

GEOMETRIC ASPECTS OF HIGH RESOLUTION SATELLITE SENSORS FOR MAPPING

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Abstract

The number of high resolution satellite sensors for mapping applications is growing very fast. Most of the sensors do have special geometric problems. Following space images have been analyzed beside the old tests made with the Metric Camera and the Large Format Camera: the Russian systems KATE200, MK4, KFA1000, KFA3000, KVR1000, the French System SPOT, the German System MOMS and also a first view has been made to the Indian IRS-1C. The use for mapping applications is different and some of the high resolution sensors are limited with the vertical accuracy. But of course for map updating the height is not required and the ground resolution is more important.

The high resolution photographic space images often do have larger geometric deformations, which can be determined only by means of ground control points. Satellite line scanner images do not show such a problem. On the other hand the information contents of the high resolution photos is better than the information contents of the available line scanner images.

INTRODUCTION

According to publications of the United Nations only 2.3% of the maps in the scale range of 1 : 50 000 are updated per year. The corresponding poor map information cannot be accepted, it is causing a loss in the national economics. One of the reason for this is the restriction in the use of aerial photos in several countries. This problem does not exist with space images and after ending the mayor confrontation between the Eastern and Western hemisphere, also high resolution space images are available now for common use. In addition no risk with the photo flights is existing and only the required images can be ordered. Not in every case the space images are less expensive than aerial photos covering the same area. Especially the high resolution Russian images are sometimes more costly.

The use of space images, both types, analogue and digital are causing some geometric problems which cannot be solved with the traditional methods for mapping with aerial images. Special software is required for handling space images in analytical or digital plotters and digital space images should be handled directly in digital stereo workstations. Also photos can be scanned and handled digitally, enabling more flexibility.

Of course not only geometric problems are existing, the information contents is especially for the map update more important, but the geometric problems should not be forgotten.

ANALYZED SPACE IMAGES

The following image types have been investigated in the University of Hannover:

Metric Camera (MC), German test 1983,

Large Format Camera (LFC), test USA 1984,

images taken with the operational photographic cameras from Russia (CIS): KFA1000, KATE200, MK4, KFA3000, KVR1000 - also named KWR1000, and handled also as digital data under the name DD5,

the operational French line scanner images from the SPOT satellite

and the German images from the Modular Opto-electronic Multispectral Stereo-Scanner MOMS-02, which is now operational as MOMS-2P

sensor	f [mm]	image size [mm]	flying height [km]	covered area [km]	ground resolution [m/lp]	height / base - ratio
MC	305	230•230	250	188•188	16 - 33	3.3
LFC	305	230•460	225 / 352	170•340 / 260•530	10	1.6
KFA1000	1000	300•300	220 / 350	66•66 / 105•105	5 - 10	8.2
KATE200	200	180•180	220 / 350	200•200 / 315•315	25 - 40	2.8

MK4	300	180•180	220 / 350	132•132 / 210•210	10 - 15	4.2
KFA3000	3000	300•300	220 / 350	22•22 / 35•35	2 - 5	no stereo
KVR1000	1000	180•(720)	220 / 350	26•(104)	(0.75) 2 - 5	no stereo
SPOT	(2086)	(150•150)	830	60•(60)	10/20m pixel	- 1.0
MOMS-02	220/ 660	6000 pixel/ 9000 Pixel	295	78• ... 37•...	13.5/4.5m pixel	1.3
MOMS-2P			390	100•./48•	16.5/3.8m	1.3

table 1: technical data of the used space images

The IRS-1C has been launched by India at December 28, 1995. The basic concept is the same like with SPOT, that means, the view direction of the line sensor can be tilted against the nadir and so from 2 neighbored orbits an area can be covered stereoscopic. The IRS-1C has a better ground resolution of 5.8m in the panchromatic band and a larger swath dimension caused by 12 000 pixel instead of 6000 pixel in the case of SPOT.

The KVR1000 is a panoramic camera using film. A moving mirror is scanning an area of $\pm 20^{\circ}40'$. The film is not distributed with the original size of 180mm • 720mm, it is cut into pieces of 180mm • 180mm.

The German Modular Opto-electronic Multispectral Scanner (MOMS) has the advantage of a stereoscopic coverage within one orbit. It has been used during a test from the Space Shuttle in 1993 as MOMS-02 and it is now in use on the Priroda-module of the Russian space station MIR as MOMS-2P.



figure 1: KVR1000 image - city of Duisburg, Germany



figure 2: IRS-1C image - city of Budapest, Hungary

MATHEMATICAL MODEL

Some of the approximations used for handling usual aerial photos are not acceptable for space images. The mathematical model is based on an orthogonal coordinate system and perspective image geometry. All differences

against this model have to be respected by some corrections. In addition the basic mathematical relation can only be used for perspective images, for scanners not only one projection center is existing, a projection line has to be used. In the case of direct use of the national net coordinates, the effect of the earth curvature is respected by a correction of the image coordinates and the effect of the map projection is neglected. This will lead to not acceptable remaining errors for space images. Not only the size of the earth curvature correction is very large with up to 1mm, there is also a second order effect to the height.

$\frac{\Delta z}{\Delta Z} = \frac{Z_f}{R}$ <p> Δz = error in height caused by earth curvature correction ΔZ = height differences on the ground R = radius of earth Z_f = flying height </p> <p>formula 1: error in height caused by traditional earth curvature correction</p>
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The influence of the earth curvature correction is negligible for aerial photos because of the smaller flying height Z_f . For a flying height of 300km we do have a scale error of the ground height of 1 : 20 or 5%. Also the map projection will cause a deformation of the model which cannot be accepted. The deformation is depending upon the size of the model and the location within the coordinate system. For example a metric-camera-model can get a deformation of up to 91m or after scale change up to 36m corresponding to 0.72mm in the map scale 1:50 000 which is too large.

The problem of the map projection and the earth curvature correction can be solved by use of an orthogonal coordinate system - the geocentric coordinate system or better for practical applications, with a tangential plane to the ellipsoid.

$Dr = (0.113 \cdot \frac{(P1 - P2) \cdot Zg}{Zf - Zg} - \left(\frac{Zf \cdot 2410}{Zf^2 - Zf \cdot 6 + 250} - \frac{Zg \cdot 2410}{Zg^2 - Zg \cdot 6 + 250} \right) \cdot \left(\frac{r^3}{f^2} \right) \cdot 10^{-6}$ <p> Z_f = flying height above mean sea level [km] Z_g = mean terrain height above mean sea level [km] formula 2: refraction correction f = focal length [mm] r = radial distance in image [mm] [μm], based on 1959 standard $P1$ = air pressure mb in terrain height atmosphere $P2$ = air pressure mb in flying height $P = e^{(6.94 - Z \cdot 0.125)}$ </p>

Also the usual formulas for the refraction correction should be checked. Several formulas are based on polynoms only valid up to the usual flying heights for aircrafts and are delivering completely wrong results for space images.

LINE SCANNER IMAGES

The line scanners like SPOT, IRS-1C and MOMS 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 photo 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 $\pm 4m$ (Jacobsen 1993). The simplified mathematical models used in some other programs have to use more control points.

The header data of digital SPOT scenes are including detailed information about the actual satellite orbit. In a first program version of BLASPO the orbit was determined in fitting the ephemeris by an ellipse. The achieved results of the SPOT orientation based on this have been total sufficient. But very often no header data were available in the case of recorded images. By this reason a simplified method was developed.

The image is rotated depending upon the known view direction. With at least 3 control points and a general information about the inclination, the semimajor axis and the eccentricity of the satellite orbit, the actual trace can be computed without any actual information of the ephemeris based on an affinity transformation. The remaining errors of the mathematical model, especially the affinity and angular affinity have to be fitted by additional unknowns (additional parameters) in the image. By this method errors of the exterior orientation caused by an inaccurate orbit or irregular movements within the orbit can be identified and respected.

With such approximate information a bundle orientation of SPOT images is possible without loss of accuracy against the use of the actual ephemeris.

The same mathematical model is used for the MOMS images. The only difference between SPOT and MOMS is the direction of stereoscopic coverage. In the case of SPOT it is across the orbit, MOMS has an inclined sensor forward and one after in the orbit, so directly in one orbit there is a stereoscopic coverage. That means in the mathematical model only the image coordinate system has to be rotated against the SPOT solution.

PANORAMIC IMAGES

The KVR1000 is a panoramic camera, that means, the image is scanned via a rotating mirror from one side to the other. As in the case of line scanner images we do not have a projection center, we do have a projection line. The information distributed by Sovinformsputnik, Moscow about the panoramic process is poor, so it was necessary to investigate the geometric relation.

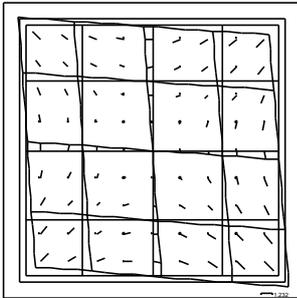


figure 3: geometric deformation of KVR1000 image in the Ruhr Area
 image size: 180mm • 180mm
 difference against perspective:
 up to 1.2mm

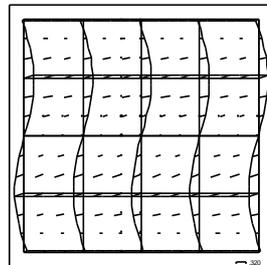
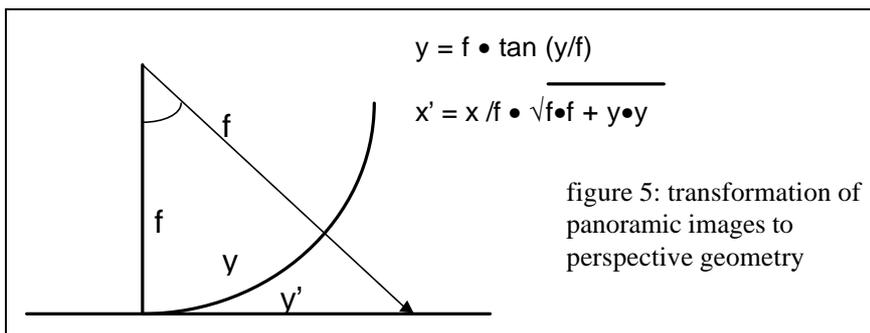


figure 4: typical S-shape deformation of panoramic images



The dominating effect of the "systematic image error" is the angular affinity caused by the earth rotation during scanning. The typical S-shape of panoramic images (figure 4) is much smaller and cannot be seen in the graphical representation of figure 3. The general panoramic correction was respected in advance (figure 5).

EMPIRICAL RESULTS

The geometry of the different space images and the accuracy of the achieved ground coordinates have been investigated by bundle block adjustment with the Hannover program system BLUH and by height measurements. The special situation of imaging from space like earth curvature, map projection, refraction and earth rotation was respected.

KATE200, MK4, KFA1000

The results achieved with the Metric Camera, the Large Format Camera, KATE200 and MK4 have been published before (Jacobsen 1986). The first both have been used as a test. The operational cameras KATE200 and MK4 do have an insufficient ground resolution for mapping in the scale 1 : 50 000, the required details cannot be seen. The KFA1000 is an important tool, the ground resolution of 5 - 10m is better than the ground resolution of SPOT images. Problems are caused by the image size of 300mm • 300mm. It is too large for analytical plotters, so only copies of parts can be handled. Also for photogrammetric image scanners this format exceeds the limits and cartographic or drum scanner are not accurate enough. A mayor problem of the KFA1000-photos is the geometric situation. The camera itself shows large systematic effects up to 100µm and the stability of the used film is limited. Because of this, a selfcalibration by additional parameters is absolutely necessary. But with a limited number of control points only a part of the systematic image errors can be determined, causing a deformation of computed ground coordinates. This is not effecting the neighborhood relation of the ground points, but the absolute accuracy is reduced. The horizontal accuracy is also with just 4 control points better than +/-15m, that means sufficient for mapping in the scale range of 1 : 50 000, but the poor height-to-base relation causes a poor vertical accuracy.

KFA3000

A contouring requires a stereoscopic coverage, which is not available for the KFA3000 and the KVR1000. Caused by the rapid movement of the satellite an endlap of 60% is not possible. On the other hand a stereoscopic overlap is not very useful for a camera with a focal length of 3m. Two slightly overlapping KFA3000 images of the area around Vienna have been inspected. Control points have been digitized from maps 1 : 50 000, 1 : 10 000 and 1:2000. The result of a spatial resection with selfcalibration by additional parameters shows a very clear dependency about the control point accuracy - this is a typical effect of the analysis of space images.

control points from maps	number of points	image Sx'	image Sy'	ground SX	ground SY
1 : 2000	115	32 μ m	24 μ m	2.8m	2.1m
1 : 10 000	97	47 μ m	33 μ m	4.0m	2.9m
1 : 50 000	88	152 μ m	150 μ m	12.6m	13.0m

table 2: accuracy of resection depending upon maps used for the control points

In relation to a map 1 : 2000 the ground accuracy of $\pm 2m - 3m$ is sufficient also for updating large scale maps. Corresponding to the rule of thumb that a ground resolution of 0.1mm up to 0.2mm in the map scale is required, mapping can be made in the map scale 1 : 25 000. For map updating the ground height must be available with an accuracy corresponding to the required horizontal accuracy multiplied with the factor of 2.5 because of the inclined view of 16° and 21.2° in this case.

KVR1000

A photo taken by the panoramic camera KVR1000 over the Ruhr-Area in Germany has been analyzed. Because of poor preinformation it was necessary to determine the geometric situation by resection with additional parameters, respecting the special condition of panoramic images (figure 3 - 5). The flying height of 220 km corresponds together with the focal length of 1m to a photo scale 1 : 220 000. Based on 112 control points digitized from maps 1 : 5000 a standard deviation of $\pm 15\mu m$ for the image coordinates, corresponding to $\pm 3.3m$ on the ground has been reached. This includes also the influence of the control point accuracy. Like the KFA3000-images, the KVR1000-photos can be used for map updating in the map scale 1 : 25 000 if the ground height is available with an accuracy of 2.7 times the required horizontal accuracy. This is caused by the fact that in advance there is no information available which part of the original film size of 180mm • 720mm is distributed. The maximal view direction can reach $20^\circ 40'$ from the nadir.

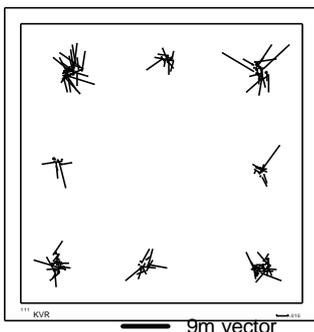


figure 6: discrepancies at control points - KVR1000

SPOT, MOMS

The mathematical model for handling the satellite line scanner images used in the program BLASPO, belonging to program system BLUH, is based on the movement of the satellite on a Kepler ellipse fixed in the space over the rotating earth. For every sensor line different orientation parameters are used. The Kepler ellipse is computed without knowledge of the ephemeris just by using very rough information about the orbit by means of at least 3 control points. This method has allowed the bundle adjustment of MOMS-02 just with the rough information of 295km flying height and the orbit inclination of 28.5° without loss of accuracy. The rough orbit information is improved in the orientation process and finally also by 2 additional parameters. 4 control points are sufficient for handling also a SPOT-flight strip over 200km with a vertical accuracy of better than $\pm 5m$.

In Dubai, where maps 1 : 10 000 have been available, the stereoscopic measurement of image points in the digital stereo workstation DISH developed by the University of Hannover of a combination of the high resolution channel together with the channel 6 (resampled by multiplication factor 3) resulted in a ground accuracy of $SX=\pm 3.3m$, $SY=\pm 3.2m$ and $SZ=\pm 4.4m$ (Schiewe 1995). The height to base relation of 2.5 indicates, that again the mean square differences are influenced by a limited control point accuracy ($SX=SZ \cdot h/b = SX=\pm 4.4m / 2.5 = \pm 1.8m$). The vertical accuracy corresponds to 0.4 pixel of the high resolution channel and 0.13pixel of the other channel.

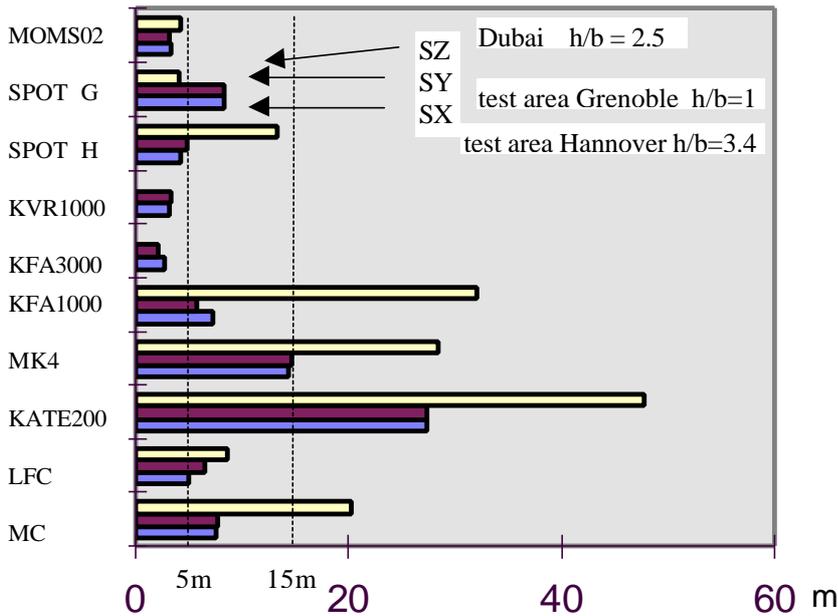


figure 7: accuracy of bundle adjustment with space images

	height/ base	SZ [m] [pixel]	spx [μm] [pixel]	table 3: accuracy of grid heights checked with independent ground points
MC p=60%	3.3	22	8.1	
MC p=20%	1.7	11	7.9	
LFC p=60%	1.7	11	8.7	
LFC p=20%	0.8	5	8.4	
KFA 1000	8.3	15	6.6	systematic image errors reduced by local fitting to control points
SPOT panchromat.	2.9	22 2.2	0.7	only 38% of the points could be measured - 2 month time interval between imaging
SPOT multispectral	3.4	18 1.8	0.5	

CONCLUSION

A self calibration is required for the handling of photographic space photos. The image deformations are much less for digital images because no problems are existing in the sensor line and the flight in the orbit is not strongly disturbed.

With a correct handling of the images the same accuracy in the image space can be achieved like with usual aerial photos. The mayor geometric problems are caused by limited control point quality. But also with poor control points the relative accuracy of a point to another in the neighborhood is not disturbed and is the same like with good control points.

Today the best resolution of the not classified space images is available with photos, especially the KFA3000 and the KVR1000. But both systems can be used only for mono-plotting. With MOMS-images the best vertical results can be achieved. SPOT- and IRS1C-images do have the problem of the time interval of imaging both scenes of a stereo model which is causing problems in the stereoscopic impression.

REFERENCES

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As it can be seen in figure 7, the horizontal accuracy determined with space images is with the exception of the KATE200 sufficient for mapping in the scale 1 : 50 000. For the vertical accuracy no general accuracy limit is available, so it is depending upon the area if the space images can be used for height determination. But the result of a bundle adjustment is not the same like a grid measurement because for height measurements also areas with not optimal contrast conditions have to be used.