Calibration of IRS-1C PAN-camera

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1. ABSTRACT

Just now, the IRS-1C PAN-camera is the operational digital space sensor usable for mapping with the highest ground resolution. The swath width of 70km for images with vertical view direction is covered by approximately 12 000 pixel. There is no commercial CCD-line sensor on the market with a length of 84mm corresponding to 7µm physical pixel size and such a number of pixel, by this reason the field of view is separated to 3 CCD-line sensors, each with 4096 pixel. The 3 sensors do have a small overlapping area. A full PAN-scene will be delivered as 3 separate files with 4096 * 14798 pixel. The geometric relation of the sensors has been determined empirically by means of 3 full scenes covering the area around Hannover with a base to height relation of up to 0.8. The data set has been cordially delivered by the Space Application Center, Ahmedabad.
Based on 30 to 50 image points in the overlapping areas, the part-scenes have been joint together. Only a shift was required, a transformation has not improved the results of +/-0.2 pixel up to +/-0.5 pixel. This accuracy is representing the pointing accuracy in the images. In addition to the shift of the part-scenes it is possible by theory that the sensors are not aligned and they may have a different scale, caused by differing focal length. By this reason, special additional parameters corresponding to the geometric relation have been introduced into the Hannover program BLASPO for bundle block adjustment of space line sensor images.
With 90 control points, digitized from maps 1 : 5000 with an accuracy of approximately SX=SY=+/-2m and SZ=+/-1m the geometric relation of the PAN-camera has been inspected. Without use of the orbit data, just with the information about the view direction and the orbit ellipse by means of the height above sea surface, the bundle block adjustment was processed. In addition to the additional parameters describing the affinity, which is belonging to the exterior orientation, the special additional parameters for the sensor alignment and the sensor scale were required. With the both most inclined scenes a ground accuracy of SX=+/-5.4m, SY=+/-4.7m and SZ=+/-8.7m has been reached corresponding to +/-1.1 pixel. This is possible without pre-knowledge of the sensor geometry with a sufficient over-determination with 8 control points for the covered area of 86km * 84km. The use of the third scene is not improving the results. The achieved accuracy is mainly representing the point identification, not the sensor accuracy itself.

2. IRS-1C PAN-CAMERA

The panchromatic camera (PAN) of the IRS-1C has a folded mirror telescope with a focal length of 982.45mm, it can be rotated across track up to +/- 26°. The approximately 12 000 sensor elements are covering 70km in the case of a vertical view, this goes up to 91km for the most inclined view. There are no CCD-line sensors available with a pixel size of 7µm and such a number of elements, by this reason the field of view is separated into 3 parts and imaged on 3 CCD-sensors, each with 4096 pixel. The relation of the 3 CCD-lines together have to be determined. 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.

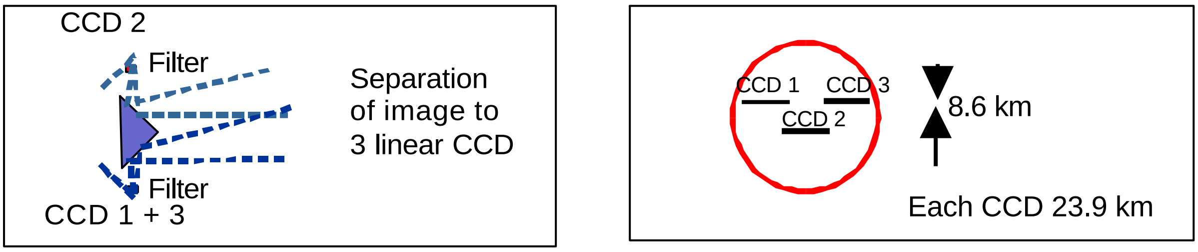

figure 1: separation of the 3 CCD-sensors in the PAN-camera

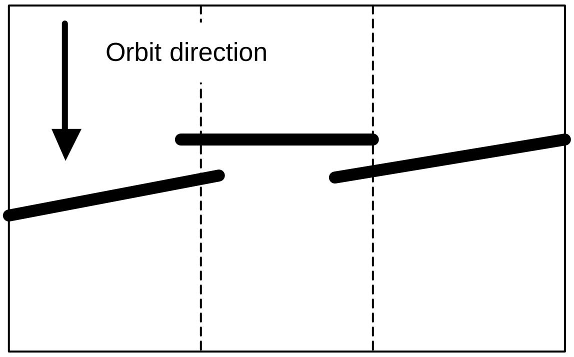

Figure 2: horizontal location of CCD-line-sensors in the image plane

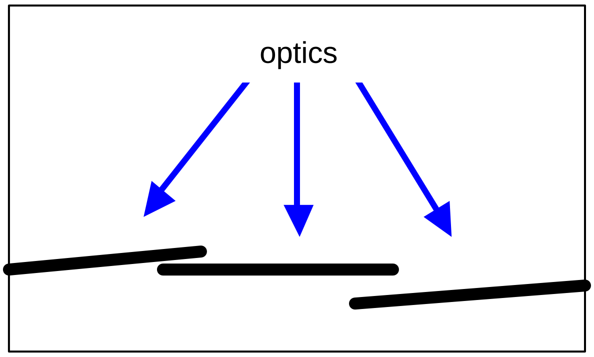

Figure 3: vertical location of the CCD-lines in the image plane

The shift of the CCD-line sensors in the orbit direction like shown on the right hand side of figure 1 and in figure 2 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 2) 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 3) 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.

3. Data Acquisition and Preparation

For the camera calibration 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 (figure 4) 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 a map accuracy of approximately +/-2m.

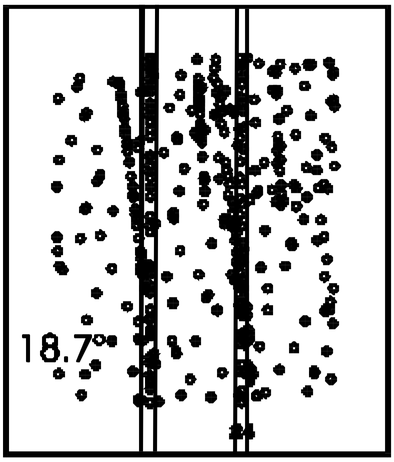

figure 4: determined image points
- image from December 24, 1996
line of tie points in the overlapping area of the sub-scenes

table 1: transformation of sub-scenes together
- similarity transformation and shift [pixel]

	left scene to center scene				right scene to center scene			
image	shift x	Sx	shift y	Sy	shift x	Sx	shift y	Sy
24 shift	-4035.6	+/-0.4	29.0	+/-0.5	3830.5	+/-0.4	30.3	+/-0.4
24 similarity 46 / 63 points	-4035.5	+/-0.3	28.2	+/-0.4	3831.1	+/-0.3	29.8	+/-0.4
25 shift	-4042.5	+/-0.5	29.3	+/-0.7	3823.5	+/-0.4	12.3	+/-0.4
25 similarity 17 / 25 points	-4039.6	+/-0.2	30.4	+/-0.2	3823.6	+/-0.4	11.4	+/-0.3
26 shift	-4039.8	+/-0.2	45.1	+/-0.3	3823.7	+/-0.3	1.5	+/-0.6
26 similarity 39 / 55 points	-4039.7	+/-0.2	44.9	+/-0.2	38225.1	+/-0.3	0.7	+/-0.4

With one exception there is no significant difference between a similarity transformation and a shift of the sub-scenes together by means of tie points. By this reason and also because of no theoretical justification of a higher degree of transformation, only the shift has been used for the final computation of unique scene coordinates. The accuracy of ±0.2 up to ±0.7 pixel represents the accuracy of the point identification.
The shift values differ significantly, that means, pre-values of another calibration cannot be used, the shift values have to be determined individually.

5. Program BLASPO

The 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)** 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, 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. 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 photos against the mathematical model of perspecitivity.

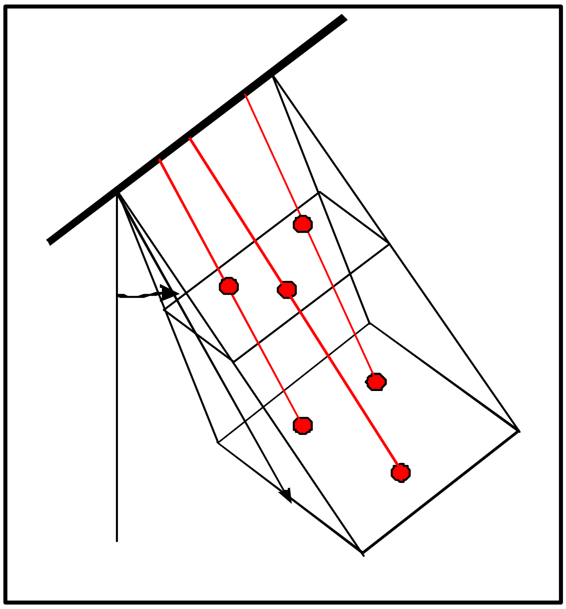

figure 5: determination of exterior orientation just based on inclination, ellipse parameters and view direction

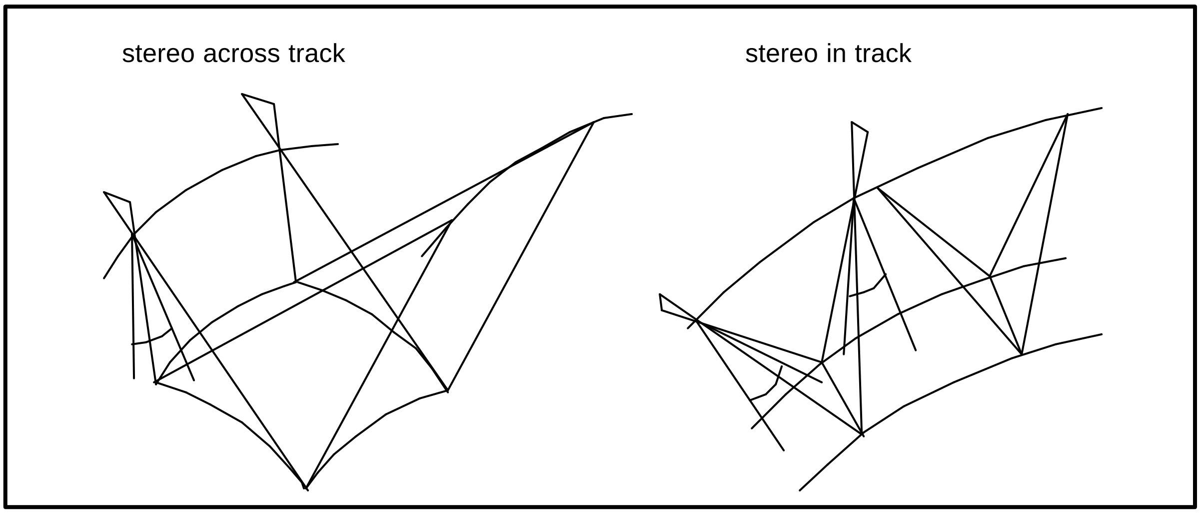

figure 6: mathematical model used in BLASPO

Irregular movements and rotations of the satellite and other problems of the mathematical model have to be covered by additional parameters.

```
 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.
12  X = X + P12 * (X+14.)     if x < -14.
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)
```

table 2: additional parameters of program BLASPO

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 and across orbit and also for the fitting of remaining errors of the satellite inclination or horizontal satellite rotation. The parameters 3 – 8 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.

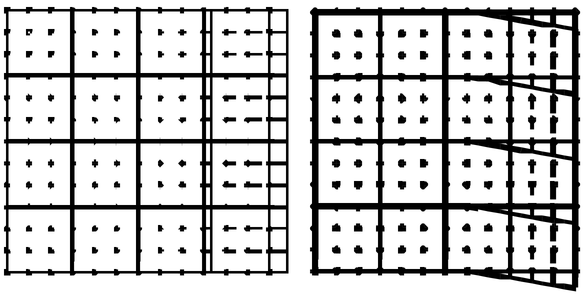

figure 7: effect of additional parameter 11 and 13 to image coordinates

6. Results of the Calibration

The empirical calibration of the IRS-1C-PAN-camera was based on 3 scenes taken at December 24, 25 and 26, 1996 over the area of Hannover with view directions of 21.27°, 0° and -23.52°. This optimal configuration was only disturbed by the low sun angle of approximately 13°. Because of this, a radiometric enhancement of the scenes was necessary. 90 control points have been digitized from German topographic maps 1:5000 with

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 3: results of the bundle adjustments

an accuracy of approximately +/-2m. The data acquisition of the image coordinates was made with the digital stereo workstation of the institute, supported by a stereoscopic point identification. This has improved the reliability, so finally only 5 points have been disregarded from the computation – a very small number for space images. With the original images, the stereoscopic impression is limited to the area around the floating mark because of y-parallaxes caused by the different rotations of the scenes.

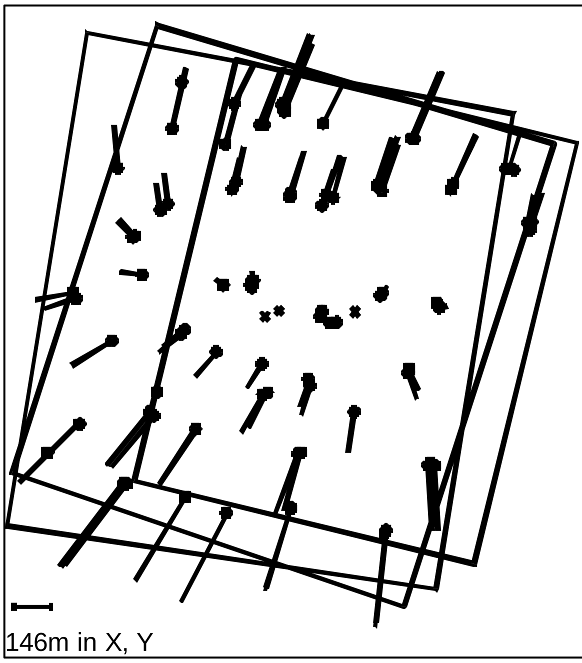

figure 8: adjustment (1) without additional parameters, area covered by the 3 scenes and X-Y-discrepancies at control points
- strong affine deformation caused by limited pre-information about imaging frequency

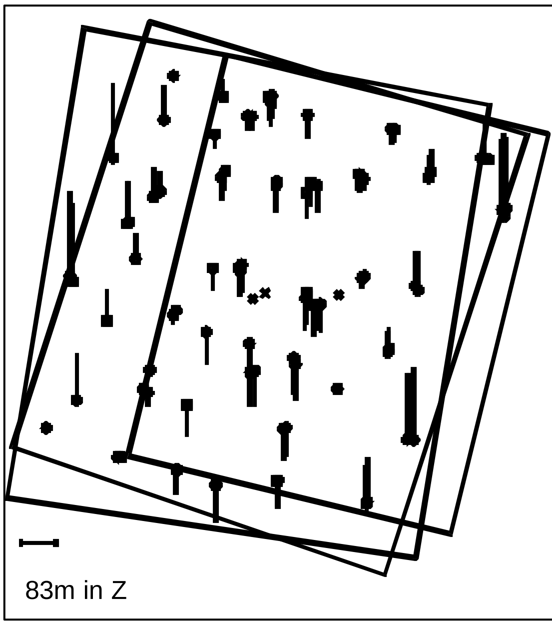

figure 9: adjustment (2) with additional parameters 1 and 2 individually for every scene, discrepancies at vertical control points
East and West part positive values, center part negative values caused by difference in focal length of the 3 CCD-sensors

As expected, the adjustment with 4 orientation elements for each scene and without additional parameters is not leading to accurate results (table 3 and figure 8). But also the adjustment 2 with the additional parameters 1 and 2 (affinity) 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 (see also figure 3 and 9). As third adjustment, the parameters 1 and 2 are determined individually for each scene and the deviations of the sensor alignment are fitted by the special additional parameters for the PAN-camera, the parameters 11 up to 14 for the determination and the consideration of possible errors of the sensor alignment (figure 2 and 3). 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 improved in 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 visual only in the horizontal components by reason 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 the 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 (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 achieved 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.

	scene 24	scene 25	scene 26
additional parameter 11 (scale, right) = focal length	137µm	-109µm	25µm
additional parameter 12 (scale, left) = focal length	-70µm	123µm	20µm
additional parameter 13 (rotation, right) = alignment	-95µm	-182µm	-42µm
additional parameter 14 (rotation, left) = alignment	126µm	-154µm	-28µm

table 4: effect of special additional parameters 11 – 14 for the extreme parts of the combined scenes

In table 4 the effect of the additional parameters to the outer parts of the combined scenes (pixel 0 and pixel 12 000, corresponding to –42mm and +42mm) is shown. The values are quite different for the 3 used scenes. This demonstrates again the requirement for the handling of the additional parameters 11 up to 14 individually for every combined scene. They only can be determined by means of control points distributed over the scene. By theory, 5 control points are sufficient, but for an operational handling also the reliability is important (figure 10).

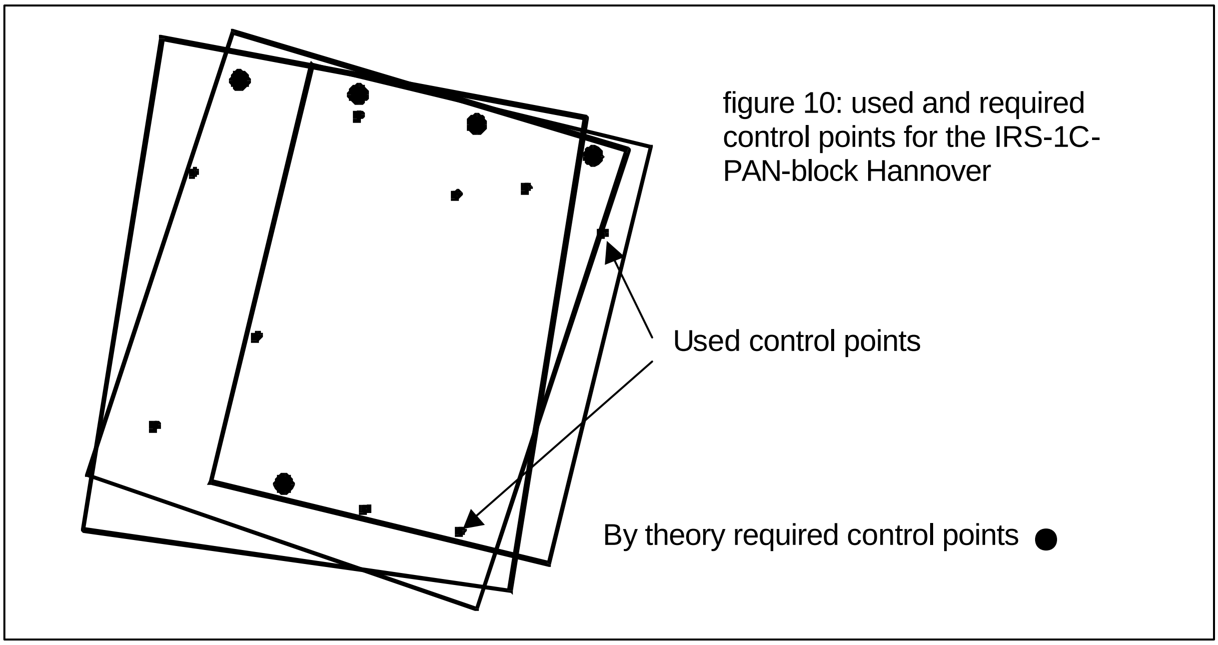

figure 10: used and required control points for the IRS-1C-PAN-block Hannover

7. Conclusion

The bundle block adjustment of IRS-1C-PAN-scenes has lead to satisfying results if special additional parameters are included which can take into account that there are 3 CCD-sensor lines in the camera. A self-calibration is required because of changing conditions. Without knowledge of the ephemeris an accuracy of approximately 1 pixel can be reached in the horizontal component and the x-parallax.

In addition to the standard configuration of just 4 control points in a stereo scene, at least 2 additional control points in the position 1/3 and 2/3 of the sensor line are required. These are more control points than necessary for a SPOT-stereo-scene, but the area covered by a complete IRS-1C-PAN-scene is 60% larger than a SPOT-scene independent upon the higher resolution of the PAN-camera.

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