# GEOMETRIC ASPECTS OF THE HANDLING OF SPACE IMAGES

Karsten Jacobsen

University of Hannover, Institute for Photogrammetry and GeoInformation
Nienburger Str. 1, D-30167 Hannover
jacobsen@ipi.uni-hannover.de

**Commission I, WG I/5**

**KEYWORDS:** space images, mathematical models, orientation, GIS

**ABSTRACT:**

Only few space images do have a perspective geometry like aerial cameras. But also the Russian perspective photos do have not negligible systematic image errors. By this reason special mathematical models have to be used for a correct handling of the space images. Polynomial models, often used for remote sensing purposes, are no economic solutions because they do mix the influence of the sensor geometry with the influence of the object elevation and require a high number of control points and do have problems with the identifications of blunders. Different mathematical models have to be used for the correct handling of perspective images together with the identification of systematic image errors, the handling of panoramic cameras like CORONA and KFA 1000, for satellite line scanner cameras and rectification derived from satellite line scanner cameras like the IKONOS Geo-images.

The different mathematical models are explained together with achieved results and problems of the sensors. The solution for the upgrade of IKONOS Geo-images based on a DEM and control points without using rational functions from SpaceImaging (SI) is described. The achieved results are better than specified by SI for the CARTERRA Precision plus.

## 1. INTRODUCTION

The data acquisition based on space images today will be done in an GIS environment. The optimal use of a GIS is requiring a correct location, the precondition for a fit of the data sets. By this reason the often used approximate solutions based on a polynomial fit, should be avoided. They do require more control points and do not respect the three dimensional shape of the earth. If original images taken with satellite line scanner cameras (usually named as level 1A) are available, just based on the general orbit information and the view direction, with only 3 control points a strict mathematical reconstruction of the geometric situation is possible. Special attention has to be taken to cameras using not only one, but a combination of 3 CCD-lines which may not be aligned precisely, like the IRS-1C or –1D. With special additional parameters the geometric problems can be solved. Also without exact knowledge of the imaging parameters of panoramic cameras like the Russian KVR 1000 (identical to SPIN 2) or CORONA, a precise mapping with such images is possible with additional parameters modelling the panoramic characteristics. Also for the precise handling of the Russian film cameras additional parameters are required to respect the not negligible film deformation.

Only derived image products are available from IKONOS, but the reconstruction of the original geometry without using the rational functions from SI is not a problem and so orthoimages or digital elevation models can be created with the full accuracy potential of the IKONOS images.

## 2. GENERAL ASPECTS

All mathematical models are based on orthogonal coordinate systems. The national coordinate systems are not orthogonal – they are following the curved earth and with the Geoid the height has a different reference. For aerial images the influence of the earth curvature is respected by a correction of the image coordinates, this is not sufficient for space images. By this reason space images should be handled in the geocentric or better a tangential coordinate system. The influence of the refraction is usually negligible. In the extreme case of IKONOS-images with a nadir angle of 45° it has an influence on the ground of 5m, which is just a shift of the scene and can be compensated by control points.

## 3. PERSPECTIVE SPACE IMAGES

Perspective images have been the first used from space like taken with Hasselblad cameras and the modified aerial camera from Zeiss used as Metric Camera in the German Spacelab mission D1 followed by the US Large Format Camera. The derived photos are today more historic and useful only for special applications. Only Russia is today still taking perspective photos in unmanned missions. Especially the KFA 1000 and the TK350, used together with the panoramic camera KVR 1000, are important. They can be a more economic solution like more expensive line scanner systems. An advantage of the space photos is the high information contents. A TK350 photo corresponds to a size of approximately 31 000 x 64 000 pixels.

The image geometry of the photographic cameras KFA 1000, MK4 and KATE 200 are not very stable. In any case larger systematic errors with values up to 85µm have been seen. They only can be identified by means of self calibration with additional parameters based on control points. The resulting systematic image errors are different from case to case and cannot be neglected. In a typical case of a KFA 1000-model (1m focal length, 30cm x 30cm image format, image scale 1:270 000, base to height relation 1 : 8), without self calibration based on 190 control points a sigma0 of 32µm, a horizontal accuracy of 15.1m and a vertical accuracy of 70.6m has been reached, with self calibration the sigma0 has been reduced to 20µm and the accuracy in X and Y to 7.1m and for Z to 40.9m.

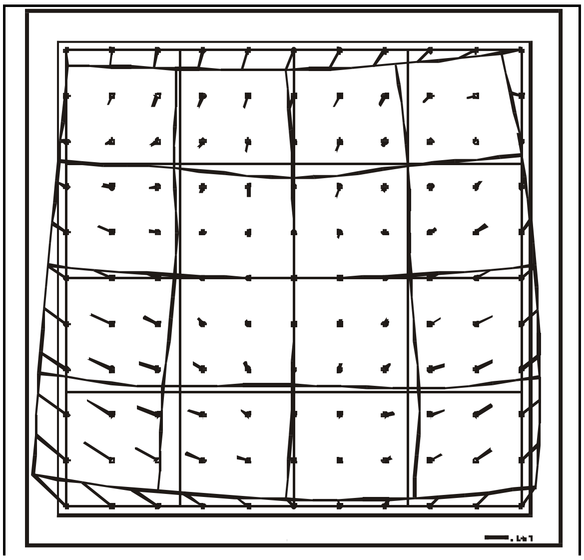

Figure 1: systematic image errors of KFA 1000, largest vector 81µm

## 4. PANORAMIC CAMERAS

Panoramic film cameras are imaging only a small part at the same time. This includes the advantage of an optimal optical system enabling a very high resolution. The US CORONA and the similar Russian KFA 1000 are belonging to this type. The former spy images are released now. The CORONA images are taken more than 30 years ago, but with the stereoscopic arrangement they do have the advantage of a determination of high quality digital elevation models (DEM's). Usually the ground surface is not changing very fast and so these images are an economic solution for the DEM generation. The covered area of approximately 17km x 278km allows with a pixel size corresponding to 2m and an angle of convergence of 30° a relative vertical accuracy of +/- 3m (Schneider et al 2001).

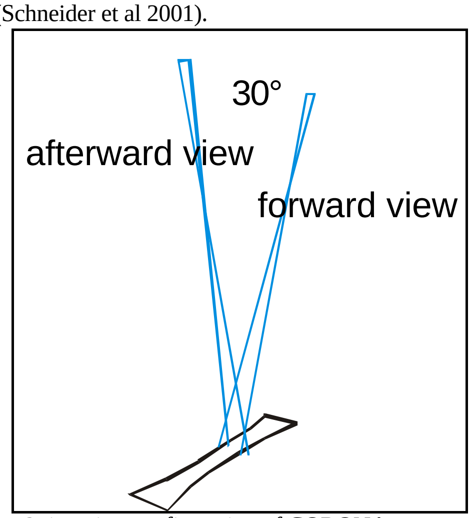


Figure 2: imaging configuration of CORONA

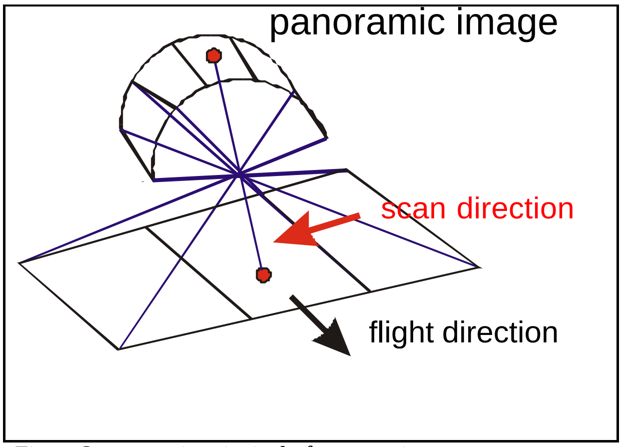


Figure 3: geometric principal of panoramic cameras

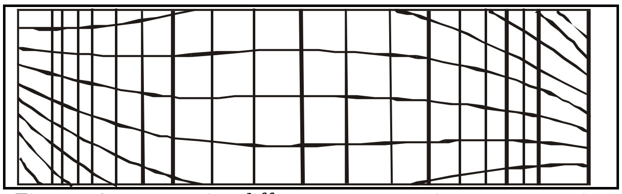

Figure 4: geometric difference panoramic – perspective image

The panoramic cameras are scanning the area from one side to the other. By this reason the image scale is depending upon the nadir angle. For the used flying height of 187km for most of the CORONA KH-4B, the scale is varying between 1 : 300 000 in the center up to 1 : 366 000 at a nadir angle of 35°. A second effect is movement of the satellite and the rotation of the earth during scanning. Both are deforming the image geometry against a perspective camera. A square grid located in the object space will be imaged in a panoramic image like shown in figure 4. Of course this is enlarged, in reality the differences are smaller, but the panoramic images do have in general such a geometry.

In the used program system BLUH, at first the panoramic images are rectified against a tangential plane to the imaging surface, this is equalising the scale. As next step the geometric deformation is handled by additional parameters. This is required because of the unknown exact imaging parameters like the scan speed. The mathematical model has been proven also with KVR1000 images – the corresponding reconnaissance camera of the USSR. In a test area in Germany with accurate control points, an accuracy of +/- 3.3m for X and Y has been reached, equivalent to 15µm in the image (Jacobsen 1997).

## 5. LINE SCANNER CAMERAS

Satellite line scanner images do have a geometry different from perspective photos. For each line we do have a different exterior orientation – the projection center (X0, Y0, Z0) and also the attitude data (phi, omega, kappa) are changing from line to line. But the satellite orbit is very regular, allowing the determination of the relation of neighboured lines and also the whole scene based on the orbit information.

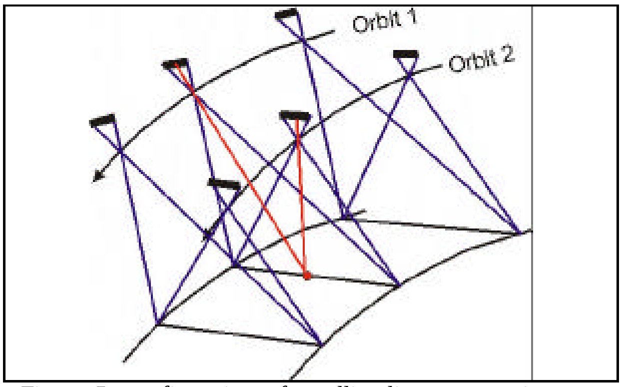


Figure 5: configuration of satellite line scanner images - stereo from neighboured orbits

Based on a rough information about the satellite orbit, the geometric relation of such satellite line scanner images can be determined based on just 3, but better 4 control points with the full possible accuracy for example with the Hannover program BLASPO. The mathematical model is based on perspective relation in the line (colinearity equation) and an exterior orientation depending upon the row of the image. Only a common correction is determined for all exterior orientations together. Because of the geometric relation as unknowns 3 rotations, Z0, affine relation and angular affinity are used.

The horizontal accuracy, which can be reached with digital images, is depending upon the pixel size on the ground – under optimal conditions (no haze, sufficient contrast, well defined points) with a standard deviation up to 0.3 pixels. As a working rule, the vertical accuracy corresponds to the horizontal accuracy multiplied by the height to base relation. The possibility of changing the view direction across the orbit enables a stereoscopic coverage in the case of SPOT or IRS-1C/1D with a base to height relation up to 1.0, so with such a configuration the vertical accuracy may be the same like the horizontal. This has been confirmed with well defined independent check points – with panchromatic SPOT images a standard deviation up to 4m has been reached for all coordinate components. But this cannot be reached for a DEM because of not optimal conditions for all ground points. The main problem for the determination of a DEM with images taken from neighboured orbits is the seasonal change of the objects. Especially in Europe with a high percentage of cloud coverage, during the next possibility of imaging the same area from another orbit, it may be covered by clouds and so it takes usually a longer time to complete a stereo model. In one case with images taken in June and in August over the area of Hannover, in the rural area no stereoscopic view was possible due to strong seasonal changes of the vegetation. Such a problem will be avoided by a stereo view from the same orbit. The German MOMS was the first sensor with a combination of different optics viewing forward, to the nadir and backwards, allowing a stereoscopic coverage in any case and with only a small difference in time (see figure 6).

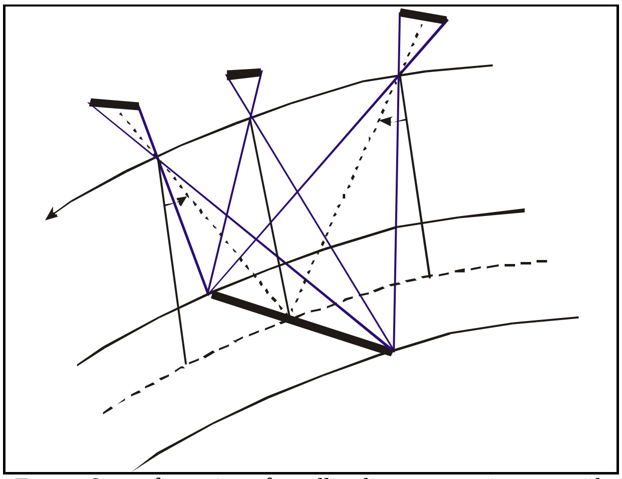

Figure 6: configuration of satellite line scanner images with stereo in the orbit

The advantage of this imaging principle is obvious, an automatic image matching is not disturbed by seasonal changes. By this reason more and more systems are following this principle like Terra-ASTER with a nadir and a 24° inclined backward view. Also SPOT V is equipped with the High Resolution Stereo (HRS) with a 20° forward and also 20° backward view. The Indian Cartosat and the Japanese ALOS will follow.

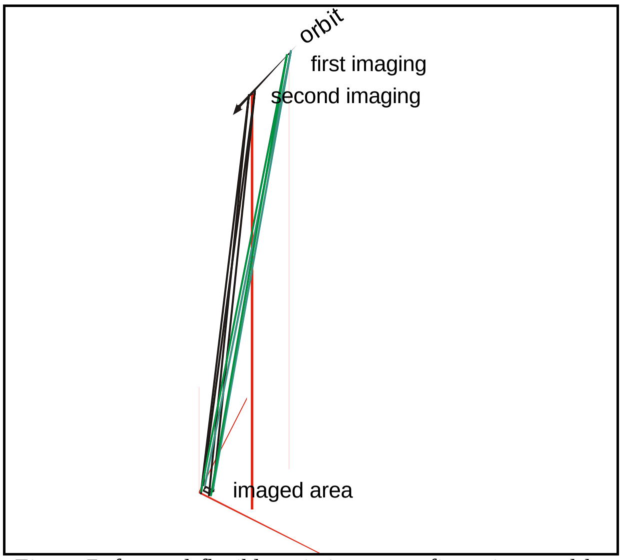


Figure 7: fast and flexible pointing – configuration used by IKONOS in Turkey

Another realisation of a stereoscopic coverage we do have with the new very high resolution sensors IKONOS, EROS A1 and Quickbird. They do allow a very fast change of the view direction enabling a stereoscopic coverage in the orbit. A configuration used by IKONOS in a project in Turkey is shown with the correct scale relations in figure 7. The used base of 90km corresponds to a time interval of just 12 seconds including also the time for imaging of 1.5 seconds. The corresponding height to base relation is 7.5 : 1.

IKONOS and Quickbird are equipped with TDI-sensors. A TDI-sensor is not just a CCD-line, it is a CCD-array with a small number of pixels in the flight direction. During imaging the charge is generated in the CCD-elements and shifted to the neighboured CCD-line corresponding to the speed of the image motion. So the charge is accumulated over a longer time than just 0.12msec. EROS A1 has no TDI, by this reason, the view direction will be rotated during imaging to increase the integration time of imaging (see figure 8). Of course this makes the correct geometric handling more difficult, but the first priority of EROS A1 is more the reconnaissance than the mapping.

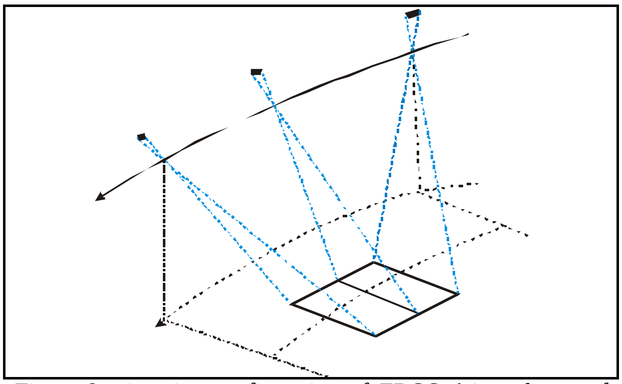

Figure 8: imaging configuration of EROS A1 – change of view direction during imaging

Not the original IKONOS-images are distributed, only derived products. Due to the price constellation ortho images of a whole scene (CARTERRA Precision plus) are up to 20 000 US$ more expensive like a rectification (CARTERRA Geo). By this reason usually only the CARTERRA Geo images are bought. For additional expenses rational functions containing the imaging geometry can be ordered, but the geometric situation of the CARTERRA Geo-images is not so complicate, so the rational functions are not required.

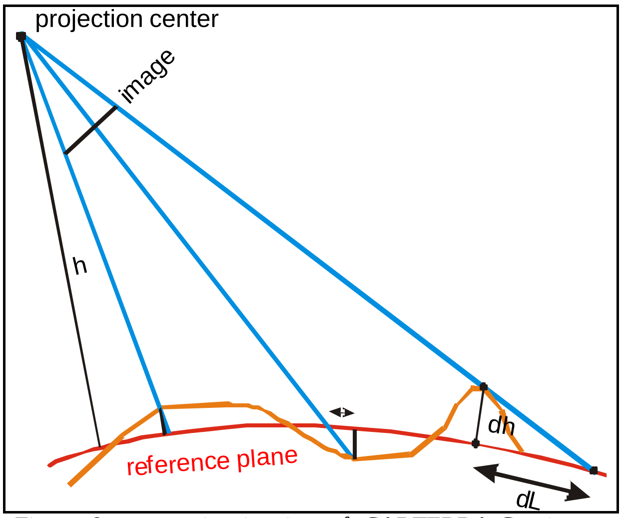


Figure 9: geometric situation of CARTERRA-Geo-images (rectified IKONOS-images)

In the metadata-file, coming together with the images, the "nominal collection elevation" and the "nominal collection azimuth" are included. Based on this horizontal and vertical view direction in relation to the scene centre, together with the general knowledge of the satellite orbit, the view direction for every point in the scene can be computed (see figure 9). The Geo-product is rectified to a specified plane parallel to the earth ellipsoid using the direct sensor orientation of the satellite which is based on GPS, inertial measurement units and star sensors. Beside the remaining errors of the image orientation, the geometry of such a rectified image is influenced by the local height difference dh against the rectification plane, causing a displacement dL as shown in figure 9, the geoid undulation and also the relation of the national coordinate system to WGS84 (datum).

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 the geometry of a CARTERRA-Map-product. The height level of the reference plane is not available for Geo-images. A deviation of the reference plane from the correct value is causing an error in the location of dl =dh•tanv. 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 an affine transformation to the control points.

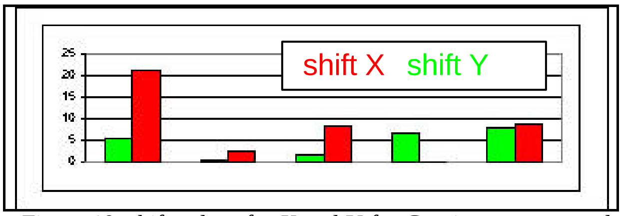


Figure 10: shift values for X and Y for Geo-images corrected by DEM [m] (projects Switzerland, USA, Malaysia, 2 x Turkey)

Figure 10 shows the accuracy of the absolute georeference of Geo-images corrected by a DEM with the mean height of the DEM as reference plane. As mean square value of 5 projects +/-9.1m have been achieved – a better result like specified by IKONOS.

Based on control points the full accuracy potential can be reached. In the OEEPE data set of the area of Lucerne the CARTERRA-Geo-image has a displacement up to 410m caused by the high mountains. After height correction and an affine transformation to the control points (Hannover program CORIKON), for well defined control points a mean square difference of +/-1.6m has been achieved. In a project in Turkey with up to 400m difference in height, but control points determined by GPS, an accuracy of approximately 1m (= 1 pixel) has been reached. By theory 3, for operational applications 4 control points are required. If control points are available in different elevations, also the nominal collection elevation and azimuth can be computed.

The determination of DEM's with Geo-images in a stereo arrangement by automatic image matching also has to respect the special geometric relation. It was possible to reach an accuracy of the x-parallax of 0.22 pixels.

## 6. ACHIEVED ACCURACIES

The accuracy achieved with the different sensors has to be separated between photographic and digital sensors. As mentioned before, the Russian space photos may be still today an economic solution.

| | Sx'/y' [µm] | Spx [µm] | SX/Y [m] | SZ [m] |
|---|---|---|---|---|
| MC | 10 | 10 | 8 | 20 |
| LFC | 9 | 8 | 7 | 9 |
| KATE200 | 21 | 19 | 30 | 39 |
| MK4 | 25 | 15 | 22 | 29 |
| KFA3000 | 33 | - | 2 | - |
| KFA1000 | 30 | 19 | 7 | 32 |
| KVR1000 | 15 | - | 3 | - |

Table 1: accuracy achieved with space photos

| | SX/Y [m] | SZ [m] | Sx'/y' [pixel] | Spx [pixel] |
|---|---|---|---|---|
| SPOT H | 4.6 | 13.4 | 0.5 | 0.5 |
| SPOT G | 8.4 | 4.1 | 0.8 | 0.4 |
| IRS-1C | 5.1 | 8.7 | 0.9 | 1.5 |
| IKONOS | 1.0 | 1.7 | 1.0 | 0.2 |
| ASTER | 10.8 | 14.6 | 0.7 | 0.5 |

Table 2: accuracy achieved with satellite line scanner images

The listed accuracy has been determined with independent check points. Not in any case the check points have been accurate enough for the analysis – especially in the case of the very accurate ground coordinates. In space photos with a stable geometry, an accuracy in the range of 10µm in the image can be reached. For images with a not very stable geometry it can go up to 20µm (see Spx in table 1). The other larger values are mainly influenced by the limited accuracy and definition of the check points.

With digital images a sub-pixel accuracy is possible if the control and check points are accurate enough and well defined.

## 7. CONCLUSION

The mathematical model used for the handling of space images has to respect the geometric conditions. The computation has to be made in an orthogonal coordinate system. For space photos a self calibration with additional parameters is required. The inner accuracy of CCD-lines does not cause any problems. Only in the case of a combination of CCD-lines special additional parameters for the alignment may be required like for the IRS-1C /1D. For rectified images like CARTERRA Geo and ASTER 1B, a special mathematical model is required, but it can be handled without additional information just based on the general orbit data.

## REFERENCES

Jacobsen, K., 1997: Geometric Aspects of High Resolution Satellite Sensors for Mapping, ASPRS Annual Convention Seattle, 1997.

Jacobsen, K., Konecny, G., Wegmann, H., 1998: High Resolution Sensor Test Comparison with SPOT, KFA1000, KVR1000, IRS-1C and DPA in Lower Saxony, ISPRS Com IV, Stuttgart / *Int. Archive for Photogr. and Rem. Sensing* 32/4.

Schneider, T., Jacobsen, K., Seitz, R., Förster, B., 2001: *Remote Sensing based Parameter Extraction for Erosion Control Purposes in the Loess Plateau of China, High Resolution Mapping from Space* 2001, Hannover.

Jacobsen, K., 1998: Status and Tendency of Sensors for Mapping, ISPRS Commission I, Bangalore 1998, *Int. Archive for Photogr. and Rem. Sensing* 32/1.