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Zagajewski B., Sobczak M., Wrzesień M., (eds)

DETERMINATION AND MONITORING OF BORESIGHT MISALIGNMENT ANGLES DURING THE HYMAP CAMPAIGNS HYEUROPE 2003 AND HYEUROPE 2004

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ABSTRACT

It is essential to have high geometric accuracy of airborne hyperspectral image data for multi-temporal studies (e.g. change detection), the generation of mosaics and the comparison and integration with other georeferenced data.

Direct georeferencing of airborne line scanner data (e.g. HyMap data) requires the combination of kinematic GPS-positioning and an inertial measurement unit (IMU). With these orientation observations the exterior orientation of the sensor is available simultaneous with the data acquisition. For accurate determination of the sensor's exterior orientation, the so-called boresight misalignment angles have to be known. These describe the angular discrepancies between the sensor and the IMU coordinate system and can be determined using ground control points (GCPs). If the misalignment proves to be stable for each mounting of the sensor, it is possible to rectify the data without using extra GCPs for every single image strip. This would speed up and simplify the process of georeferencing.

For this study, the misalignment angles were determined with the ortho-rectification software ORTHO developed by DLR, which is an essential part of the automatic processor of the forthcoming ARES (Airborne Reflective Emissive Spectrometer) sensor.

Within this study, the long term stability of boresight misalignment angles were investigated during the HyMap campaigns HyEurope 2003 and HyEurope 2004, where the mounting of the HyMap sensor remained unchanged for several weeks. Repeated data acquisitions over a test field around Oberpfaffenhofen with approximately 40 GCPs were collected to calculate the misalignment angles. The results from each campaign were compared and applied to independent sets of HyMap data to investigate the stability and the threshold of accuracy for the boresight misalignment angles to fulfil the requested accuracy of the rectified image. Furthermore, the study allowed the evaluation of the quality of the GCPs within the test field. The result was a significant improvement of the existing GCPs in addition with the definition and surveying of new GCPs.

INTRODUCTION

The ortho-rectification of airborne linescanner data based on direct georeferencing technique requires accurate determination of the sensor's exterior and interior orientation. Where the parameters for the interior orientation are specified by the manufacturer, the exterior orientation is derived from the continuous acquisition of the sensor's position and attitude with combined GPS- and IMU-measurements. These measurements have to be related to the sensor's coordinate frame. For this reason, the angular discrepancies between the sensor and the IMU coordinate frame (boresight misalignment) and the leverarms between sensor and GPS antenna have to be determined (i). The leverarms can be measured with conventional surveying methods. The boresight misalignment angles are calculated from Ground Control Points (GCPs) collected at a calibration field.

Two field campaigns have been conducted in 2001 and 2004 to collect calibration GCPs datasets. During these campaigns, the GCPs were comprehensively surveyed with differential GPS. A total of 44 GCPs that can be clearly identified in the HyMap scenes were characterized and surveyed. Figure 1 shows an overview of the calibration site and some examples of GCPs.

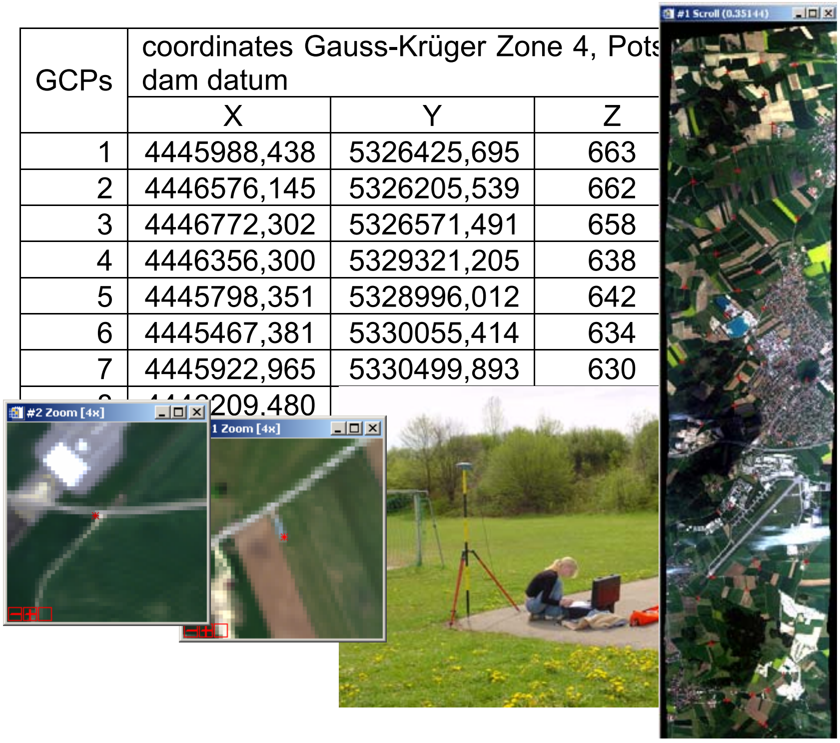

Figure 1: Calibration field close to Oberpfaffenhofen with its Ground Control Points surveyed with differential GPS

From the 25th of June until the 5th of August 2003 the HyMap sensor was based at DLR Oberpfaffenhofen for the airborne hyperspectral campaign HyEurope2003. The data acquisition over the calibration area was conducted at the beginning and at the end of the campaign. A total of three HyMap strips could be used to determine the boresight misalignment angles. The second HyMap campaign in Europe took place between 17th of May to 16th of August 2004. During HyEurope 2004 three overflights of the calibration site were completed. The flight parameters (flight altitude, heading, etc.) of the different data acquisitions in 2003 and 2004 are summarized in table 1.

Table 1: Data acquisitions of the calibration field in 2003 and 2004

Date of over-flight	Mounting	flight altitude (asl)	flight altitude (agl)	pixel size (m)	heading
30.06.2003	CFFU-1	3820	3230	7,0	0°
05.08.2003	CFFU-2	3810	3220	7,0	0°
05.08.2003	CFFU-2	2390	1800	4,0	0°
20.05.2004	CODE	2970	2380	5,0	0°
07.06.2004	CFFU	2580	1990	4,0	0°
07.06.2004	CFFU	2580	1990	4,0	0°
26.06.2004	CFFU	2620	2030	4,0	0°
26.06.2004	CFFU	4130	3540	7,0	0°

The mounting was changed once during both HyEurope campaigns because of aircraft check-ups or aircraft allocations. It was assumed that the boresight angles remain unchanged in between the two mountings as the IMU is rigidly installed in the HyMap sensor (ii).

METHODS

The boresight misalignment angles can be calculated by iterative least squares adjustments of the linearised collinearity equation of the GCPs. The collinearity equation maps 2D image space to 3D object space coordinates and is defined as follows (iii, iv):

$$r^m = r_s^m + \lambda \cdot R_b^m \cdot R_s^b \cdot r^s$$

where

r^m = vector of object point P expressed in mapping coordinate frame (m-frame)

r_s^m = vector of sensor projection center (derived from DGPS and IMU measurement)

λ = scale factor

R_b^m = rotation matrix from body coordination frame (b-frame) to m-frame (IMU measurement)

R_s^b = rotation matrix from sensor coordinate frame (s-frame) to b-frame (boresight misalignment angles)

r^s = vector of object point P expressed in s-frame

These are illustrated in figure 2.

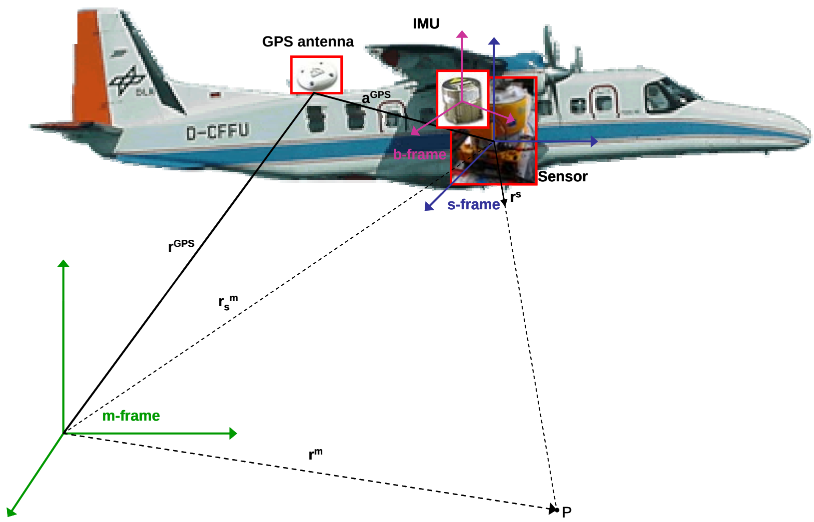

Figure 2: Detailed diagram of elements of direct georeferencing for the airborne case (e.g. HyMap)

The software package ORTHO is used at the working group imaging spectroscopy at DLR for the geometric correction of linescanner data. ORTHO is an in-house package developed by R. Müller (iii). It is integrated within the automatic processing chain of the future ARES sensor (v) including automated system correction, atmospheric correction (vi) and geocoding (iii, vii). The ORTHO image processor contains a tool called ESTIMATE which determines the boresight misalignment angles. Input parameters required for the calculation are the sensor model (interior orientation), the sensor's position and attitude (exterior orientation), the GCPs with their coordinates in object and image space.

An example for an output of the boresight misalignment angles estimation is given in figure 3, where "measurement" describes the GCPs transformed into the s-frame and the "calculation" stands for the calculated image space coordinates of the GCPs after applying the final corrections. The number of iterations is dependent on a threshold of 0.05 pixel on the difference between subsequent corrections. In this case, the corrected data converges to the boresight misalignment angles omega, phi and kappa after 2-3 iterations.

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Point	Measurement [pixel]		Calculation [pixel]		Difference [pixel]		
[0]	-0.28	+138.84	-0.10	+139.98	-0.18	-1.15	+1.16
[1]	-0.17	-48.95	-0.31	-50.07	+0.14	+1.12	+1.13
[2]	+0.40	+58.69	+0.94	+57.49	-0.54	+1.21	+1.32
[3]	+0.06	+187.38	+0.26	+188.04	-0.20	-0.66	+0.69
[4]	+0.28	+264.52	+0.80	+265.40	-0.52	-0.87	+1.02
[5]	-0.17	+163.28	-0.31	+163.84	+0.14	-0.56	+0.58
[6]	-0.42	+93.16	+0.25	+93.67	-0.67	-0.52	+0.84
[7]	+0.33	-56.34	+0.77	-56.71	-0.44	+0.37	+0.57
...							

BORESIGHT ANGLES [°]

Omega	Phi	Kappa
-0.116499	-0.680607	+0.216323

Figure 3: Output of boresight misalignment estimation

RESULTS

GCPs were identified on each scene of the calibration site and used as input for the estimation of the boresight misalignment angles. If the difference between calculation and measurement of the GCPs was bigger than 1.5 pixel (figure 3), the GCP was not used for the final calculation. The number of GCPs used for the estimated boresight misalignment angle is stated below in table 2.

Table 2: Number of GCPs per HyMap scene used for boresight misalignment calculation

Date of overflight	Mounting	flight altitude (asl)	pixel size (m)	number of GCPs
30.06.2003	CFFU-1	3820	7,0	32
05.08.2003	CFFU-2	3810	7,0	37
05.08.2003	CFFU-2	2390	4,0	33
20.05.2004	CODE	2970	5,0	32
07.06.2004	CFFU	2580	4,0	34
07.06.2004	CFFU	2580	4,0	33
26.06.2004	CFFU	2620	4,0	34
26.06.2004	CFFU	4130	7,0	38

As a result of the selection of GCPs, the quality of the calibration site could be evaluated. Table 3 illustrates the relative position of the different GCPs to each other with their ID. The colour coding displays the usability of each point, where green stands for very good, yellow for good, orange for sufficient and red for poor usability. The evaluation is based on the number of times a point was rejected for the estimation for the boresight misalignment angles. Only two of the 44 GCPs seem to be of poor quality. Most of the remaining points are of very good or good quality and cover the calibration scene evenly.

Table 3: Quality and relative position of GCPs to each other (green = very good, yellow = good, orange = sufficient, red = poor)

30	28	27	26	
		29		102
		25		
	23			
22	24			
21	19		103	101
	20			
	32			
33	31	18		
	8	9		
	7			
6		10	108	
		4		106
	5		104	105
			107	
		17	16	
	1	3		
	13	2		
	14		15	
	12	11	109	
		110	111	

The three boresight misalignment angles omega, phi and kappa were calculated for three scenes in 2003 and five scenes in 2004. The results are demonstrated in figure 4 (unit = degree), where every chart corresponds to one angle and year. Note that the scale of omega is different from the one of phi and kappa. In 2003 the values of the three angles have all the same trend. Remarkable is the difference of the omega values of the two overflights on the 5th of August, even though the values should not change for two acquisitions at the same day. This difference indicates the difficulty in addressing the GCPs in two different scenes with different pixel resolution at exact the same position. Also the quality of the exterior orientation parameters has a significant influence on the results. With the five values in 2004 the trend is much more consistent. The difference in values for the kappa angle is less remarkable, since kappa is the angle most difficult to determine.

To get a better idea about the impact of the difference in values and the stability of the boresight misalignment angles, the deviation from the nadir position was calculated, which also demonstrates the possible error not using the boresight misalignment angles. The effect of the misalignment should be the same during the whole period of the campaign. The result of the off-nadir positions are illustrated in figure 5. The blue dots refer to the actual estimated angles of the different HyMap scenes, the pink dot refers to the mean value of the boresight misalignment angles. The grating refers to half a pixel. The location of the projected points is within 1.5 pixel for the results in 2003 and 1 pixel for the estimated values in 2004. Keeping in mind, that the input values for the estimation of boresight misalignment angles are afflicted with systematic and random errors, the result is satisfying.

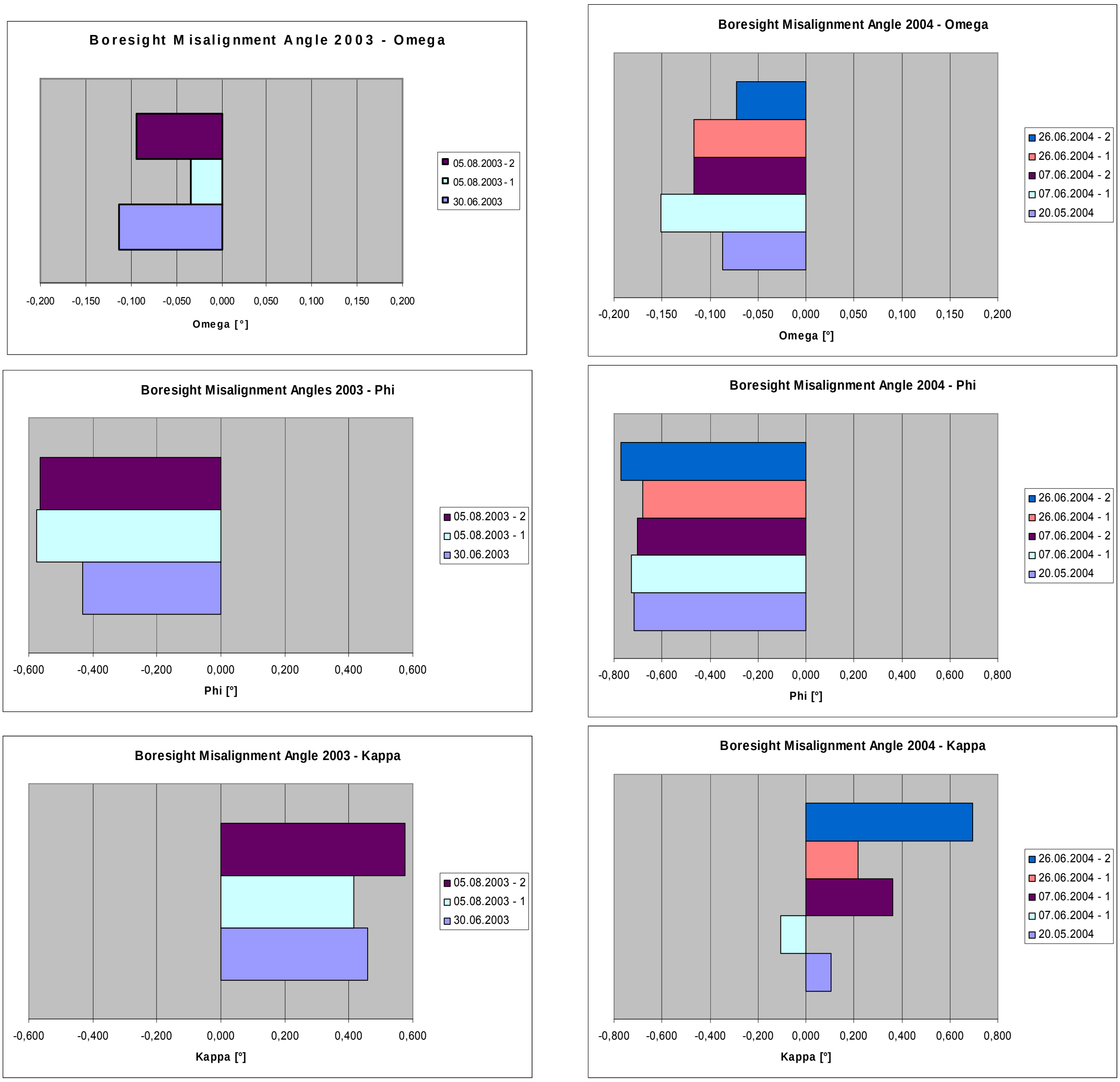

Figure 4: Boresight misalignment angles determined in 2003 and 2004 (units: degrees)

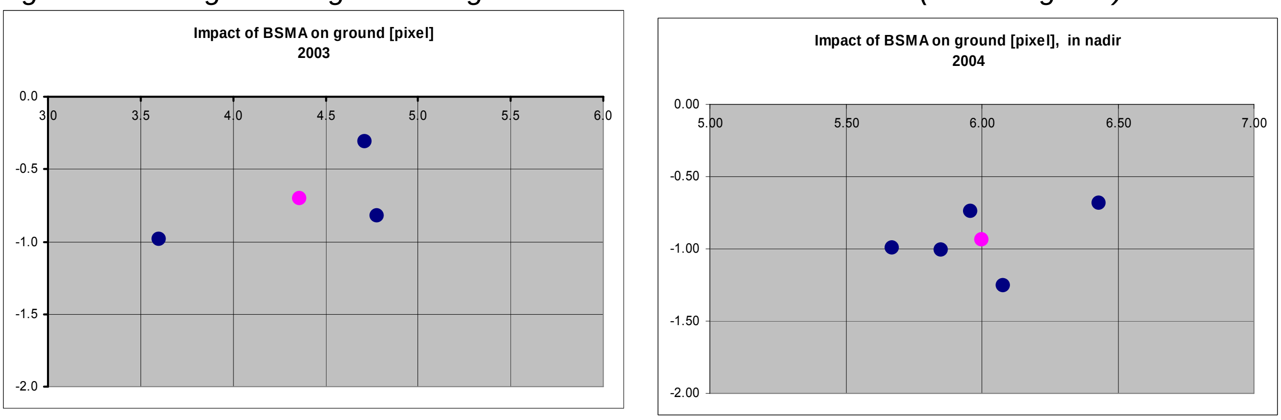

Figure 5: Impact of boresight misalignment angles on nadir position (values of 2003 and 2004, units: pixel)

The mean values of the boresight misalignment angles of 2003 were used as input values for the ortho-rectification of two additional HyMap scenes over Oberpfaffenhofen on the 15th and 22nd of July, which cover only parts of the calibration field. The results were compared to the ortho-rectified images where the few GCPs which could be identified within the images were used for the geometric processing. Figure 6 shows the different results overlaid with three GCPs. The first GCP should be located at the upper right corner of the basketball field, the second GCP in the middle of the curve and the third one right at the intersection. The positions are true for the first column, which refers to the result of the rectified image of 22nd of July with GCPs as input values. The second column only shows a small deviation at the third GCP. The mean boresight misalignment angles were used to do the geometric correction of the HyMap scene. For the third and fourth column the location of the GCPs differs especially for the first and third example. Both columns refer to the HyMap scene of 15th of July. Since the result with the use of GCPs is also not as good as expected, there might be an error within the values of the exterior orientation.

Figure 6: Result of ortho-rectification. 1st and 2nd column: HyMap scene 22.07.2003, left with GCPs, right with mean boresight misalignment angles. 3rd and 4th column: HyMap scene 15.07.2003, left with GCPs, right with mean boresight misalignment angles

The same examination has been done with two scenes in 2004 acquired at the same day (26th of May). The two strips can be merged to a mosaic, therefore there are only very few GCPs which can be found at the overlapping area of both images. Two GCPs were considered to check the accuracy (figure 7), as well as the resulting mosaic (figure 8). With the use of GCPs the result of the mosaic and the location of the points are within sub-pixel accuracy. Using the mean boresight misalignment angles does not result in a good mosaic. Reason for that might be small changes between the different mountings, which cause the most errors at the border of the image line. For the mean value of the boresight misalignment angles only one set of values out of five refers to the first mounting of the sensor.

Figure 7: Result of ortho-rectification. 1st and 2nd column: HyMap scene 1 26.05.2004, left with GCPs, right with mean boresight misalignment angles. 3rd and 4th column: HyMap scene 2 26.05.2004, left with GCPs, right with mean boresight misalignment angles

Figure 8: Mosaic of scene 1 and 2: left with GCPs, right with mean boresight misalignment angles

Another testing was done with data acquired in Spain in 2004. The result of the ortho-rectification of the image data of Cabo de Gata using the mean boresight misalignment angles is shown in figure 9. The merged neighbouring scenes result in a very accurate mosaic even within a mountainous area. To emphasis the geometric correctness of the image, parts of the mosaic were overlaid with the topographic map of the area.

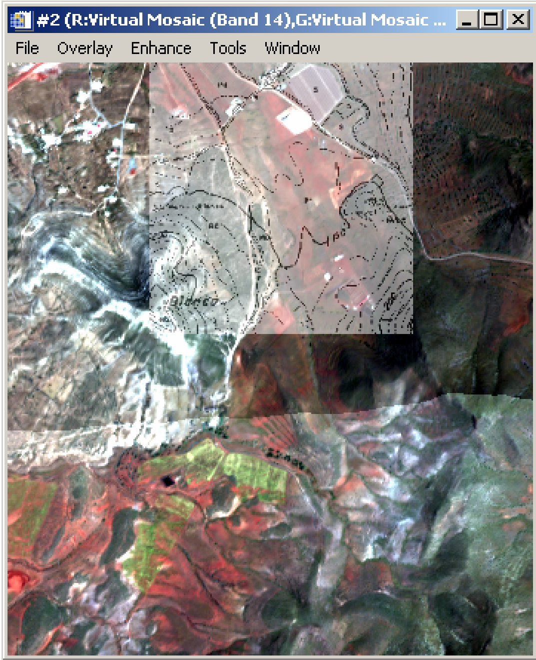

Figure 9: Mosaic of two ortho-rectified HyMap scenes of Cabo de Gata (Spain), where the mean BSA was used as input for ORTHO. The mosaic is partly overlaid by a topographic map.

CONCLUSIONS

The determination of boresight misalignment angles and therefore the calibration of the navigation system is essential for the geometric correction of airborne hyperspectral data. In 2003 and 2004 the calibration was accomplished using several overflights over the calibration area of Oberpfaffenhofen with about 40 GCPs. The small differences in values of the misalignment angles can be explained with the fact that estimation is subject to systematic and measurement errors. Keeping this in mind, the result leads to the conclusion that the boresight misalignment angles are stable within the period of a sensor mounting, and the mean is a qualified input for the geometric correction of the HyMap data. This could be shown in the case of the test site Cabo de Gata in Spain.

For the ARES instrument (viii), the deviation from nominal boresight misalignment angles are expected to be much smaller than for HyMap, since the performance specifications of the integrated GPS/IMU system (Applanix PosAV 410) are much better than the performance specifications of the Boeing Cmigit system used for HyMap (i).

References

i Cramer M, 2002. Experiences on operational GPS/inertial system calibration in aiborne photogrammetry. Journal GIS – Geoinformationssysteme, 14(6): 37-42.

ii Cocks T, R Jenssen, I Stewart, I Willson & T Shields, 1998. The HyMap™ Airborne Hyperspectral Sensor: The System, Calibration and Performance. In: 1st EARSeL Workshop on Imaging Spectroscopy, edited by M Schaepman, D Schläpfer & K Itten (RSL, Zürich), 37-42 iii Müller R, M Lehner, R Müller, P Reinartz M Schroeder & B Vollmer, 2002. A program for direct georeferencing of airborne and spaceborne line scanner images. In: IAPRS, Vol.XXXIV, part 1, ISSN 1682-1750, edited by S Morain & A Budge (ISPRS Comm.I)

iv Kraus K., 1997. Photogrammetrie, Band 1, Grundlagen und Standardverfahren (Dümmler Verlag) pp 394

v Habermeyer M, A Müller, S Holzwarth, R Richter, R Müller, K.-H. Seitz, P Seifert & P Strobl, 2003. Development of a Fully Automatic Processing Chain for the Upcoming Hyperspectral Scanner ARES. In: 3rd EARSeL Workshop on Imaging Spectroscopy, edited by M Habermeyer, A Müller & S Holzwarth (DLR, Oberpfaffenhofen), 82-87

vi Richter R & D Schläpfer, 2001. Geo-atmospheric correction of airborne imaging spectrometry data. Part II: Atmospheric and topographic correction. International Journal of Remote Sensing, 23(13): 2609-2630

vii Schläpfer D & R Richter, 2002. Geo-atmospheric correction of airborne imaging spectrometry data. Part I: Parametric Ortho-Rectification Process. International Journal of Remote Sensing, 23(13): 2609-2630

viii Wilson, I. & T Cocks, 2003. Development of the Airborne Reflective Emmissive Spectrometer (ARES), a Progress Report, In: 3rd EARSeL Workshop on Imaging Spectroscopy, edited by M Habermeyer, A Müller & S Holzwarth (DLR, Oberpfaffenhofen), 50-55