COMPARISON OF HIGH RESOLUTION MAPPING FROM SPACE

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1. ABSTRACT

The today available very high resolution space images do have a resolution which is partially in competition to aerial images. For mapping, the geometric potential and also the information contents are important as well as the required information about the imaging situation. Because of the fast creation, ortho images are becoming more and more important, but they do require digital elevation models (DEM). DEM's can be created by automatic image matching based on the space images if they are available in a stereoscopic arrangement. Not all imaging systems do allow a stereoscopic coverage, but the situation will be improved in the near future by systems like Cartosat and ALOS. Also today by ADEOS a generally stereoscopic coverage with 15m resolution is given. In addition at the end of this year a world wide DEM created by Interferometric Synthetic Aperture Radar (INSAR) with the SRTM mission will be available. The derived elevation models do represent the visual surface and not the bare ground, so they have to be filtered by an intelligent method identifying the points not located on the ground.

The mathematical model of the different high resolution space sensors will be described. This includes also the handling of rectifications of the IKONOS images available as CARTERRA Geo and the Digital Globe QuickBird Standard Imagery. The geometry of these images can be reconstructed without use of the rational functions available from SpaceImaging and Digital Globe for additional expenses. It can be based on the information about the view direction available as "nominal collection elevation and azimuth" in the metadata. With control points in different height levels it can be introduced also as unknown. The achieved accuracies have to be seen in relation to the information contents, which is usually limiting the maximal scale of maps, which can be created, based on space images. Under optimal conditions the horizontal coordinates can be determined with sub-pixel accuracy. This requires very good point identification, which is not available for usual topographic objects. So the usual accuracy of topographic objects is more in the range of 1 pixel or even more worse if the object cannot be identified so well.

The experiences with the generation of DEM's from space images by automatic image matching will be shown together with the possibilities, but also limitations of intelligent filtering. The achieved accuracy is depending upon the pixel size, the base to height relation, the contrast and slope of the area, but also the time interval between imaging both scenes. Under optimal conditions with IKONOS-images with a base to height relation of 1 : 7.5 and a time interval of just 12 sec for imaging, an accuracy of the x-parallax of 0.25 pixels has been reached. An analysis of the DEM generation by the X-band of the SRTM mission will be included.

The information contents of maps based on high resolution space images, starting from the Russian space photos over SPOT, IRS-1C up to IKONOS-images will be shown. There is a very clear dependency of the information contents to the image resolution. Color is improving the object identification like also a stereoscopic view. Finally the image quality and contrast is important. Haze is reducing the accuracy of interpretation. As rule of thumb

approximately 0.1mm pixel size in the map scale is required. Beside the listed facts improving this, it is also important how many details shall be included in the map and what a structure the object does have. In urban areas much more details have to be identified like in rural areas. Also the structure of the cities and fields do play a role – it is more easy to generate maps in planned areas like in unplanned not homogenous.

2. SENSORS

The first high resolution sensors used in space have been photographic sensors. The taken photos are now not any more classified and are available for civilian use. Only Russia is still operating photographic sensors. The very high ground resolution has just recently reached and surpassed by the civilian available high resolution digital sensors like IKONOS and QuickBird, but they are not corresponding to the information contents of the large areas covered by the photographic sensors. The photos do have the disadvantage of not very actual information, but for some purposes they are still useful.

Sensor	f [mm]	image size [mm]	flying height [km]	covered area [km]	ground resolution [Pixel]	height-base-relation
CORONA KH-4B	610	56•762	187	~17•130	2m	1,85
Metric Camera	305	230•230	250	189•189	18	3,2
Large Format Camera	305	460•230	270	196•392	7	1,6
MK4	300	180•180	220 /350	132 / 210	10 - 15	4,2
TK -350	350	300•450	220 / 350	200•300 310•470	10-15	1,8
KFA-1000	1000	300•300	220 / 350	66•66 / 105•105	2.5 – 5	8,2
KFA-3000	3000	300•300	220 / 350	22•22 / 35•35	1 – 2.5	no stereo
KVR-1000	1000	180• 800	220 / 350	40•180 / 60•280	1 – 2.5	no stereo

Table 1: technical data of high resolution space film cameras

The former US spy satellites CORONA up to version 6 have been used from 1960 up to 1972. The approximately 860000 images are released now and copies can be bought from the EROS Data Center for a small amount (http://edc.usgs.gov/products/satellite/corona.html). The most often used camera was the CORONA KH-4B with a convergence angle between the 2 cameras of 30°, which makes them also today usable for the generation of digital elevation models (DEM).

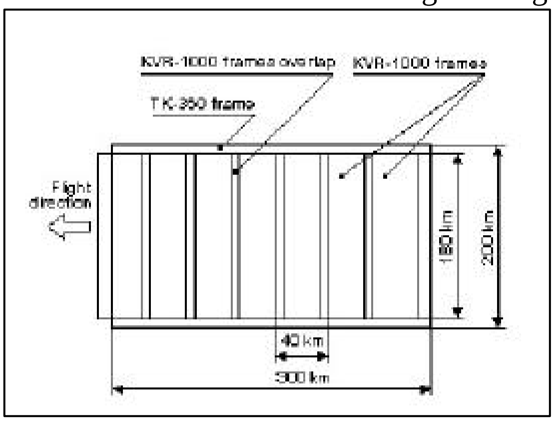


Figure 1: configuration TK-350 and KVR-1000

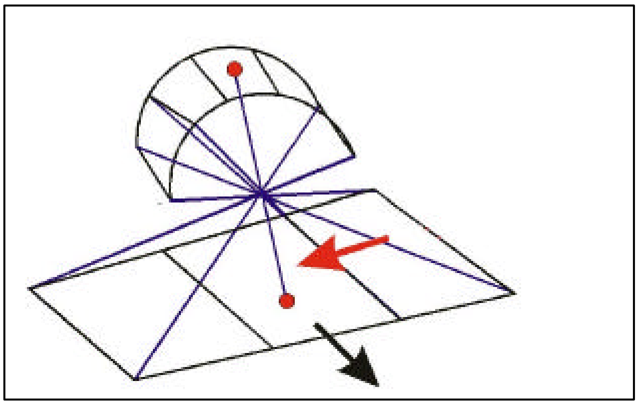
Metric Camera and Large Format Camera have been experiments on the Space Shuttle with standard and over-large format photographic cameras. The photos, covering a large part of the earth, are available but of course not actual. The former

USSR, continued by Russia, has a series of photographic cameras, which are still in use. SojuzKarta and some reseller distribute the images. Important is the KOMETA mission including a combination of the TK350 with the very high resolution panoramic camera KVR-1000. The TK350 covers a wide range stereoscopically while 90% of the swath with is imaged by the KVR-1000 (see figure 1). KVR-1000-images can be ordered as film copies, but also digitized with a ground pixel size of 2m.

The geometry of the panoramic cameras CORONA and KVR-1000 is not perspective because of the scanning from one side to the other, but it is not too far away from the perspective relation. So in a first step, the images can be projected to a tangential plane (formula 1).

$$y' = f \bullet \tan(y/f) \qquad x' = \frac{x}{f} \bullet \sqrt{f \bullet f + y \bullet y}$$

Formula 1: panoramic correction



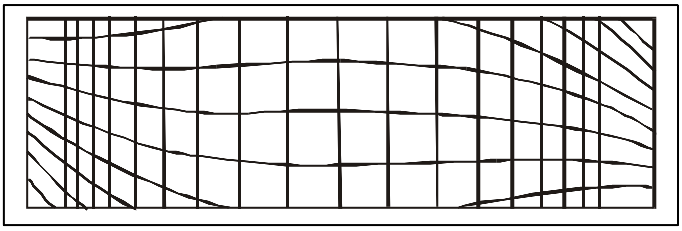


Figure 2: above: imaging of a grid in object space

left: principle of panoramic imaging

After the panoramic correction according to formula 1, it is necessary to respect also the influence of the movement of the projection center during scanning a scene. The dynamic effect to the scene can be seen in figure 2. The scanning speed in relation to the movement of the projection center is not known or not known accurate enough. In the Hannover program system for bundle block adjustment BLUH it will be determined as additional parameter based on few control points.

The information contents of photos can be expressed with the film resolution in line pairs / mm. This has to be transformed into pixel size on the ground, based on the simple, but realistic relation of 2 pixels corresponding to 1 line pair and respecting also the image scale. For example a KVR-1000-image with 60lp/mm corresponds to 120 pixel/mm or a pixel size in the film of 8.3µm. This multiplied with an image scale of 220 000 (flying height 220km) leads to a pixel size on the ground of 1.8m.

More actual images can be achieved with digital images directly or with a short delay broadcasted from the satellite to the ground station. The permanent imaging digital systems do have a quite higher capacity like the film-based systems. Nevertheless, the existing space photos may be for some applications an economic solution.

The operational mapping based on space images started for civilian applications in1986 with SPOT 1. The pixel size on the ground of 10m for panchromatic images was not sufficient for the claimed mapping scale 1 : 50 000, by this reason SPOT was mainly used for special applications. A request for a higher resolution existed, but it took up to 1995 when IRS-1C was launched. Only the short time MOMS-D2-mission could deliver before a smaller pixel size on the ground. These systems are including the capability of stereoscopic mapping. SPOT and IRS-1C /1D can view across the orbit, so a time delay in viewing to the same area from another orbit cannot be avoided. Especially in Europe, the high percentage of cloud coverage makes the acquisition of stereo models difficult. A longer time period between both images of a stereo scene may cause problems with the stereoscopic impression if the vegetation is changing. So in one example no stereo view was possible with an image combination taken in June and August when in Germany the grain is changing its color from green to yellow. Such a problem can be avoided with a camera combination, which for digital civilian systems was firstly used by MOMS, with viewing in the orbit direction forward and backward, creating stereo models with only few seconds time interval. This combination has been accepted as standard combination for the new sensors without fast change of the viewing direction like ASTER, Cartosat and ALOS.

	company or institution / country	launch	number of pixels	mode	ground pixel size (nadir) [m]	swath (nadir) [km]	viewing in orbit direction	viewing across orbit direction	height [km]
SPOT 1, 2, 4	SPOT Image France	1986 1990 1998	6000 pan 3000 ms	pan 3 / 4 multisp.	10 pan 20 multisp	60	-	up to +/- 27°	822
SPOT 5	SPOT Image France	May 2002	12000 pan 6000 ms HRS-camera 12 000	pan ms pan	5 (3) 10 5 orbit 10 across	60 60	- +20°,-20°	up to +/- 27° -	822
MOMS	DLR Germany	1993 D2 1996 2P	9000 /6000	3 pan 4 multisp.	4,5 / 13,5 (6) / 18	37 / 78 100	+/- 21,4° + nadir	--	295 390
IRS-1C IRS-1D	ISRO India	1995 1997	3*4096 pan	pan 4 multisp.	5,8 pan 23,5 ms	70 pan 140 ms	+/- 26°	--	817
ADEOS	NASDA Japan	1996 up to 1997	10 000 pan 5 000 ms	pan 5 multisp.	8 pan 16 ms	80	--	up t0 +/- 40°	800
TERRA - ASTER	USA / Japan	June 1998	VNIR 4100x4200	ms	15 VNIR	61	nadir + 27.2°	-	705
CBERS 1 , 2	Brazil / China	Oct. 99 + 2002	5600	CCD 4 multisp.	20	113	--	up to +/-32°	778
Landsat 7	NASA USA	April 99	1 16	ETM+ pan 7 multisp	15 30 60 TIR	185	nadir	--	705
Ikonos 2	Space Imaging EOSAT,USA	Sept. 99	13816 3454	pan 4 multisp. 11bit	0.82 3.2	11.3	up to +/-45°	up to +/-45°	680
KOMP-SAT 1	KARI South Korea	Jan. 2000		pan	6.6	17	-	+/-45°	685
Resurs DK1	Sovinform Sputnik	?	28300	pan	0.95	28,3	?	?	350
EROS A1	ImageSat Internat. N.V. Cyprus / Israel	Dec. 2000	7000	pan	1.8	12.6	up to +/-50°	up to +/-50°	480
Quick Bird 2	Earth Watch USA	October 2001	27000 6700	pan 4 multisp. 11 bit	0.61 2.44	17 17	up to +/-30°	up to +/-30°	450

Table 2: technical data of high resolution digital space cameras

The well-situated SPOT program was supplemented in May 2002 by the higher resolution SPOT 5 with 5m pixel size for panchromatic and 10m for multispectral. The both identical HRG-cameras can be operate together to generate a larger swath. Also the "Supermode" with 2.5m pixel size is possible - it is based on staggered CCD-lines (50% overlay of neighbored pixels), that means the nominal 2.5m ground pixel size, corresponding to an information contents of 3m pixel size. In addition SPOT 5 is equipped with the "High Resolution Stereo" (HRS) sensor, viewing forward and backward with a base to height relation of 0.8. These images shall not be distributed; SPOT Image only likes to sell the generated worldwide digital elevation model (DEM), which shall have an elevation accuracy better than 10m and a location accuracy better than 15m.

With IRS-1C / 1D a higher resolution was available like for SPOT 1 – 4, suitable for better object identification. Because of the power problem the number of stereoscopic pairs is limited, but also from SPOT Image a stereoscopic coverage of larger areas is not available in the archive. The Japanese ADEOS was also able to generate stereoscopic image pairs, but unfortunately it was only active for 1 year. Very often used are the images of the Japanese ASTER-sensor located on the US EOS-TERRA-platform. ASTER has a backward looking channel, so it generates in general stereoscopic scenes with negligible time interval. The spectral resolution is better like for Landsat. Up to August 2002 the images have been free available in the Internet, now a handling fee of US$60.- has to be paid for a scene.

Several new countries have entered the field of imaging from space like China together with Brazil and South Korea. They are using the images mainly for their own purposes, but there are more existing and announced medium up to high resolution systems based on small satellites. Especially Surrey Satellite Technology, UK plays an important role in this field. They are operating the UOSAT-12 with 2 CCD-frame cameras with a little more than 1000 x 1000 pixels and a pixel size up to 10m. In addition they are preparing several systems for countries like Malaysia, Nigeria and Turkey. Also some other countries like Germany and Morocco do have some small systems, which are used more for research than for mapping.

With IKONOS-2 a new era in mapping from space started. Now very high resolution space images are available which can compete in some areas with aerial photos. In addition the IKONOS and the QuickBird-images are geo-referenced without control points based on GPS, gyros and star finder. The fast change of the viewing direction enables the generation of stereo models from the same orbit.

There is only limited information available about the digital Russian systems. DK1-images with 1m pixel size are distributed in a limited number. This system seems to be used mainly for military applications. The launch of the ARKON for commercial reasons with 1m pixel size failed in July 2002.

	company of organisation / country	launch	number of pixels	mode	pixel size (nadir) [m]	swath [km] (nadir)	viewing in orbit direction	viewing across orbit	height [km]
Orb View 3	Orb-image USA	2002	8000 2000	pan 4 multisp.	1 / 2 4	8	up to +/-50°	up to +/-50°	470
IRS-P6 Resource-sat	ISRO India	2003	12288 6000	**LISS-4** pan + 3 multisp. **LISS-3** 4 multisp.	5.8 23	70 pan 24 ms 140	--	--	817
IRS-P5 Cartosat	ISRO India	2004	12 288	pan	2.5	27 / 30	+20°, -5° fixed		617
Arkon	Russia				1				
ALOS	NASDA Japan	2004	28000 14000	pan Nadir pan +/-24°	2,5	70 35	+24°,0°, -24°	--	692
EROS B	Image Sat Internat.N.V Cyprus / Israel.	2003 – 2004 2 / Jahr	20000 5000	pan multisp. 4 bands	0.82 4	16.4	up to +/-45°	up to +/-45°	600
RapidEye	RapidEye Germany	2005 24000	pan	5 multisp.	6.5m	2 x 78 (2 cameras)	up to 30°	up to 30°	600
	on ISS	„	„	„	4m	2x 48km	up to 30°	up to 30°	400

Table 3: technical data of some announced high resolution digital space cameras

More systems like listed in table 3 are announced for the near future, partially they are named as experimental systems, partially they shall be used exclusively only for one country. A typical example is the British TOPSAT mission, a light weight satellite with a CCD-array of 4000 x 4000 pixels and a pixel size of 2.5m which can be pointed from 600km altitude up to 30° in any direction. The systems listed in table 3 shall be made commercially available and because of the high resolution they can be used for mapping purposes. In general there is a trend to more light weight satellites with free viewing directions or stereoscopic arrangement of the cameras and a higher resolution. Also SPOT Image will go into this direction with the Pleiades Program, the follow on program to SPOT (Baudoin et all 2001). The light weight satellites will reduce the overall cost.

Radar-satellites are not included in the lists because mapping is quite difficult with Synthetic Aperture Radar (SAR) images. The information contents of SAR-images cannot be compared with optical images with the same pixel size. The information contents of SAR-images is corresponding to optical images with approximately 3-5 times larger pixel size. In the near future SAR-systems with 1 m pixel size will be commercially available and this can change the situation. Nevertheless there are imaging problems with SAR in cities and mountainous regions.

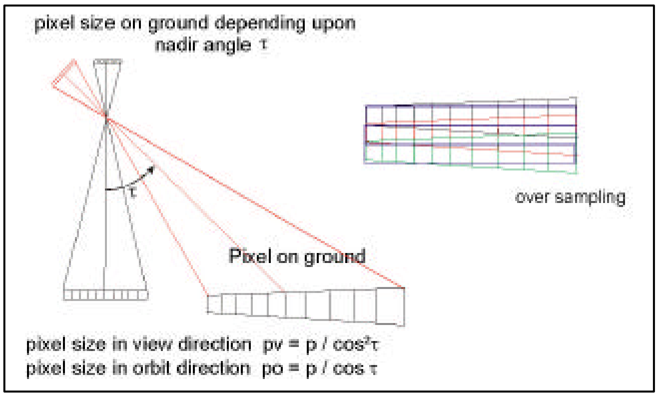


Figure 3: ground pixel size depending upon nadir angle

The ground pixel size of images with inclined view, like IKONOS and QuickBird, is depending upon the nadir angle like shown in figure 3. Across the view direction the dependency is limited and causing an over-sampling, reducing the contrast. In the view direction the pixel size is changing more – at a nadir angle of 45° the pixel size is twice as much as in the nadir.

3. GEOMETRIC RELATION

Space images are covering a larger part of the curved earth. The mathematical model used for the reconstruction of the geometric relations usually is based on an orthogonal coordinate system, this is not available with the national net. A simple earth curvature correction is sufficient only for smaller areas. Larger areas should be handled in an orthogonal coordinate system – proposed is a tangential system to the earth ellipsoid. In a geocentric system, the horizontal and the vertical accuracy are mixed and the analysis is more difficult.

The perspective space images, that means all photos shown in table 1 with the exception of CORONA and KVR-1000, can be handled like usual aerial photos. But there are some problems with the geometric stability of the Russian space photos requiring a self calibration with additional parameters.

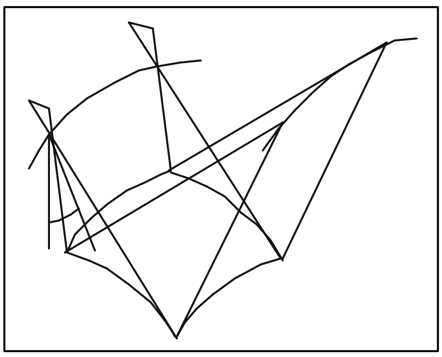


Figure 4: geometric relation of satellite line scanner images

Satellite line scanners images do have the perspective geometry only in the sensor line. In the direction of the orbit it is close to a parallel projection. So the image coordinates as input for the collinearity equation are simplified to **x'** = (x', 0, -f) or (0,y',-f) - the photo coordinate y' or x' is identical to 0.0 (by theory up to 50% of the pixel size can be reached). The pixel coordinates in the orbit-direction of a scene are a function of the satellite position, or reverse, the exterior orientation of the sensor can be determined depending upon the image position in the orbit-direction. With the traditional photogrammetric solution the exterior orientation of each single line cannot be determined. But the orientations of the neighbored lines, or even in the whole scene, are highly correlated. In addition no rapid angular movements are happening. A fitting of the exterior orientation by an ellipse fixed in the sidereal system - the earth rotation has to be respected - is used in the program BLASPO of the Hannover program system for bundle block adjustment BLUH. This has been shown as sufficient for the SPOT sensor also over larger distances. In the OEEPE test area Grenoble by this method a combination of 4 neighbored SPOT scenes over a distance of 200km could be oriented with just 4 control points (in the orbit direction 200km distance between the control points) with an accuracy in the height of ±4m (Jacobsen 1993). The simplified mathematical models used in some other programs have to use more control points.
Original IKONOS and QuickBird images can be handled with the same mathematical model like explained before, but usually only images rectified to a plane with constant height in relation to the earth ellipsoid are available, namely the Geo-product of IKONOS and the Standard Imagery of QuickBird. These rectifications are geo-referenced based on the direct sensor orientation determined by GPS, gyros and star sensors. Without influence of the terrain height the accuracy is specified as CE90 with 23 and 24m. CE90, the circular error with 90% probability level, can be compared with the standard deviation by dividing it with the factor 2.1, corresponding to a standard deviation of 11m.

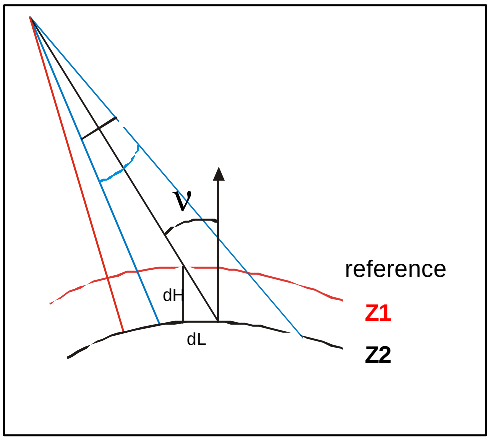


Figure 5: influence of the reference height to the geo-reference of rectifications

IKONOS and QuickBird images are usually not taken in the nadir direction, by this reason, the height level of the reference plane for the rectification is important like shown in figure 5 if no control points are available. The information of the used height level is not given in the header data. Some investigations with IKONOS Geo-images have shown the best results with the reference height corresponding to the mean height of the DEM. Based on 5 different scenes, a mean square accuracy of the absolute geo-referencing without control points of 9.1m has been reached – better than specified by Space Imaging.

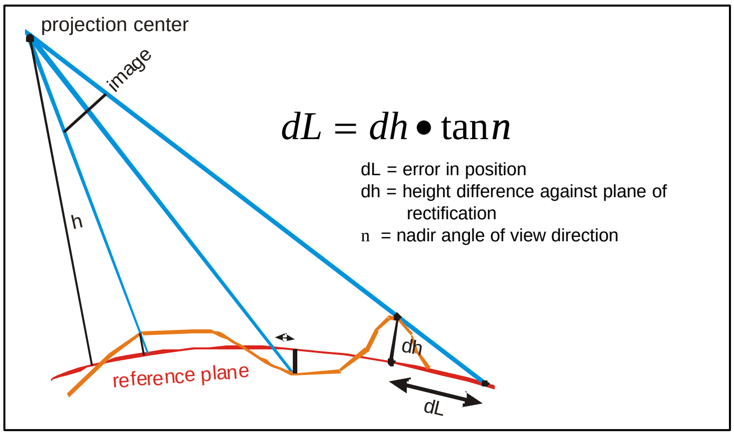


Figure 6: geometric situation of IKONOS Geo-images and QuickBird Standard images

The information about the geometry of the rectification with IKONOS and QuickBird can be bought for an additional amount as rational functions. The rational functions are describing the geometry by the relation of polynomials. This is an approximation of the geometry of the sensor model, sufficient for most applications, but it cannot be updated in a simple manner by control points. It is not necessary to use these functions because of the simple geometric relation of the rectification shown in figure 6. The horizontal and vertical view direction of the scenes is available in the header data - SpaceImaging is naming it "nominal collection elevation" and "nominal collection azimuth". Based on this horizontal and vertical view direction in relation to the scene center, together with the general knowledge about the satellite orbit, the view direction for every point in the scene can be computed. The dislocation of the Geo-images caused by the simple rectification to a reference plane can be improved by a digital elevation model (DEM), changing it to an ortho image which is identical to the geometry of a CARTERRA-Map-product. A deviation of the reference plane from the correct reference height is causing an error in the location of $dl = dh \bullet \tan\nu$ (see figure 6). Together with the remaining deviation of the sensor orientation this can be determined by means of control points. At first a height correction is required followed by a transformation to the control points

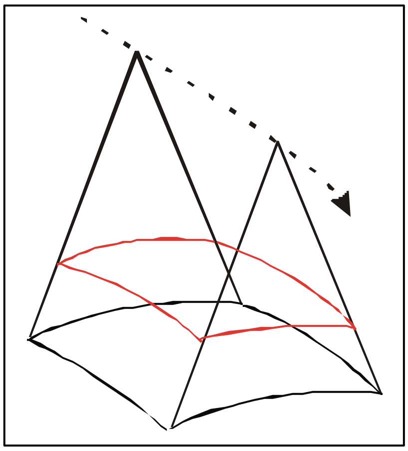


Figure 7: influence of the height level to the required type of transformation to control points

As visible in figure 7, an error in the reference height is causing an affine deformation of the ortho rectified image, so at least an affine transformation is required for the improvement to the location of control points.

As extreme case for the determination of the correct ground location based on CARTERRA-Geo-images, the OEEPE-data set from Lucerne has been used. The altitude in the mountainous scene goes from 415m to 2197m above mean sea level (figure 8).

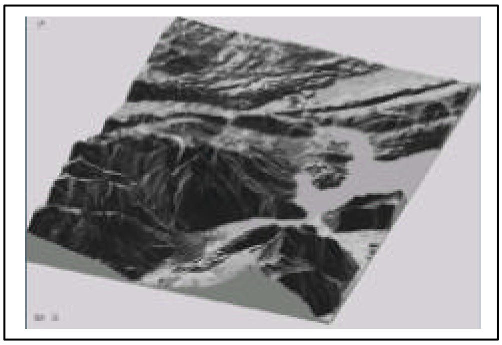
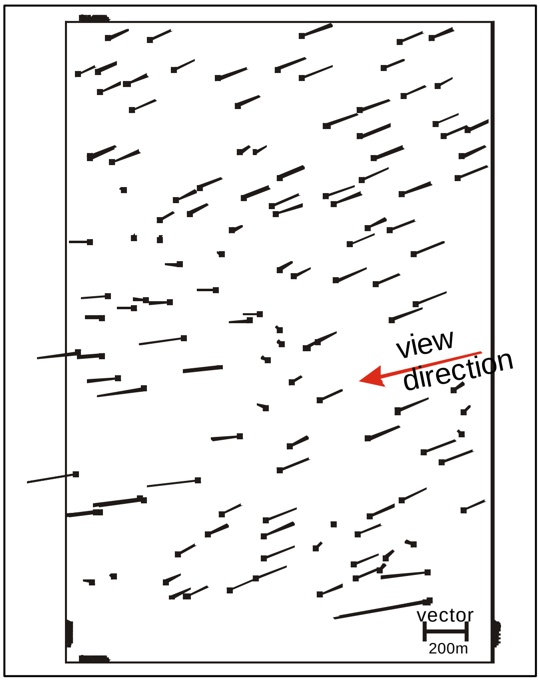


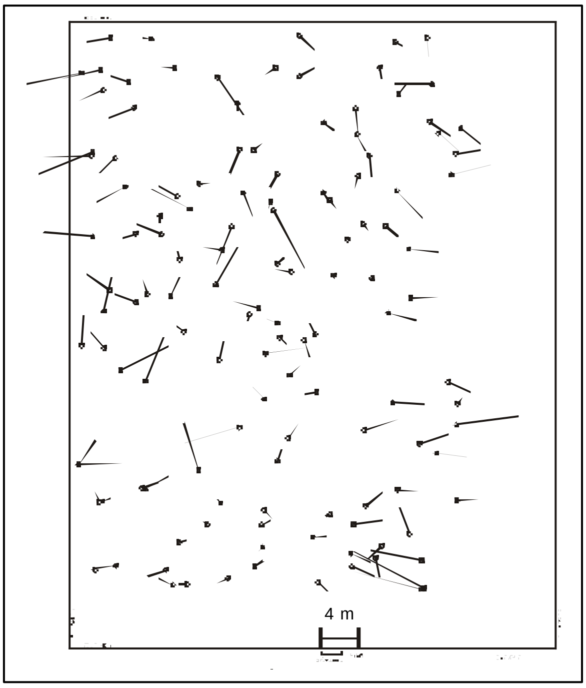
Figure 8: DEM of the Swiss test field

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



← **Figure 9:** discrepancies CARTERRA-Geo against control points

Figure 10 →: differences after correction by the relief displacement + affine



transformation to control points

The root mean square discrepancies between the Geo-image and control points are RMSX=+/-124m and RMSY=+/- 40m with extreme values up to 420m (see figure 9). The sign and the size of the differences are clearly correlated to the terrain altitude. After height correction in relation to a reference level of 800m above mean sea level, but without use of control points, the discrepancies are reduced to RMSX=+/-7.5m and RMSY=+/-18.5m with a clear systematic component. The shift of -6.8m in X and 18.3m in Y is showing the accuracy of the direct sensor orientation. After a simple shift to the control points, the mean square differences are reduced to RMSE X=+/-3.5m and RMSE Y = +/-2.3m but still showing clear systematic errors, mainly a rotation of the scene of 0.4°. No more systematic effects can be seen after an affine transformation to the control points. This is reducing the discrepancies at the 128 control points to RMSX=+/-2.52m and RMSY=+/-1.72m (see figure 10).

area	SX	SY
Switzerland	2.52m	1.72m
New Jersey	1.74m	0.94m
Zonguldak	1.00m	1.29m
Turkey (left scene)	0.52m	1.40m
Turkey (right scene)	1.73m	1.52m

Table 4: root mean square differences of IKONOS orientations after correction by relief displacement + affine transformation to control points

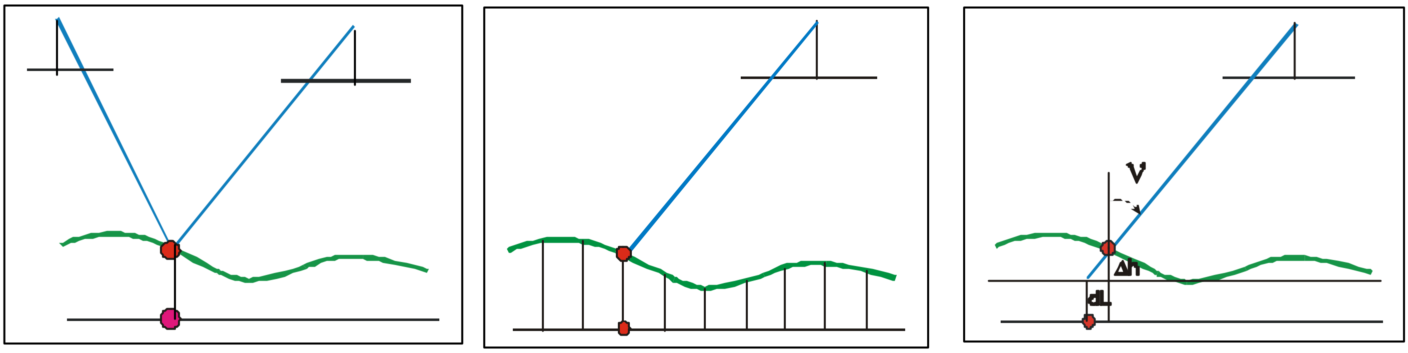
In other areas a better accuracy has been reached (table 4) like in Switzerland. This can be explained by better control points determined mainly with GPS. The average accuracy of 1.3m, identical to 1.3 pixel is totally sufficient. A further improvement only can be reached with optimal control points (sufficient size, symmetric and good contrast).

Sensor / test area	SX [m]	SY [m]	SZ [m]	h/b	remarks
MC / Germany	7,4	7,7	20,2	3,3	Metric Camera
LFC / Germany	6,0	6,6	8,6	1,6	Large Format Camera
KATE-200 / Hannover	27,4	27,4	47,7	2,8	poor resolution
MK4 / Hildesheim	14,4	14,6	28,5	4,2	control points from map 1 : 50 000
KFA-1000 / Hannover	7,4	5,8	32,1	8,2	systematic image errors
KFA-3000 / Vienna	2,8	2,1	40	50	limitation by point identification
KVR-1000 / Duisburg	3,3	3,2	-	-	poor control points
SPOT / Hannover	4,3	4,9	13,4	2,9	SPOT PAN, problems with stereo
SPOT / Grenoble	8,4	8,4	4,1	1,0	poor XY, good Z control, long strip
MOMS 02 / Dubai	3,3	3,2	4,4	2,5	combination HR with other channels
MOMS / Black Forest	15,1	21,4	25,8	2,5	control points from map 1 : 50 000
Kompsat-1	8,8	8,8	7,8	?	Jeong, S. 2002 (KARI)
IRS-1C / Hannover	5,5	4,7	8,7	1,0	IRS-1C PAN
ASTER Zonguldak	11.4	10.2	14.6	2,0	control points from map 1 : 50 000
IKONOS	1.3	1.3	-	-	RMS mean of 4 areas
IKONOS stereo	1.1	1.5	1,7	7,5	stereo model

Table 5: accuracy of bundle orientation - selected projects (IPI with exception of Kompsat-1)

The image orientation of space images should be determined by bundle orientation respecting the correct image geometry. Some of the achieved results are shown in table 5.

A typical problem of the bundle orientation is the quality of the control points – in general no better accuracy with the bundle orientation can be reached like the control point accuracy itself. Very often this is the limitation. The digitising of control points from maps 1 : 50 000 do not allow a better point accuracy like +/-12m – see results achieved with the MK4 and ASTER. For MOMS in the Black Forest even more problems where existing – few control points are forest corners which cannot be identified very well. With this exception, only with the KATE 200 the accuracy required for mapping in the scale 1 : 50 000 could not be reached. In general the horizontal mapping accuracy is not the limiting factor for the possible map scale which can be generated with space images.



3-dimensional **result:** correct X, Y, Z — ortho rectification based on DEM correct X, Y (Z=input) — rectification to a plane Z=constant approximate X, Y

Figure 11: possibilities of data acquisition

The data acquisition with space images can be done, like shown in figure 11 on the left hand side, correctly 3-dimensional based on a stereo model, delivering the 3-dimensional ground coordinates or like shown in the centre by an ortho rectification using an existing DEM, delivering the correct X and Y-ground coordinates. If only one image and no DEM is available, the data acquisition has to be made approximately in relation to an approximate height level. This is causing discrepancies in the position depending upon the height difference to the reference height and the local nadir angle of the view direction $dL = dh \bullet \tan\nu$. Some data acquisition programs are using polynomials based on control points. This may cause uncontrolled discrepancies in the achieved positions - with the polynomials the effect of the height variation will be compensated. If a control point is located in a deep valley, also the neighboured points will get a similar positional correction. In addition unavoidable discrepancies at control points cannot be identified.

In addition to optical images more and more SAR-images are available now. The ERS1, ERS 2, JERS, RADARSAT and ENVISAT-images are not suitable for topographic mapping, but higher resolution systems will come soon.

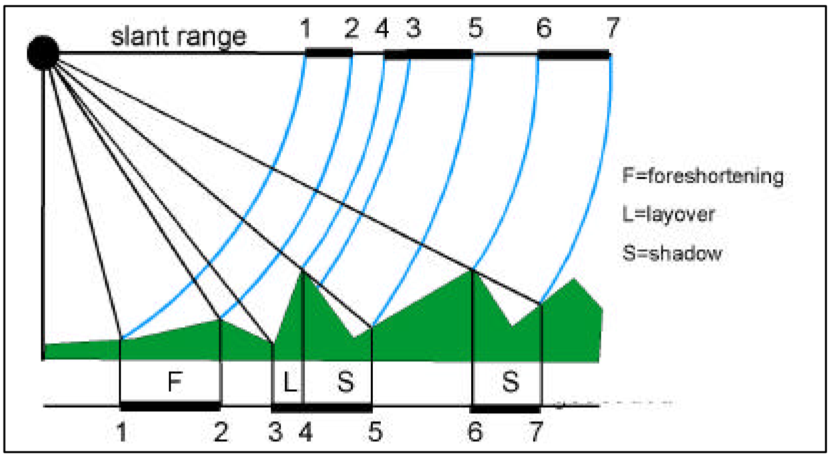


Figure 12: geometry of a SAR-image

Figure 12 demonstrates the problems of imaging based on the local incidence angle. Especially in mountainous areas and cities problems with the unequivocal positioning are existing. A layover cannot be corrected based on a DEM. In addition the geometric displacements caused by the height are usually larger like for optical images. A smaller incidence angle ν is causing larger displacements in hilly or mountainous areas (formula 2). A larger incidence angle would reduce the displacement, but it requires more power for the active SAR sensor and is enlarging the problems of shadowing.

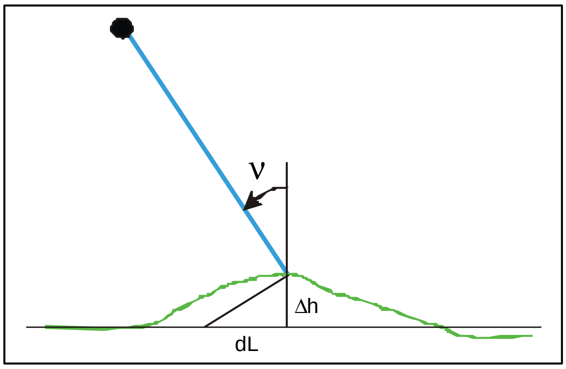


Figure 13: displacement dL of SAR-images by height differences Δh

$$dL = \frac{dh}{\tan \nu}$$

Formula 2: displacement of SAR-images by height differences

4. INFORMATION CONTENTS

The limiting factor for mapping from space is the information contents (semantic information). The required information contents of maps is depending upon the map scale – in large scales more details are shown like in small scales, but some information, like railways, have to be shown independent upon the map scale. Of course there are differences between different countries – in Switzerland much more details are in the maps like in the USA. In addition, the information contents which has to be shown is also depending upon the area itself. In cities more details are available like in rural areas and in a small city in the USA not so many details are available like in densely populated cities of developing countries. By this reason only approximate rules for the possible mapping scale depending upon the image resolution can be found.

As mentioned before, the information contents of Radar-images (SAR) cannot be compared with optical images. In addition they are strongly effected by speckle, requiring a filtering. The difference between a Median-filter and the higher number of special Radar-filters is usually not important.

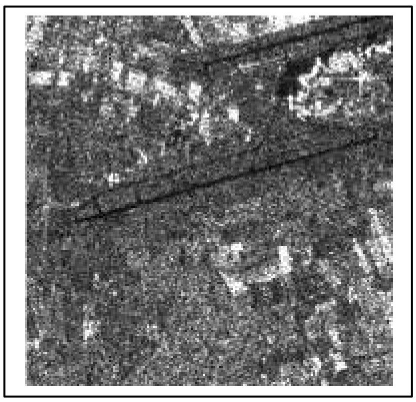


Figure 14: ERS1 SAR-image not filtered, pixel 27m

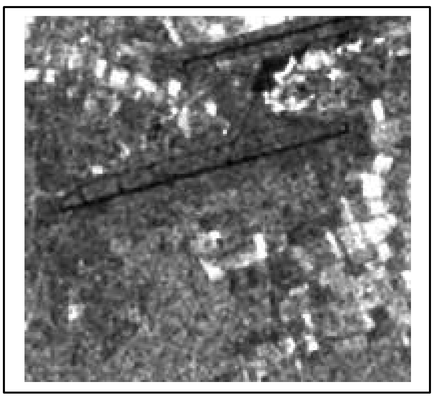


Figure 15: filtered ERS 1 image Median-filter, pixel 27m

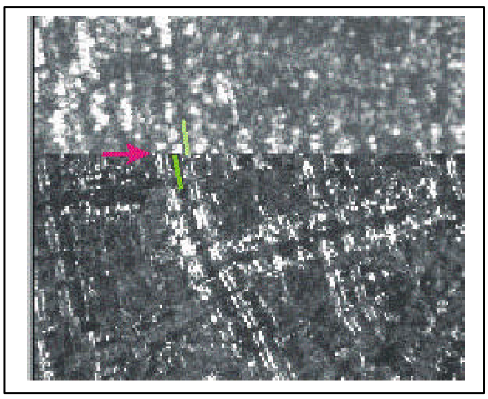


Figure 16: AeS1 airborne SAR upper part: P-band, pixel 2.5m lower part: X-band, pixel 1m

The figures 14 and 15 are showing the limited information contents of SAR-images and also the requirement for filtering. In figure 16 the information contents of high resolution SAR-images is demonstrated at an example over a suburb area – roads and individual buildings can be identified. Figure 16 also is pointing out the imaging problems of SAR. Both SAR-images are correctly geo-coded, but the P-band in the upper part was imaged from the right hand side and the X-band in the lower part from the left hand side, causing a shift of the elevated buildings and a fictitious shift of the road.

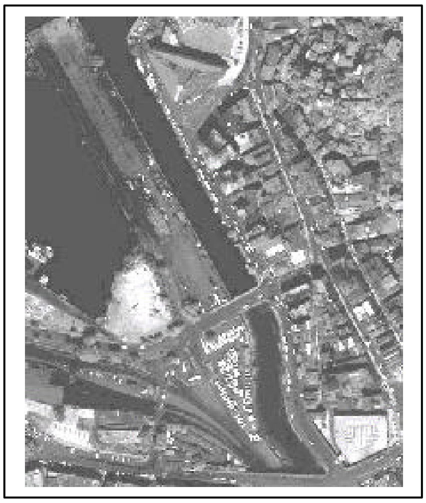


Figure 17: IKONOS panchromatic pixel size 1m

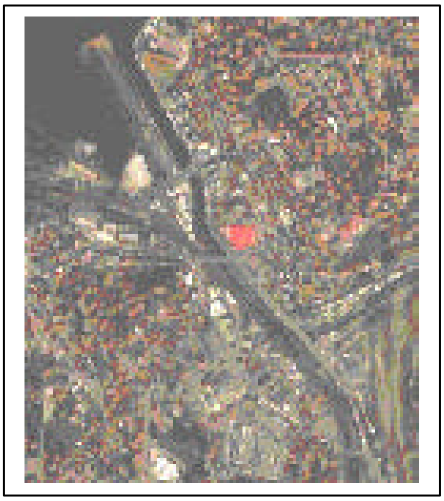


Figure 18: IKONOS multispectral pixel size 4m

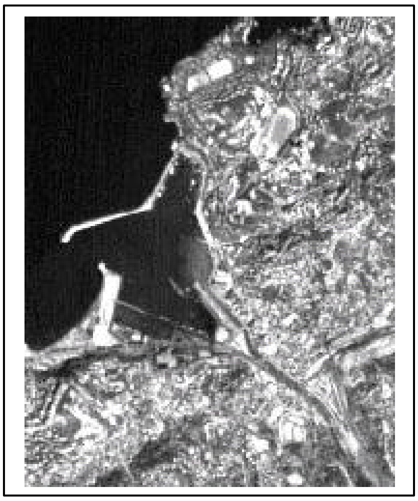


Figure 19 : IRS-1C pan pixel size 5.8m

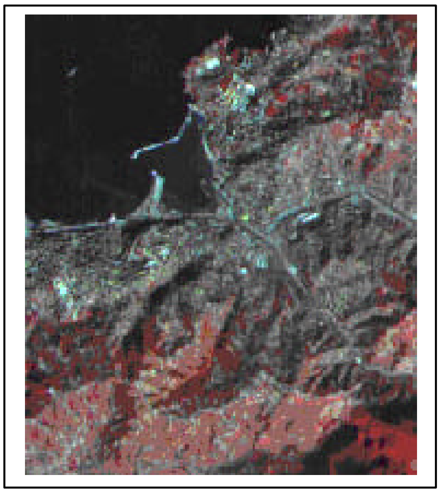


Figure 20: ASTER pixel size 15m

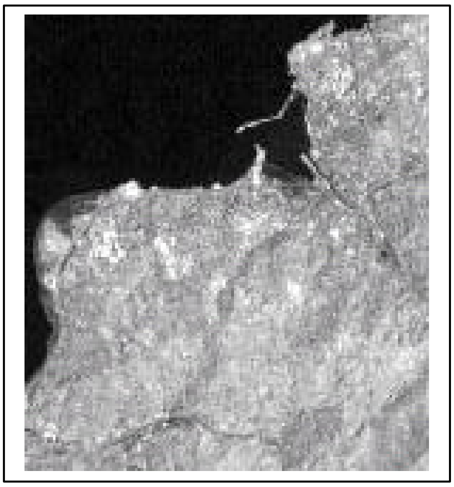


Figure 21: Landsat 7 pan pixel size 15m

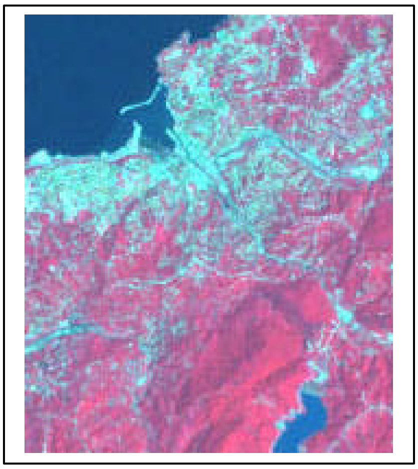


Figure 22 : Landsat 7 pixel size 30m

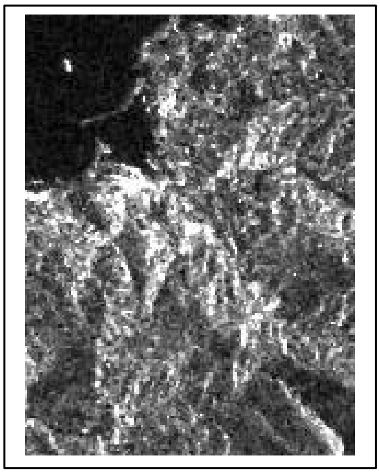
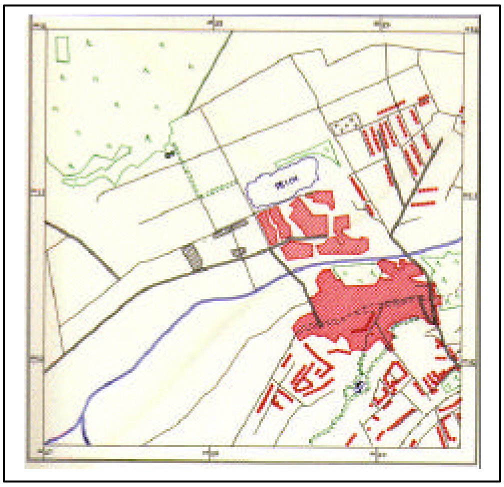


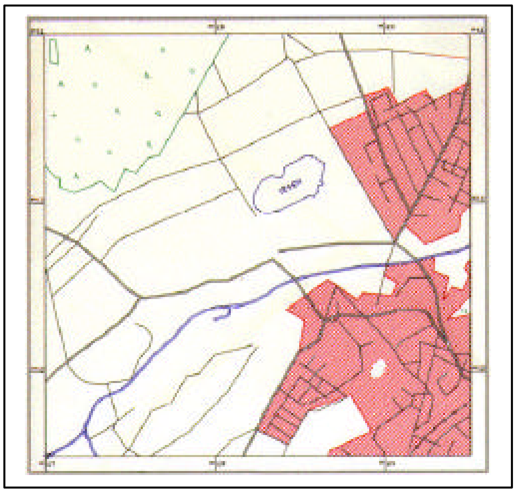
Figure 23: JERS SAR-image, pixel size 18m

The 7 space images of the same area (figure 17 – 23) do show very well the influence of the image resolution to the object recognition, expressed by the pixel size on the ground. Colour is supporting the object identification. The poor result of the SAR-image is obvious. Corresponding to this, maps with different scale can be created. As a rule of thumb, **0.1mm/pixel in the map scale is required for mapping** – leading to 0.1mm/pixel • 50 000 = 5m/pixel for the map scale 1 : 50 000 or 1m pixel size for the map scale 1 : 10 000.

← **Figure 23:** map based on IRS-1C LISS (24m pixel size)

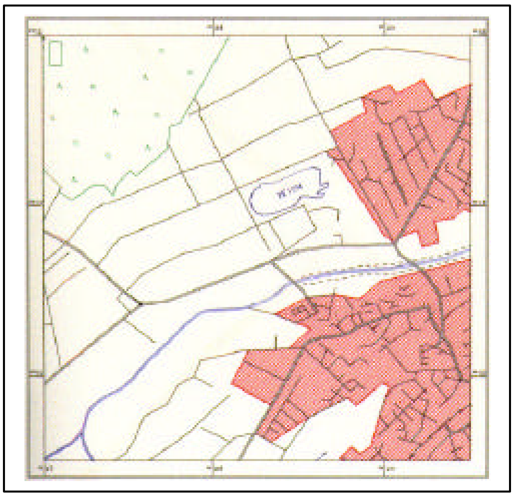
Figure 24 →: map based on KFA-1000 (5-10m pixel size)

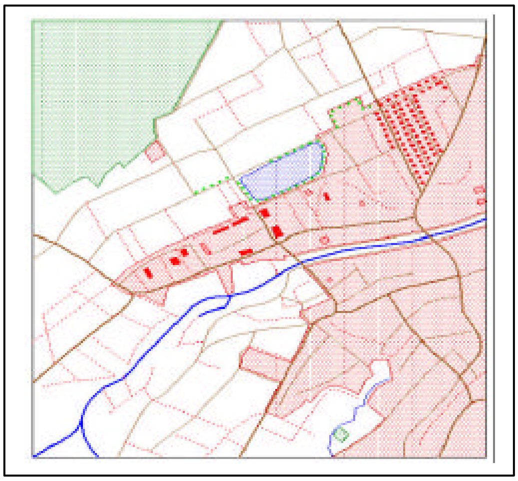




← **Figure 25:** map based on SPOT multispectral (20m pixel size)

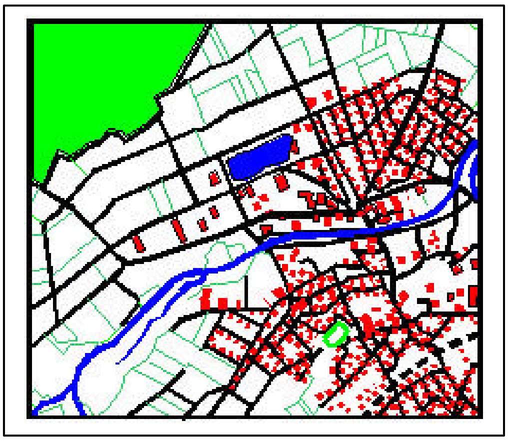
Figure 25 →: map based on SPOT pan (10m pixel size)





← **Figure 26:** map based on IRS-1C pan (5.8m pixel size)

Figure 27 →: map based on KVR-1000 (3m pixel size)



In figures 23 – 27 some examples of mapping based on space images can be seen. The relation between information contents and pixel size is obvious. A comparison of the maps based on SPOT panchromatic and SPOT multispectral shows only limited differences in the details – the colour is improving the object identification. The problems are not included in the accuracy of the pointing, this can be done sufficiently. If the mapping is supported by an existing map, much more details can be achieved – for example the not easy decision if a visible line is a field path or just a field boundary will be supported by it. In general, the above mentioned rule of thumb between required image resolution and the possible map scale has been confirmed by these examples.

5. DIGITAL ELEVATION MODELS

A more and more important product based on space images are digital elevation models. They are important as additional information for a GIS, but of course they are required for the creation of ortho images. The 3-dimensional shape of the earth is usually not changing so fast, so also not only the latest images can be used for the creation. The manual creation of DEM's is very time consuming, by this reason an automatic image matching should be preferred. This includes the disadvantage of a not selected location of the ground points – they may be located on vegetation and buildings. Such an automatic generated DEM has to be edited for points not located on the bare surface. A manual editing is too time consuming, this should be done automatically. In the University of Hannover the program RASCOR has been developed (Passini et al, 2002) for the automatic elimination of all points not belonging to the bare ground. Depending upon the area, up to 30% of the matched points are eliminated. After this, the data set can be used also for the computation of contour lines.

As result of the generation of several DEM's, in general an accuracy of the x-parallax of approximately Spx=6 to 8µm has been reached with space photos and for digital images it was in the range of Spx= 0.5 up to 0.7µm.

$SZ = \frac{h}{b} \bullet sn \bullet Spx$	$SZ = \frac{h}{b} \bullet SPX$	**Formula 3**: Standard deviation of Z
based on photos	based on digital images	h/b=height to base relation sn = scale number of image

Only in few cases problems occurred if there has been only a small time interval between imaging. Especially in dark forest areas or on snow field an automatic image matching has had problems, like also the human operator. With larger time differences between imaging, it becomes more difficult up to the case when no image matching is possible because of too strong changes of the object itself.

Better results have been reached with IKONOS data. An area has been imaged from the same orbit two times with a time interval of 12 seconds, corresponding to a base of 90km. The nominal collection elevation of the first scene was 78.3°, for the second scene 82.9°. This does not mean that the height to base relation is identical to 1/tangent (82.9° - 78.3°) = 12.5; because of the three-dimensional situation we do have in this case a relation of 7.5. The automatic image matching has been made with the Hannover program DPCOR in the image space. At first an image correlation will be used, followed by a least squares matching, the highest accurate possibility of automatic matching. The contrast and image quality in the working area was very good, which is not the case for every IKONOS image. In the project area a city with usually separated buildings and the surroundings are included. Caused by the image quality and the very structured area, the correlation coefficients have been very high, 81% of the points do have a correlation coefficient larger than 0.95 and only 4.8% a coefficient below the used tolerance limit of 0.80. A root mean square difference of the building heights of +/-1.7m has been reached corresponding to a standard deviation of the x-parallax of +/-0.22 m = 0.22 pixel. This high accuracy only can be reached under good contrast conditions, that means for rural area and a lower sun elevation which is usually causing a not so good image quality, the result may not be the same. Following the results based on IKONOS, with CORONA and IRS-1C / 1D an accuracy of 5 – 7m has been reached which these.

During the US-German/Italian Satellite Radar Topographic Mission (SRTM) in February 2000, by interferometric radar the largest part of the earth has been mapped. With the higher resoluting German / Italian X-SAR a standard deviation of the DEM of +/-3.3m in open landscape has been reached after an improvement of the orientation. The absolute accuracy without improvement is in the range of 4 to 6m (Heipke et al 2002). Unfortunately the SRTM X-SAR gives not a complete coverage opposite to the US SIR-C. The DEM-accuracy based on the SIR-C shall be on the level of +/-10m up to 16m, but the distribution of this DEM has not been clarified up to now.

CONCLUSION

A photogrammetric break through in the use of space images is on the way. Over several years the commercial applications have been limited by the 10m-pixel size and the across track stereo of SPOT. Since 1996 the resolution was improved by IRS 1C to 5.8m pixel size. The distribution of the Russian space photos with very high resolution was not acceptable, but has been improved yet. Now the first systems with 0.7m and 1m pixel size are operational, but it is still the question if 1m pixel size is really required – for several applications a pixel size of 2m up to 2.5m is sufficient and may be more economic.

The competition will show if a larger part of the mapping will be based on space images in future. If no problems with the access to aerial images are existing, it has to be more economic than the traditional method. Only for special applications the price for the images is not important, but the price of space images avoids just now a more wide use. By the competition of the different systems the price for the very high resolution space images has been reduced always in the USA. The fast distribution has been solved, because the major use of the space images is not in the field of mapping but in the field of time critical information. The announced accuracy of geo-location without control points up to +/-11m has been confirmed. It requires also the knowledge of the datum of the national net.

The use of synthetic aperture radar will be limited to special applications because of the limited object identification. Only if the radar interferometry can be used without problems and limitations, this will support the mono-plotting based on ortho-images using the derived digital elevation models.

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