSD of approximately 0.1mm in the map scale is required, corresponding to a map scale 1 : 10 000 for 1m GSD or even 1 : 5000 for QuickBird images. With the 41cm GSD of WorldView-1 and –2 as well as with OrbView-5 this will be improved.

A direct comparison with analogue aerial images is difficult. Operationally they do have a resolution of 40 linepairs per mm or 12 µm pixel size, but this is still influenced by the film grain, so it should be compared with 20µmpixel size. That means, the coming 41cm GSD of space sensors corresponds to an aerial image scale 1 : 20 000. For mapping purposes, even if it is GIS based, no better accuracy than 0.2mm in the map scale is required, corresponding to the mentioned relation to 2 GSD. This easily can be reached at well defined points. So the limiting factor for the use of space images for mapping is not the accuracy but the information contents.

The generation of digital elevation models requires a stereo coverage. For very high resolution space images only a limited number of stereo coverage's taken from the same orbit exist. Here the new stereo systems Cartosat-1 and ALOS-PRISM as well as SPOT 5 HRS are improving the situation.

1. INTRODUCTION

With the very high resolution space sensors a competition between aerial and space images exists. For medium and small scale mapping the decision of the use of aerial or space images is just a question of availability and financial relation. Space images do have the advantage of covering a large area with just one scene, requiring only a limited number of ground control points. With IKONOS, QuickBird and OrbView-3 the absolute geo-reference is in the range of 10m or better, so even for some cases mapping is possible without control points. For the announced GeoEye-1 the absolute georeferencing without control points is proposed with a standard deviation in the range of 1m.

In most cases no stereoscopic coverage of very high resolution images is available, so a digital elevation model (DEM) is required for mapping. With the free of charge available height model of the Shuttle Radar Topography Mission (SRTM), DEMs with a sufficient accuracy for several purposes are given. In addition with the stereo sensors from Cartosat-1 and ALOS stereo models with a ground sampling distance (GSD) of 2.5m can be used. SPOT-5 includes also the stereo sensor HRS with a GSD of 5m in orbit direction, but these stereo models are not distributed; only the generated DEMs can be bought.

The number of high and very high resolution space sensors is growing very fast. The competition has always improved the order conditions and this will become even better in near future. In this presentation only the civilian or dual use sensors with general access to the images are respected. The military systems are not included.

2. HIGH RESOLUTION OPTICAL SPACE SENSORS

The newer high and very high resolution space sensors are highly agile. They are equipped with reaction wheels, in future also with the more powerful control moment gyros, allowing a controlled fast rotation of the whole satellite. The rotation of the satellite is even possible during imaging, not reducing the geometric accuracy. The footprint speed of the satellites is in the range of 7km/sec. So for a GSD of 1m only an exposure time of 0.14ms is available; this is not sufficient for a qualified image. This situation can be improved with transfer delay and integration (TDI) sensors, they do not have CCD-lines but small arrays. The energy collected in a CCD-element is shifted with the speed of the forward motion to the next CCD and more energy can be added (figure 1). This is mostly done over 13 CCD-elements. The sensors not having a TDI have to solve it with a different method. For example OrbView-3 is using staggered arrays – a combination of 2 CCD-lines shifted against each other by half a pixel. So the ground pixel size is 2m, but the neighbored ground pixels are over sampled by 50%, so from one pixel centre on the ground to the next 1m distance is leading to the GSD of 1m. A similar method is used for the supermode of SPOT 5 having 2.5m GSD based on a ground pixel size of 5m. Of course this method is reducing the image quality but only by a factor of approximately 1.2. Another method is the slow down mode – the satellite is rotating permanently during imaging reducing the forward motion (figure 2). So over a longer distance in the orbit a smaller scene size is imaged. QuickBird and OrbView-3 have to use this in addition to the TDI or slow down mode because the sampling rate is below the image progress for the size of the GSD during parallel view direction. So QuickBird has to use a slow down factor of 1.7 and OrbView-3 at least 1.4. This is not reducing the geometric and radiometric image quality; it is only reducing the imaging capacity.

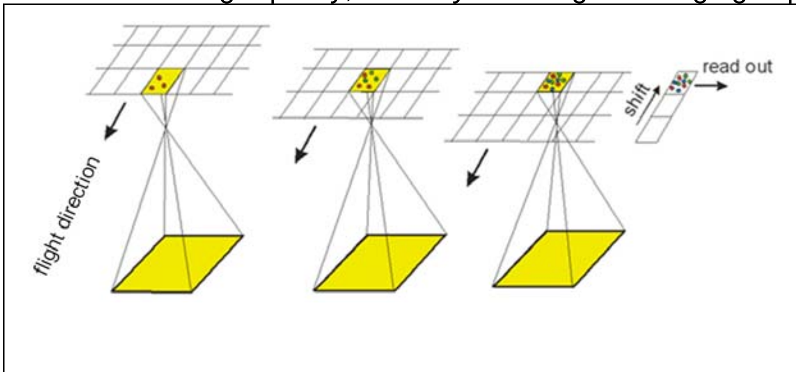


Fig. 1: transfer delay and integration (TDI)

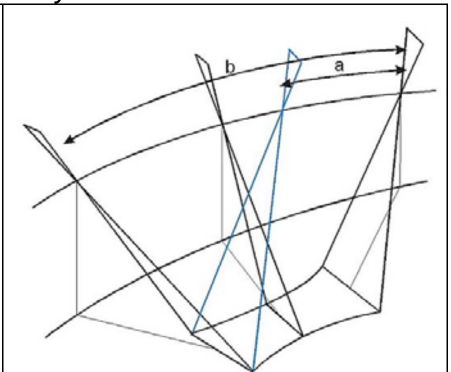


Fig. 2: slow down mode b/a

The number of high and very high resolution is increasing. From 1995 up to 2005 in the average 1 satellite with a GSD below 10m has been launched per year. In 2005 two satellites and in 2006 up to now 4 satellites have been launched and 1 more is proposed (figure 3). Also for 2007 three sensors are announced.

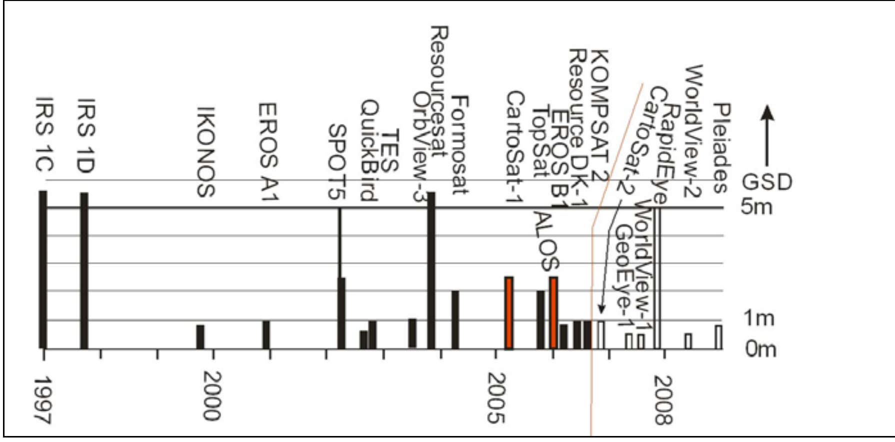


figure 3: time of satellite launches and GSD of the panchromatic channel

system	launch	GSD [m] pan / MS	swath [km]	remarks
SPOT 5 France	2002	5 / 10 (2.5)	60	+/-27°across orbit 2 CCD-lines for pan
HRS (stereo)		5*10	120	23° ahead, 23° behind
MOMS 02, Germany	1993	4.5 / 13.5	37 / 78	nadir + 21.5° fore + 21.5° aft
MOMS-2P Germany	1996	6 / 18	48 / 100	like MOMS 02
IRS-1C India	1995	5.7 / 23	70 / 142	+/-26° across orbit
IRS-1D India	1997	5.7 / 23	like IRS-1C	
IRS P6 India Resourcesat	2003	5.7 MS	24 / 70	+/-26° across orbit
KOMPSAT-1, South Korea	1999	6.6 pan	17	+/-45° across orbit
IKONOS-2 USA SpaceImage	1999	**0.82** / 3.24	11	free view direction, TDI
EROS A1, Israel	2000	1.8 pan	12.6	free view direction
TES India	2001	**1** pan	15	free view direction
QuickBird-2 USA DigitalGlobe	2002	0.62 / 2.48	17	free view direction, TDI
OrbView-3 USA OrbImage	2003	**1** / 4	8	free view direction, staggered CCDs
FORMOSAT-2 Taiwan	2004	2 / 8	24	free view direction, TDI
Cartosat-1, India (stereo)	2005	2.5	30	26° ahead, 5° behind
TopSat, UK	2005	2.5 / 5	15 / 10	free view direction, TDI
ALOS, Japan (stereo)	2006	2.5 / 10	35	nadir, 24° aft, 24° forward
EROS-B1, Israel	2006	0.7	7	free view direction, TDI
ResourceSat DK-1, Russia	2006	**1** / 3	28	free view direction, TDI height 356 – 585km, inclination 69.9°
KOMPSAT-2, South Korea	2006	**1** / 4	15	free view direction, TDI

Table 1: high and very high resolution optical space sensors MS = multispectral

Resourcesat DK-1 and KOMPSAT-2 just recently have been lauched; they are in the preparation for operational use. From the announced sensors especially the WorldView 1 and 2 from Digital Globe, USA and GeoEye 1 from GeoEye, USA have to be mentioned. They will have a GSD of 45cm respectively 41cm and a large imaging capacity. WorldView 2 is planned with 8 color bands. In general the number of countries active with imaging systems from space is growing. From Germany and from Italy also synthetic aperture radar (SAR) systems with up to 1m GSD will come. The information contents of radar images is not the same like for optical images with the same GSD, but radar has the advantage that clouds are penetrated and the imaging is independent from sun light.

3. SCENE ORIENTATION

3.1 General

Most image types are available as close to original images, only improved by the inner orientation, stitching of sub-images and radiometric calibration – this product most often is named level 1A. In addition roughly geo-referenced images projected to a plane with constant object height - the level 1B product is distributed as well as higher level products like orthoimages. Level 1A and 1B scenes are on the same price level while higher level products are quite more expensive.

The newer sensors are enabling the direct sensor orientation without use of ground control points. They are equipped with a positioning system like GPS and attitude control systems by gyros, supported by star sensors. IKONOS is reaching a standard deviation of ground coordinates X and Y with given height values up to 4m. Other systems are not far away from this. Often more problems exist with unknown national datum, requiring control points for fitting the satellite images to existing maps.

The orientation process has to respect the available image type. There are some solutions trying to reconstruct the original images from the projections to a plane with constant height – this is possible, but not necessary. Rigorous mathematical models are in use like also approximations. In addition the available orientation information may be used completely, partially or even not. There is a clear trend, that the direct sensor orientation information is distributed as rational polynomial functions describing the scene position as a function of ground coordinates.

$xij = \frac{Pi1(X,Y,Z)j}{Pi2(X,Y,Z)j}$	$yij = \frac{Pi3(X,Y,Z)j}{Pi4(X,Y,Z)j}$
$Pn(X,Y,Z)j = a_1 + a_2*Y + a_3*X + a_4*Z + a_5*Y*X + a_6*Y*Z + a_7*X*Z + a_8*Y^2 + a_9*X^2 + a_{10}*Z^2 + a_{11}*Y*X*Z + a_{12}*Y^3 + a_{13}*Y*X^2 + a_{14}*Y*Z^2 + a_{15}*Y^2*X + a_{16}*X^3 + a_{17}*X*Z^2 + a_{18}*Y^2*Z + a_{19}*X^2*Z + a_{20}*Z^3$	
Formula 1: rational polynomial coefficients xij, yij =scene coordinates X,Y = geographic object coordinates Z=height	

Usually third order polynomials are used, so with 4 * 20 coefficients the relation between ground and scene position can be described (Grodecki 2001).

3.2 Images Projected to Plane with Constant Height – level 1B type

The level 1B type scenes are often used caused by IKONOS distributed just as such a type and simplifying also the use of approximate orientation methods.

Sensor oriented Rational Polynomial Coefficients (RPCs) - the RPCs are used as first step in the orientation, after this the relation to the control points has to be determined by a horizontal transformation – named also bias corrected RPCs. For IKONOS just a simple shift, that means 2 unknowns are sufficient, for most other sensors an affine transformation with 6 unknowns is required.

Reconstruction of imaging geometry: For the scene centre or the first line, the direction to the satellite is available in the image header data. This direction can be intersected with the orbit of the satellite published with its Keppler elements. Depending upon the location of an image point and the slow down factor, the location of the corresponding projection centre on the satellite orbit together with the view direction can be computed. So the view direction from any ground point to the corresponding projection centre can be reconstructed. This method requires the same number of control points like the sensor oriented RPC-solution; that means it can be used also without control points if the direct sensor orientation is accepted as accurate enough. It requires the same additional transformation of the computed object points to the control points like the bias corrected RPCs.

The **three-dimensional affine transformation** is not using available sensor orientation information. The 8 unknowns for the transformation of the object point coordinates to the image coordinates have to be computed based on control points located not in the same plane (formula 2) (Hanley et al 2002). At least 4 three-dimensional well distributed control points are required. The computed unknowns should be checked for high correlation values between the unknowns – large values are indicating numerical problems which cannot be seen at the residuals of the control points, but they may cause large geometric problems for extrapolations outside the three-dimensional area of control points. Three dimensional means also the height, so problems with the location of a mountain top may be caused if the control points are only located in the valleys. A simple significance check of the parameters, e.g. by a Student test, is not sufficient. The 3D-affinity transformation is based on a parallel projection which is approximately given in the orbit direction if no slow down factor will be used but not in the direction of the CCD-line.

$$xij = a1 + a2 * X + a3 * Y + a4 * Z$$
$$yij = a5 + a6 * X + a7 * Y + a8 * Z$$

Formula 2: 3D-affine transformation

The mathematical model of parallel projection is not a problem for the narrow field of view if the height differences are not very large. For large height differences and unknown slow down mode, extended formulas are available in the Hannover program TRAN3D.

$$xij = a1 + a2 * X + a3 * Y + a4 * Z + a9 * X*Z + a10*Y*Z$$
$$yij = a5 + a6 * X + a7 * Y + a8 * Z + a11*X*Z + a12*Y*Z$$

Formula 3: extended 3D-affine transformation

For the handling of original images a further extension has been made (formula 4)

$$xij=a1 +a2*X +a3*Y +a4*Z +a9 *X*Z +a10*Y*Z +a13*X*X$$
$$yij =a5+a6*X +a7*Y +a8*Z +a11*X*Z + a12*Y*Z+a14*X*Y$$

Formula 4: extended 3D-affine transformation for original images

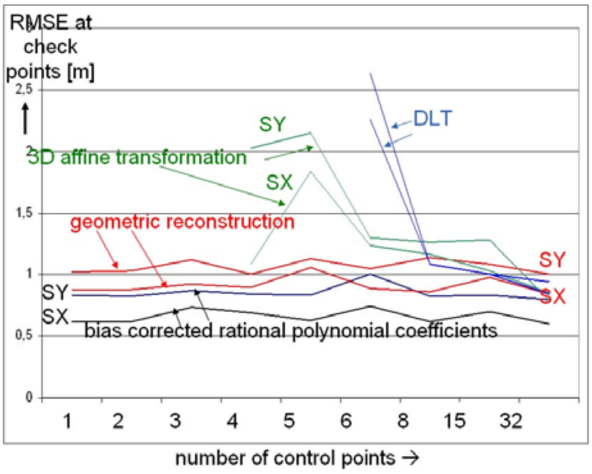
Direct Linear Transformation (DLT): Like the 3D-affine transformation the DLT is not using any pre-information. The 11 unknowns for the transformation of the object point coordinates to the image coordinates have to be determined with at least 6 control points. The small field of view for high resolution satellite images together with the limited object height distribution in relation to the satellite flying height is causing quite more numerical problems like for the 3D-affine transformation. The DLT is based on a perspective image geometry which is available only in the direction of the CCD-line. There is no justification for the use of this method for the orientation of satellite images having more unknowns as required.

$$xij = \frac{L1 * X + L2 * Y + L3 * Z + L4}{L9 * X + L10 * Y + L11 * Z + 1} \qquad yij = \frac{L5 * X + L6 * Y + L7 * Z + L8}{L9 * X + L10 * Y + L11 * Z + 1}$$

Formula 5: DLT transformation

The mathematical model of the DLT is a perspective image including its inner orientation. Like the 3D-affine transformation this is an approximation and the correlation of the unknowns has to be checked.

Terrain dependent RPCs: The relation scene to object coordinates can be approximated based on control points by a limited number of the polynomial coefficients shown in formula 1. The number of chosen unknowns is quite dependent upon the number and three-dimensional distribution of the control points. Just by the residuals at the control points the effect of this method cannot be controlled. Some commercial programs offering this method do not use any statistical checks for high correlations of the unknowns making the correct handling very difficult. A selection of the unknowns may lead to the three-dimensional affine transformation. This method is not serious and should be avoided.



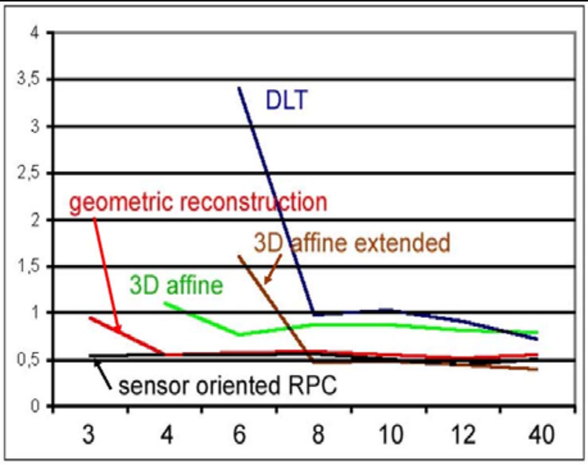


Figure 4: standard deviation of independent check points depending upon type of orientation as a function of the number of control points, test field Zonguldak
left: IKONOS Geo right: QuickBird OR Standard

As it can be seen in figure 4, the orientation with the approximate solutions 3D affine transformation and DLT require more control points like the strict solutions of bias corrected RPCs and geometric reconstruction. For QuickBird only with the extended affine transformation the same accuracy can be reached. The disadvantages of the approximate orientation methods are obvious.

3.3 Original Images – level 1A type

The solutions for geometric correct image orientation of original space images are not new, at first they have been developed for SPOT images. In the Hannover program BLASPO, the image geometry is reconstructed based on the given view direction, the general satellite orbit and few control points. Based on control points the attitudes and the satellite height are improved. The X- and Y-locations of the projection line are fixed because they are nearly numerical dependent upon the view direction. In addition two additional parameters for image affinity and angular affinity are required. For these 6 unknowns 3 control points are necessary. More additional parameters can be introduced if geometric problems exist. Only for scenes with totally unknown orientation the full sensor orientation with 6 orientation elements will be adjusted together with necessary additional parameters. This requires a good vertical distribution of control points; for flat areas the full orientation cannot be computed. Other solutions do use the full given sensor orientation together with some required correction parameters. On the other hand no pre-information is required for 3D-affine transformation, DLT and terrain dependent RPCs (see above). Like with the solution for images projected to a plane with constant height, more control points with a good three-dimensional distribution are required if the existing sensor orientation information will not be used. Recently also for the level 1A type products RPCs are available. Similar to the level 1B type they can be used for a bias corrected RPC solution. The required reverse relation of the ground positions as a function of the image coordinates has to be computed iteratively.

As obvious from the OrbView-3 and the QuickBird Basic orientation results (figure 5) similar relations like for the level 1B products exists. The simple orientation methods of 3D affine transformation and DLT cannot be accepted for original images because both mathematical models do not fit in a sufficient manner to the image geometry. The mathematical model of perspective images used by DLT does not correspond to the slow down mode. The 3D affine transformation is based on a parallel projection; even the scene sides projected to the ground are not parallel. Only with the extension of the formula of the 3D affine transformation to original images (formula 4) the results of the OrbView-3 orientation are not to far away from the RPC-results, but quite more and 3D well distributed control points are required. The results of all affine transformations as well as the DLT based on QuickBird Basic (figure 6) cannot be accepted. The geometric reconstruction with the Hannover program BLASPO and the bias corrected RPC solution are on a similar level, but for the geometric reconstruction additional parameters were required.

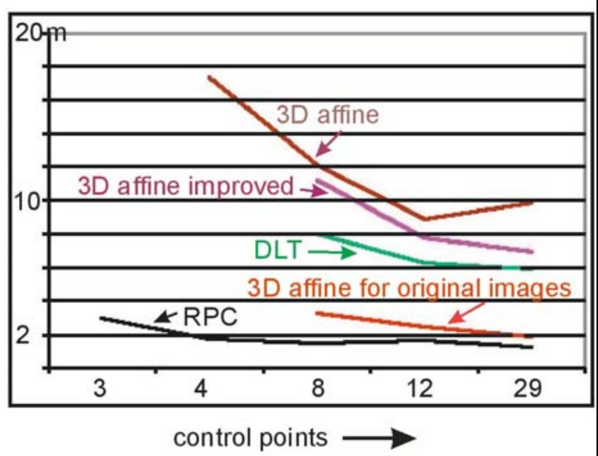


Fig. 5: Orientation of OrbView-3 Basic – root mean square differences at independent check points

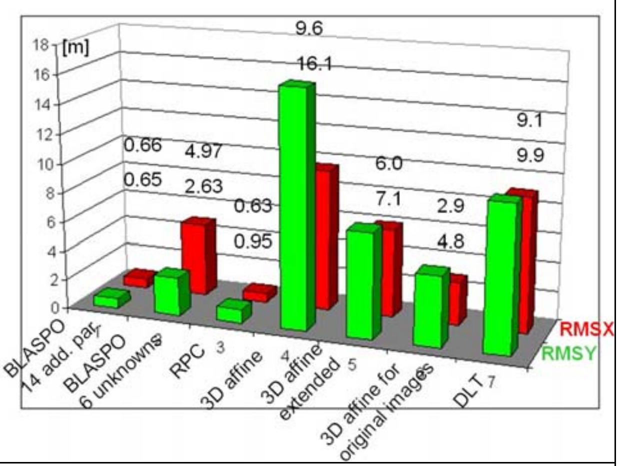


Fig. 5: Orientation of QuickBird Basic based on 380 control points with resulting RMS values

Most of the high and very high resolution space images have been analyzed. For several no RPCs have been available, requiring the orientation by geometric reconstruction. The dominating factor for the orientation is the control point quality. Not only the accuracies of the ground coordinates are important; the point identification in the scenes has the same meaning. With well defined control points a standard deviation of the ground coordinates X any Y in the range of 1 GSD or even better has been reached. An exception is OrbView-3, it is not better than approximately 1.4m for 1m GSD, but OrbView-3 has an object pixel size of 2m, leading with the 50% over sampling to 1m GSD. In this relation also with OrbView-3 sub pixel accuracy has been reached.

4. DEM GENERATION

Digital elevation models (DEMs) are a basic component of any geo information system (GIS). The terrain cannot only be described by the horizontal components; the height belongs to complete information. In addition height models are required for the generation of orthoimages – one of the most often used photogrammetric product. DEMs can be generated by laser scanning, photogrammetric methods or interferometric synthetic aperture radar (InSAR). In any case it is time consuming and expensive. The worldwide lack of qualified and accessible DEMs has been improved with the Shuttle Radar Topography Mission (SRTM) in February 2000. Based on InSAR height models have been generated covering the world from 56° southern up to 60.25° northern latitude. The DEMs based on the US C-band are available free of charge in the internet via http://www2.jpl.nasa.gov/srtm/ with a spacing of 3 arcsec, corresponding to approximately 92m at the equator. Only for the USA data with a spacing of 1 arcsec (~ 30m) are also in the WEB. The DEMs based on the German / Italian X-band can be ordered from the DLR, Germany with a spacing of 1 arcsec. But without scanSAR-mode the X-band DEM has large gaps between the swaths of 45km width.

Several SRTM height models have been analyzed. SRTM height points determined by C-band and X-band do have approximately the same accuracy. The accuracy has to be described by the relation: $SZ = A + B*\tan\alpha$, where SZ is the standard deviation of the height and α is the terrain inclination. The dependency of the accuracy from the terrain inclination cannot be neglected. In general a digital surface model (DSM) is given with the height of the visible objects, because C-band and X-band radar cannot penetrate the vegetation.

	RMSZ [m]	bias [m]	RMSZ F(slope) [m]
Arizona, partly mountainous	3.9	1.3	2.9 + 22.5 ∗ tan α
Williamsburg NJ, flat	4.7	-3.2	4.7 + 2.4 ∗ tan α
Atlantic City NJ, flat	4.7	-3.6	4.9 + 7.6 ∗ tan α
Bavaria, rolling	4.6	-1.1	2.7 + 8.8 ∗ tan α
Bavaria, mountainous	8.0	-2.4	4.4 + 33.4 ∗ tan α
Zonguldak, mountainous	7.0	-4.4	5.9 + 5.6 ∗ tan α
Mausanne, flat + rolling	3.9	-0.9	2.1 + 11.9 ∗ tan α

Table 1: accuracy of SRTM C-band DEMs for open areas α = terrain inclination

The bias (systematic error) of the results listed in table 1 is caused by the orientation of SRTM. This part can be eliminated in using control areas. The mayor disadvantage of the SRTM C-band DEM is the spacing of 3 arcsec, corresponding to 92m at the equator, causing a loss of morphologic details. If this and the accuracy cannot be accepted, height models should be generated by automatic matching of space images. The conditions for the DEM generation are different depending upon the area and used sensor.

All methods of image matching for the generation of a digital surface model (DSM) are based on a continuous and differentiable surface. The DSM includes the height of the visible surface; that means, also buildings and vegetation. A DSM is not differentiable because the change of the direction from the facade to the roof top. Also the difference in the view direction of the used images is causing problems. A facade may be shown in one image, but not in the other – so some image pixels do not have conjugate pixels in the other image (figure 6).

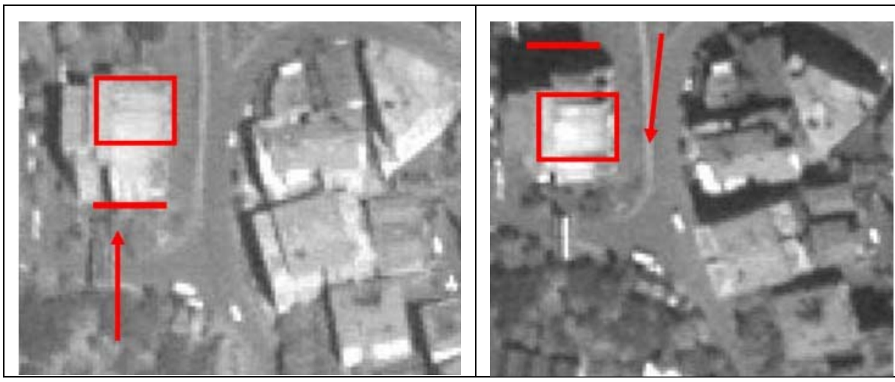


Fig. 6: presentation of a higher building in a stereo pair of OrbView-3-images,

different facades are shown

height / base = 1.4

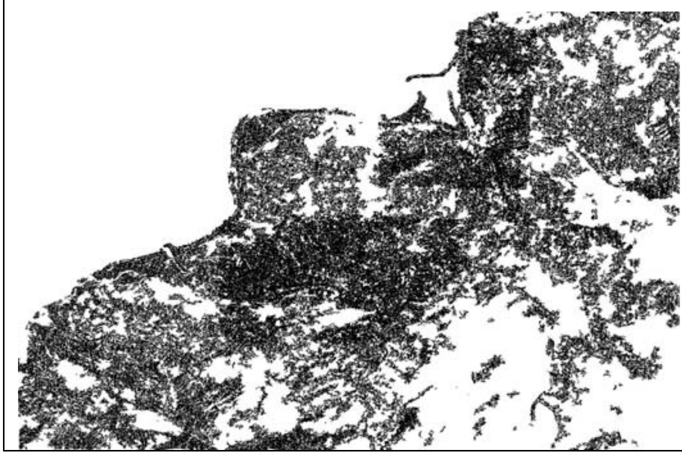


Fig. 7: points (dark) determined by automatic image matching of OrbView-3 images (~ 2,5 million points)

upper left = Black Sea

lower right = forest in mountain

height / base = 1.4

Even under good conditions of taking the stereo pair from one orbit, the matching of scenes with a larger angle of convergence (small height to base relation) may be difficult in build up areas and also in mountainous parts, especially if they are covered by forest like in the case of an OrbView-3 stereo pair in the area of Zonguldak like shown in figure 7 with the distribution of matched points. On the other hand a stereo pair from IKONOS in the city of Maras (table 2) also taken from the same orbit with a small convergence angle of just a height to base relation of 7 was leading to optimal image matching and resulting heights caused by the very good standard deviation of the determined x-parallax. So not in any case a large convergence angle has an advantage.

SZ = h/b * Spx   formula 6: standard deviation of Z (SZ)   h=height b=base
Spx = standard deviation of x-parallax [GSD]

In general the matching results are strongly depending upon the image contrast. Especially in forest areas the contrast is low if the infrared part is not used for imaging, causing problems in matching. If both scenes of a stereo combination are taken with a larger time interval, the object and the shadows may change causing problems in matching up to total fail. Table 2 gives an overview about matching results checked with reference DEMs. Corresponding to formula 6, the absolute accuracy is depending upon the height to base relation multiplied with the standard deviation of the x-parallax in units of GSD (x-parallax = geometric difference of both images in the base direction). The standard deviation of the x-parallax in the unit of GSD is the dominating characteristics of the quality of matched DEMs. In most cases sub-GSD accuracy has been reached. Of course for the forest the results are not so good like in open areas, caused by problems with contrast and the vegetation height. Especially at check points quite better results can be reached because check points do have good contrast and are not influenced by neighboring elements. The limited accuracy based on the IKONOS stereo combination in Zonguldak of just 1.5 GSD is coming from the time interval of more than 1 month between both images.

Sensor	area	RMSZ [m]	RMSZ F(slope) [m]	Spx flat areas [GSD]
ASTER Zonguldak, mountainous	open areas	25.0	21.7+14.5*tanα	0.7
	forest	31.2	27.9+18.5*tanα	0.9
	check points	12.7		0.4
KOMPSAT-1 Zonguldak, mountainous	open areas	13.6	11.3+11.5*tanα	0.8
	forest	14.7	14.1+12.1*tanα	1.0
SPOT 5 Zonguldak, mountainous	open areas	11.9	5.3 + 5.9*tan α	0.6
	forest	15.0	6.6 + 6.3*tan α	0.7
	check points	3.8	3.5 + 0.9*tan α	0.4
SPOT 5 HRS, Gars, rolling	open areas	4.7	4.3 + 1.0*tan α	0.7
	forest	13.0	11.0 + 6.2*tan α	1.8
IKONOS, Zonguldak	open areas	5.8		1.5
IKONOS, Maras, flat	city	1.4		0.22
Cartosat-1, Warszawa, flat	open areas	2.5	2.4 + 8*tan α	0.6

Table 2: accuracy of height models generated by automatic image matching

The accuracy of the height values does not directly say something about the morphologic contents; that means the detailed shape of the contour lines. In the extremely mountainous area of Zonguldak even with the not so good ASTER-DEM having a point spacing of 45m, more morphologic details could be seen than in the quite more accurate SRTM height model having a spacing of 92m times 70m. Of course with the quite detailed Cartosat-1 stereo model, generated with a spacing of 7.5m, far more details are available.

5. INFORMATION CONTENTS

For mapping purposes the identification of objects in the images is important. For larger mapping scales more details are required than for smaller mapping scales. Based on experience as rule of thumb 0.1mm GSD in the map scale is required, corresponding to 1m GSD for a map scale 1 : 10 000 or 5m GSD for a map scale 1 : 50 000. Of course the individual image conditions, image quality and availability of color are influencing this relation, so it may vary also a little. The effective pixel size can be checked by edge analysis, leading to the point spread function, including the effective GSD (Topan et al 2004). Only for analog images, IRS-1C and OrbView-3 a difference between the nominal and the effective GSD could be seen. Of course this depends upon the actual used images which may be taken under not optimal atmospheric conditions. In the case of OrbView-3 we do have the difference between the ground pixel size of 2m in relation to the 1m GSD.

Fig. 8: influence of color to object identification
left: panchromatic IKONOS right: pan sharpened IKONOS

The color supports the object identification, it is easier to classify the objects, but a careful mapping with panchromatic images leads nearly to the same result like the handling of pan sharpened scenes.

Fig. 9: imaging of IKONOS with sun elevation 46° 41° 61° and slightly different azimuth

A comparison of 3 IKONOS images taken under different sun elevation and slightly different sun azimuth (figure 9) demonstrates that even with the same sensor the mapping conditions are not the same. The image with the sun elevation of 61° shows the streets in the part of Zonguldak very clear, while especially in the center image of figure 9 even the decision if it is a backyard or a street is not simple. The buildings can be mapped in any case without problems.

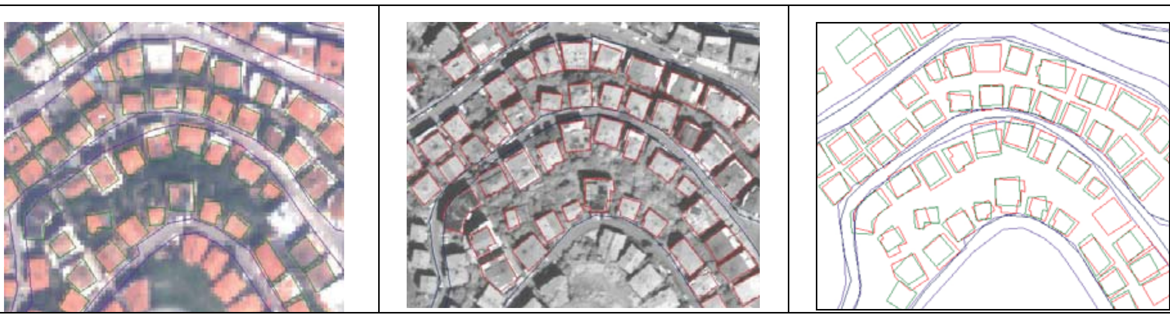


Fig. 10: mapping buildings left: QuickBird 2.4m GSD, center: pan 2.4m GSD, right: overlay

The mapping of buildings in multispectral QuickBird images with 2.4m GSD (figure10 left) and with QuickBird panchromatic images with 0.6m GSD (figure 10 center) shows very clear the influence of the image resolution. With 2.4m GSD not the detailed building extensions like with 0.6m can be identified confirming the above mentioned rule of thumb.

With mapping using the different type of space images with different GSD, the rule in general has been confirmed with the exception that at least a GSD of 5m should be available. With a larger GSD the tendency of generating maps possible scales still continues, but some important features like railways not in any case could be identified.

CONCLUSION

With the high and very high resolution space images today a mapping up to the scale 1:5000 is possible. The situation even will be improved soon with the announced higher resolution of WorldView-1 and -2 as well as GeoEye. For smaller map scales even a geo-referenced mapping without control points is possible and this situation will be improved in near future. But nevertheless today it is more serious to use ground control points. The orientation of the scenes should be made with bias corrected sensor oriented RPCs or with geometric reconstruction. Both methods allow a similar accuracy with a minimal number of control points. The approximate orientation methods should be avoided.

For several purposes the free of charge available SRTM height model can be used. More details can be achieved with DEMs determined by automatic matching of higher resolution stereo scenes. The images for matching should come from the same orbit, but only a limited number of stereo pairs have been taken with the agile very high resolution satellites. Here the situation has been improved with the stereo sensors SPOT 5 HRS, Cartosat-1 and ALOS-PRISM.

Intensive mapping confirmed the rule of thumb of required GSD in the range of 0.1mm in the map scale. For mapping the information contents is limiting the possible scale. A map should have accuracy between 0.2 and 0.3 mm in the map scale and this is guranteed with a standard deviation of the object coordinates of approximately 1m GSD in any case.

The growing number of high and very high resolution satellites simplifies the use of the less expensive archive images, but also the imaging of a specified area will be improved by the higher number of space sensors available now and in near future.

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