MAPPING WITH IRS-1C-IMAGES

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ABSTRACT

The images of the panchromatic camera (PAN) of the Indian Remote Sensing Satellite do provide with 5m pixel size the highest resolution of the operational civilian cartographic space sensor usable for three dimensional mapping. But in relation to other space images the radiometric quality is limited by the 6 bit gray value representation. So before starting with mapping a radiometric enhancement is required. The 12 000 pixel of the PAN-camera are composed by 3 CCD-line sensors, each with 4096 pixel. This complicates the sensor geometry because the relation has to be determined by self calibration. 5 control points in the covered area of at least 70km x 84km are required for this. Based on such images the information contents of German topographic 1 : 50 000 could be reached, which was not possible with other space images like SPOT and KVR1000.

IRS-1C PAN-CAMERA

The Indian Remote Sensing Satellite IRS-1C, launched in December 1995 and the identical IRS-1D, launched in September 1997 do have 3 sensors on board, the high resolution PAN-camera with a pixel size of 5.8m, the Linear Self Scanning camera LISS-III with 3 spectral bands having a ground resolution of 23.5m (band 2: 0.52µm – 0.59µm, band 3: 0.62µm – 0.68µm, band 4: 0.77µm – 0.86µm) and one spectral band with 70.5m pixel size (band 5: 1.55µm – 1.70µm) and the Wide Field Sensor WiFS with a pixel size of 188m (band 3: 0.62µm – 0.68µm, band 4: 0.77µm – 0.86µm). With 6000 pixel LISS-III has a swath width of 141km, The WiFS is imaging a width of 804km. A stereoscopic coverage of the ground is possible by a rotation of the whole PAN-camera up to +/-26° across track, corresponding to SPOT.
There is no CCD-line available with 12 000 pixel and a pixel size of 7µm, corresponding to a length of 84mm, by this reason the imaging with the PAN-camera is separated to 3 CCD-lines. Each CCD-line has 4096 pixel. There is a small overlap of the 3 lines, so the effective size of the combination corresponds to approximately 12 000 pixel.

SELF-CALIBRATION OF PAN-CAMERA IMAGES

Sensor geometry

The relation of the 3 CCD-lines together have to be determined. A full PAN-scene will be delivered as in 3 files, one file for each original CCD-sensor. Based on points, located in the overlapping area of the 3 sub-scenes it is possible to transform the sub-scenes together. In general there are the following geometric problems:

1. the sensors may have a different focal length
2. the sensors may be rotated against a straight line in the image plane
3. there may be a rotation against the image plane
4. there may be a shift in the image plane

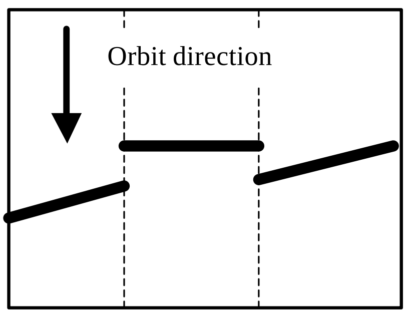

Figure 1: horizontal location of CCD-line-sensors in the image plane

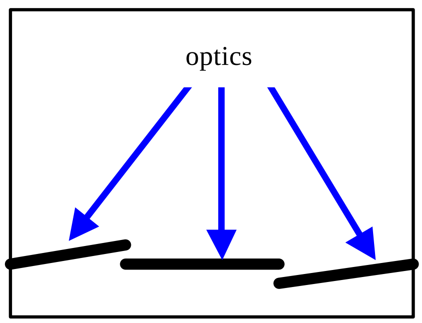

Figure 2: vertical location of the CCD-in the image plane

The shift of the CCD-line sensors in the orbit direction like shown in figure 1 can be respected by a time shift, or remaining errors by a shift of one scene to the other. A horizontal rotation against the reference CCD-line (figure 1) must be corrected by a resampling or an improved mathematical model of the block adjustment and/or the model handling. A vertical rotation and also a different focal length (figure 2) will cause a scale change in the x-direction (direction of sensor lines) of the outer scenes in relation to the reference scene in the center. There is no influence to the y-direction (orbit direction), a discrepancy of the focal length will only cause an over- or under-sampling.
For the investigation 3 scenes of the area around Hannover were available. The first with a view direction of 18.7° was taken at December 1996, the second as nadir view was taken one day later and the third again one day later with a view direction of –20.6°. The second scene is partly covered by clouds. A

disadvantage is the low sun angle of ~13°, the long shadows caused some difficulties with the exact point identification.
The image coordinates have been determined with a digital stereo workstation. As first step tie points in the overlapping area of the sub-scenes were measured. This is necessary for the transformation of the sub-scenes together. But these points also were measured in the other scenes to enable a better connection of the 3-image-block. Control points were selected from base maps 1 : 5000 with an accuracy of approximately +/-2m.
The transformation of the sub-scenes together has been checked by similarity transformation and by a simple shift. Corresponding to the theory, no significant differences are existing between both methods. Based on approximately 40 tie points in each overlapping area, the transformation was possible with an accuracy of +/-0.4 pixel. This indicates also the pointing accuracy.

Bundle adjustment

A line scanner like IRS-1C 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)** for stereo across track or **(0,y’,-f)** for stereo in track - 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 (time), 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.
The used program BLASPO of the Hannover program system for bundle block adjustment BLUH is using a fitting of the exterior orientation by an ellipse fixed in the sidereal system - the earth rotation is respected. This has been shown as sufficient for other space sensors also over larger distances. 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. Because of an extreme correlation between the 6 traditional orientation elements, only the rotations and Zo are used as unknowns. 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 orientation. By this method errors of the exterior orientation caused by an inaccurate orbit or irregular movements within the orbit can be identified and respected. This is in general the same solution like with the discrepancies of usual aerial photos against the mathematical model of perspecitivity.

table 1: additional parameters of program BLASPO (program system BLUH)

1	Y = Y + P1 * Y		
2	X = X + P2 * Y		
3	X = X + P3 * X * Y		
4	Y = Y + P4 * X * Y		
5	Y = Y + P5 * SIN(Y * 0.06283)		
6	Y = Y + P6 * COS(Y * 0.06283)		
7	Y = Y + P7 * SIN(Y * 0.12566)		
8	Y = Y + P8 * COS(Y * 0.12566)		
9	Y = Y + P9 * SIN(X * 0.04500)		
10	X = X + P10 * COS(X * 0.03600)		
11	X = X + P11 * (X-14.)	if x > 14.	special parameters for
12	X = X + P12 * (X+14.)	if x < -14.	IRS-1C (1D) PAN-camera
13	Y = Y + P13 * (X-14.)	if x > 14.	"
14	Y = Y + P14 * (X+14.)	if x < -14.	"
15	X = X + P15 *SIN(X * 0.11)*SIN(Y*0.03)		

The first 2 additional parameters are corresponding to an affinity deformation of the scene, they are required by the used mathematical model for the determination of the difference of the pixel size in orbit to across orbit and also for the fitting of remaining errors of the satellite inclination or horizontal satellite rotation. The parameters 3 – 10 can cover irregular movements and rotations of the satellite, they are usually not so important and they can only be determined by means of a sufficient number of control points. The parameters 11 – 14 can determine errors of the alignment and differences in the focal length of the 3 CCD-lines of the IRS-1C-PAN-camera. The parameter 15 can fit remaining systematic effects.

The empirical calibration of the IRS-1C-PAN-camera was based on 3 full scenes over the area of Hannover with view directions of 21.27°, 0° and -23.52° in relation to a tangential plane – because of the earth curvature, these angles are larger than the rotations against the nadir. This optimal configuration was only disturbed by the low sun angle of approximately 13°. Because of this, a radiometric enhancement by a not linear look up table of the scenes was necessary. 90 control points have been digitized from German topographic maps 1:5000 with an accuracy of approximately +/-2m in X and Y and +/-1m in Z. The data acquisition of the image coordinates was made with the digital stereo workstation of the institute, supported by a stereoscopic point identification. The stereo view has improved the reliability, so finally only 5 points have been disregarded from the computation – a very small number for space images. The original images are not epipolar, so the stereoscopic impression is limited to the area around the floating mark because of y-parallaxes caused by the different rotations of the scenes.

adjustment	additional parameters	sigma 0 [µm]	SX [m]	SY [m]	SZ [m]
1	0	205.9	97.4	191.0	471.6
2	1 + 2	28.3	8.6	10.5	82.8
3	1,2, 11-14 for all scenes together	27.7	8.6	7.1	83.2
4	1,2,11,12	17.3	7.0	9.4	10.5
5	1,2,13,14	23.9	9.0	5.7	84.0
6	1,2,11-14	7.9	7.1	5.0	9.7
7	1,2,11-14 only both inclined scenes	7.8	7.6	5.1	9.2
8	1 - 15	7.6	5.5	4.7	8.7
9	1,2,11-14 9 control points	5.8	8.8	5.4	10.6

table 2: results of the bundle adjustments

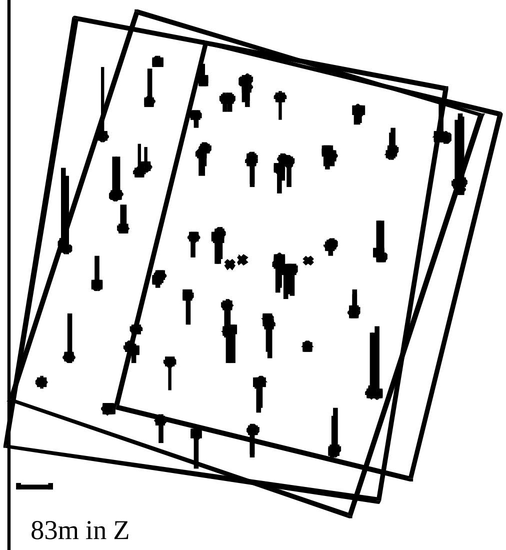

figure 3: adjustment (2) with additional parameters 1 and 2 individually for every scene, discrepancies at vertical control points East and West part positive values, center part negative values caused by difference in focal length of the 3 CCD-sensors

As expected, the adjustment with 4 orientation elements for each scene and without additional parameters is not leading to accurate results (table 2). But also the adjustment 2 with the additional parameters 1 and 2 (affinity) (figure3) is limited in the vertical elements, that means, the 3 CCD line sensors of the IRS-1C PAN-camera do not have the same focal length. In the third adjustment, the parameters 1 and 2 are determined individually for each scene and the deviations of the sensor alignments is fitted by the special additional parameters for the PAN-camera, the parameters 11 up to 14. In this case these special parameters are determined for all scenes together. This is justified if the relation of the CCD-lines is stable over the time. But the result is only slightly improving the Y-component, the large discrepancies in the height of the control points are still existing.

An adjustment with the parameters 1, 2 (affinity) and 11 , 12 (change of scale for the outside located CCD-lines) individually for each scene is improving the quality of the Z-component drastically from more than +/-80m to +/-10.5m. A corresponding run with the parameters 1, 2 and 13, 14 is improving the horizontal accuracy, but the height is still poor. Optimal results are achieved with the combination 1,2 and 11 up to 14 individually for each scene. That means, the CCD-lines are not exactly aligned and they do have a different focal length, causing a scale change of the corresponding partial scenes and the relation of the CCD-lines is not stable.

The influence of the center scene to the point determination was checked with the computation 7. Under the same condition like the preceding adjustment with 3 scenes, there is more or less no change of the quality of the results. Of course the use of only 50% of this scene, caused by a partial cloud coverage has to be respected, but also in the northern part with a good overlap of the 3 scenes there is no improvement. In general the improvement of the ground coordinate accuracy by a vertical scene between 2 inclined scenes should be seen only in the horizontal components because of one more image for a better identification of the control points.

There are still some remaining systematic effects at the control points shown by a covariance analysis. Up to a distance of 8km, the corrections of the control points are correlated in the Z-component up to 0.49. Such remaining systematic effects can be respected by the other additional parameters. An adjustment (8) with all additional parameters is improving the results to SX=+/-5.4m, SY=+/-4.7m and SZ=+/-8.7m. But this can de done only with a higher number of control points.

An adjustment with such a high number of control points is required for the analysis of the sensor geometry, but it is unrealistic for an operational case. Because of the special characteristic of the combination of 3 CCD-sensors in the PAN-camera, it is not possible to handle the problem with just 4 control points. Based on 9 control points (figure 4) (additional parameters 1,2 and 11 – 14 individually for every scene) and comparing the results with the not used points as independent check points (adjustment 9), there is only a limited reduction of the precision. The achieved accuracy of SX=+/-8.8m, SZ=+/-5.4m and SZ=+/-10.6m is sufficient for mapping in the scale 1 : 50 000.

The accuracy has to be seen in relation to the pixel size of 5.8m in the ground coordinate system and 7µm in the image. The mean of the horizontal accuracy is close to 1 pixel and in the case of the height, the base to height relation of

1:1.26 has to be taken into account, leading to +/-1.3 pixel in the x-parallax. Sigma0 is also in the range of 1.1 pixel.
By theory, 5 control points are sufficient, but for an operational handling also the reliability is important (figure 4).

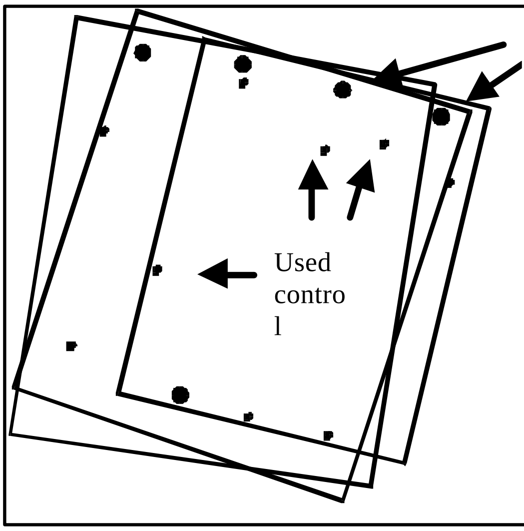

figure 4: used and required control points for the IRS-1C-PAN-block Hannover

MAPPING

For mapping the information contents of the images is more important than the geometric accuracy. An indication of the information contents is the pixel size on the ground. But not only this nominal figure, also the radiometric situation is important. This is of course also influenced by the individual imaging conditions like time of the year, sun elevation and atmospheric conditions and contrast of the imaged area.
As a rule of thumb, the pixel size on the ground shall not exceed 0.05 up to 0.1mm in the map scale. So for mapping in the scale 1 : 50 000 a pixel size of 2.5 – 5m should not be exceeded. If this condition cannot be matched by the available images, not the whole required map contents can be extracted. The range between the lower and the upper value of this rule is depending upon the structure of the area and the national map standards.
For the area of the city Wunstorf, located close to Hannover, IRS-1C PAN-, SPOT XS and pan-, KFA1000-, KVR1000- and high altitude photo flight images (1:120 000) are available. A mapping of the area was made with all of them. Not the original KVR1000 images, but heavily compressed digital data with 3m pixel size, corresponding to a contents like 5m pixel size have been used. The IRS-1C PAN-images do have a quantization of 6bit or 64 different gray values. The poor contrast of the original images was improved with a not

linear look up table resulting in satisfying images. Long shadows in the case of the IRS-1C PAN-images are disturbing the object identification, nevertheless

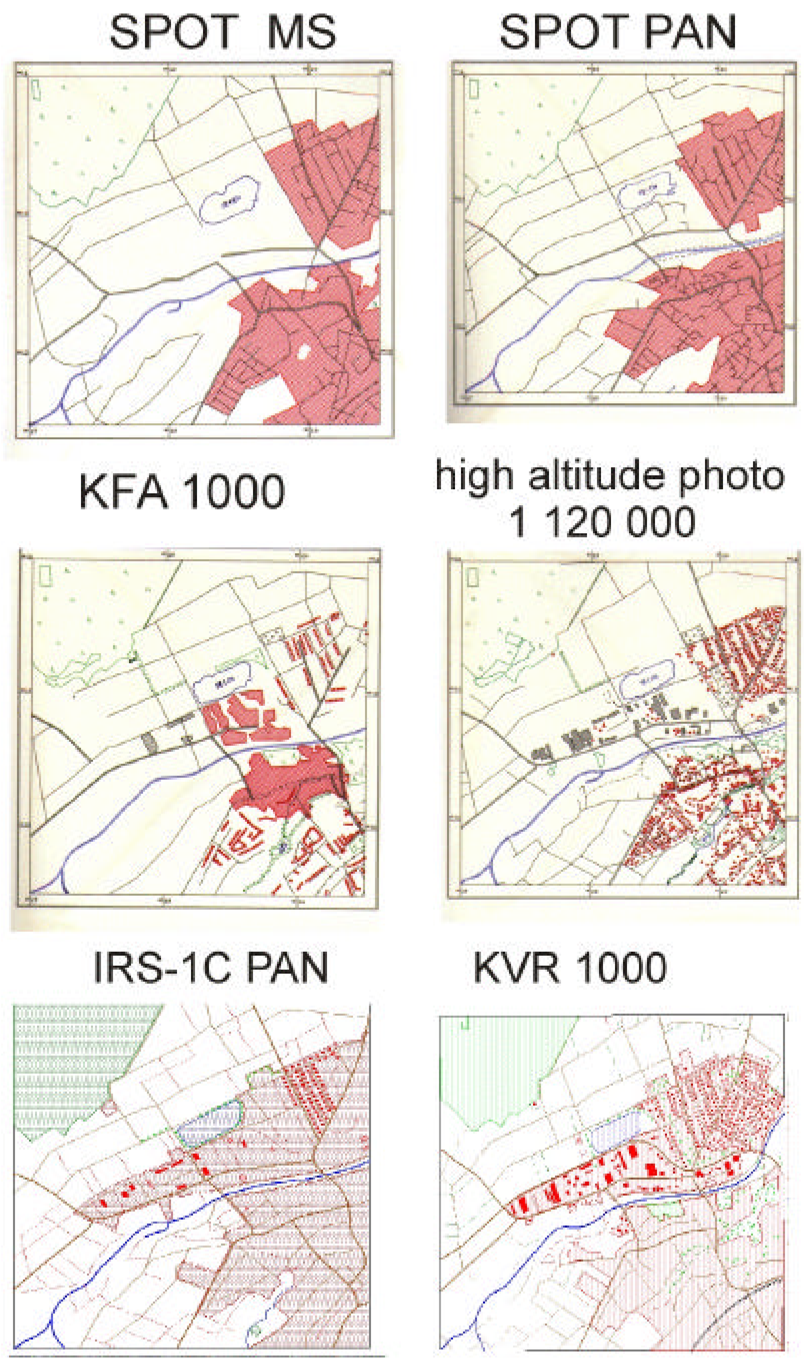

figure 5: area of Wunstorf mapped with different space images

nearly all objects available in the topographic map 1: 50 000 could be mapped. Also with the compressed KVR1000 images the result was satisfying. There was no doubt with the optimal results based on the high altitude photos with a photo scale 1 : 120 000 corresponding to a ground resolution of 3m/lp or a pixel size of 1.5m. With these images all details of the topographic map 1:25000 could be seen.

Not only the pixel size is important, the spectral information supports the object identification. So in spite of the relation of the pixel size by the factor 2, the information contents of the panchromatic and the multispectral SPOT images was approximately the same. In the multispectral images the water bodies do have a good contrast and can be identified more easy than in the higher resolution panchromatic images. But in general the pixel size of SPOT with 10m and 20m is not sufficient for the creation of maps with the contents of German topographic maps 1 : 50 000. Especially the details in the build up areas cannot be seen. Only wide streets can be identified and in the rural areas a separation between a boundary line with a hedge and a small road is not possible. No individual buildings, even if they are large, can be recognized.

The situation with the KFA1000 is better, only in the city itself the identification of streets is difficult. In the area outside the city with individual houses, the buildings can be mapped.

CONCLUSION

The resolution and quality of the available space images has been improved and this will be continued also in the next years with the announced very high resolution commercial space system of the USA and the IRS-P4 Cartosat. Also SPOT goes to a higher resolution.

With IRS-1C PAN –images today a mapping with satisfying results in the map scale 1 : 50 000 is possible. The achieved results are confirming the rule of thumb of a required pixel size of 0.05 up to 0.1mm pixel size in the map scale corresponding to 2.5 – 5m on the ground for the important map scale 1:50 000. Of course a field check is required because some details can be seen but not identified.

The required horizontal accuracy for mapping is reached without problems also just based on 4 control points. The vertical accuracy is still limited to approximately +/-10m for areas with sufficient contrast.

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