An accuracy investigation of an integrated GPS/Inertial system

Direct exterior orientation of airborne sensors

Many applications can be realized more efficiently and economically with direct georeferencing. Direct georeferencing means on-flight measurement of the exterior orientation of a remote sensing instrument. For this purpose, an integrated system is used consisting of GPS and a strap-down Inertial Measurement Unit (IMU). An integrated GPS/IMU system enables a reduction in, or even elimination of, ground control and tie points. A test is presented to demonstrate the potential and accuracy of a commercially-available integrated GPS/inertial system.
This article should be read in conjunction with a paper published in the June 1999 issue of GIM International. Presented here is the potential of the POS/DG310 developed by Applanix Corp. Markham/ON Canada. The presented sensor configuration includes a Litton LR86 IMU, which was rigidly mounted on a Zeiss RMK Top15 aerial camera (Figure 1). The performance of the integrated POS/DG system for the direct measurement of the exterior orientation is evaluated. For this purpose a photo flight was carried out over a well-surveyed testfield close to Stuttgart, Germany.

Testflight design

The testflight scenario, including the photogrammetric strips, the camera air stations and the available ground control points is depicted in Figure 2. During the testflight additional GPS receivers with different baseline length from 0-380km were used as reference stations to check the influence of varying baselines on the performance of the GPS/inertial orientation parameters. The GPS antenna was centred above the camera on top of the fuselage of the aircraft. Aerial imagery was captured at a flying height of 1000m and 2000m above ground, resulting in image scales of 1:6000 and 1:13000. The large scale image block covers only the eastern part of the test site and consists of two strips each with 8 images. The 1:13000 block covered the whole test area by three long and three cross image strips. Both blocks were flown twice to extend the flying time. Overall, 104 images were captured in a period of 1.5h.

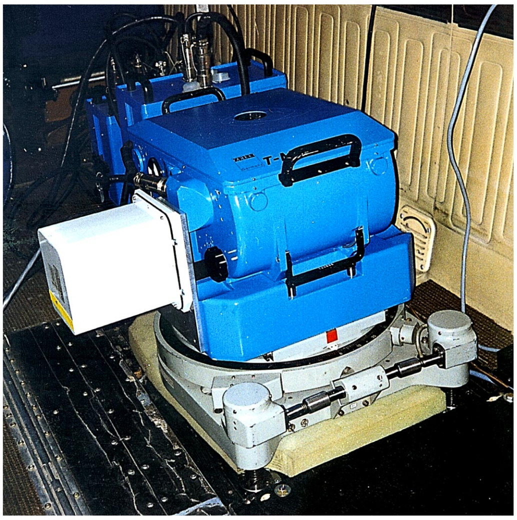

Figure 1, The sensor system

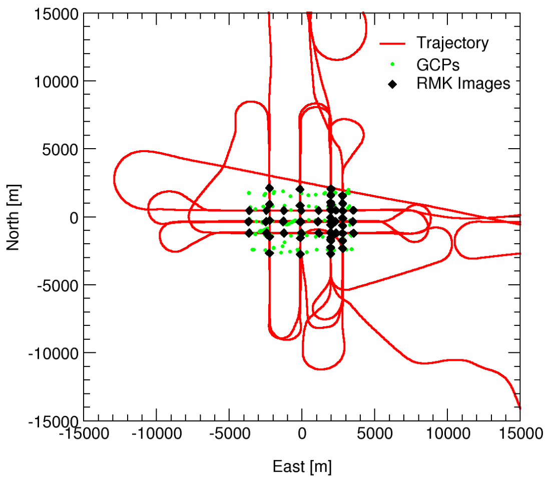

Figure 2, Testflight scenario (17.12.1998)

Reference data

Seventy eight signalized points were available for accuracy investigations. A subset of these was determined using static GPS surveys. These points were used as control points in an aerial triangulation (AT) to determine the object coordinates for the remaining signalized points and manually measured tie points. Altogether, 142 control points with theoretical standard deviations better than five centimetres were available for the accuracy test. Additionally, AT provides reference values for the exterior orientations directly measured. Camera stations and control points were used as references.

GPS/inertial processing

The integration of the GPS/inertial raw data was done using Applanix POSPac software. The GPS trajectory (position, velocity) is determined by using a standard GPS software package first. This GPS data is used as update information to perform an optimal integration with the IMU measurements in a second step, using a Kalman filter approach. Afterwards, a smoothing computes a blended solution from the data obtained in the previous step. The initial alignment of the IMU is obtained utilizing the in-air alignment capability of the system. After processing, position, velocity and attitude data from POS/DG are continuously available for the complete trajectory with a data rate at 50Hz.

Internal accuracy

To check the internal accuracy of the GPS/inertial trajectories, position and attitude differences between the different solutions were calculated. One solution (S2 master station) served as reference trajectory. The internal differences of the solutions for the baselines are depicted in Table 1. The baseline length for the different master stations is about 0km (V), 25km (S1, S2), 130km (F), 210km (M), 230km (B) and 380km (H), respectively. The solutions of GPS/inertial integration provided from POS/DG are very consistent. For the position differences the RMS values are about one decimetre for the horizontal and one to two decimetres for the vertical. The maximum deviations did not exceed 50cm, even for the 380km baseline. For the attitude the RMS values are below 3 arc sec for all baseline differences except one. The V baseline performs slightly worse due to the lack of GPS data for the in-air alignment manoeuvre for processing. This is the reason for the larger RMS values and maximum deviations for the S2-V difference.

Diff.	Position						Attitude					
	RMS [cm]			Max.Dev. [cm]			RMS [10^{-3} °]			Max.Dev. [10^{-3} °]		
	East	North	Vert.	East	North	Vert.	ω	φ	κ	ω	φ	κ
S2-V	1.9	4.1	9.4	4.5	36.5	17.8	0.4	4.1	4.3	3.5	56.6	30.4
S2-S1	1.0	1.5	8.5	3.6	7.9	13.5	<0.1	<0.1	0.3	0.3	0.5	0.8
S2-F	2.8	5.1	17.2	6.5	14.7	39.0	0.1	0.2	0.9	0.8	1.8	2.4
S2-M	9.5	6.0	21.9	26.1	16.1	47.0	0.3	0.4	1.2	1.8	2.4	3.3
S2-B	10.9	5.5	8.1	18.0	14.3	22.6	0.2	0.3	0.7	1.4	1.3	2.2
S2-H	6.2	8.3	12.1	16.6	19.7	25.3	0.1	0.2	1.0	0.7	1.2	2.8

Table 1, Internal accuracy of GPS/inertial trajectories

External quality

To obtain absolute accuracy values the GPS/inertial orientations have to be compared to the reference data from AT. Utilizing the recorded trigger times the camera air stations were interpolated into the 50Hz trajectory solution obtained from the S2 reference station. To relate orientation and camera module, the spatial and rotational offsets between the different sensor components were applied where the misalignment between IMU and camera frame was estimated from the attitude differences between the exterior orientations from AT and direct georeferencing. In order to get best results two sets of misalignment parameters were estimated for the 1:6000 and 1:13000 image blocks, respectively. The absolute accuracy of exterior orientations from POS/DG compared to 72 and 32 camera air stations from AT is depicted in Figures 3 and 4. The RMS values in camera positions are about 15cm horizontally and 30cm vertically for the 1:13000 scale and about 10cm and 15cm for the 1:6000 images, respectively. Nevertheless, a significant offset exists in the vertical coordinate correlated with the image scale. This offset is due to errors in the calibration of the photogrammetric camera (focal length). With improvement in the focal length, the systematic error is corrected and the deviations in height are about 5cm and 10cm. This is most likely what may be expected from the photogrammetric reference values. The attitude RMS values are within 10 arc sec, 7 arc sec, 14 arc sec (1:6000) and about 11 arc sec, 11 arc sec and 21 arc sec (1:13000) for ω, φ and κ, respectively. The maximum deviations did not exceed 25 arc sec (1:6000) and 50 arc sec (1:13000). Due to the higher theoretical accuracy of the large scale imagery the accuracy obtained from 1:6000 images is better compared to the 1:13000 scale. The differences are randomly distributed and no time dependent effects are visible. Within the available time period of about 90min systematic IMU errors could be eliminated from the GPS updates very effectively.

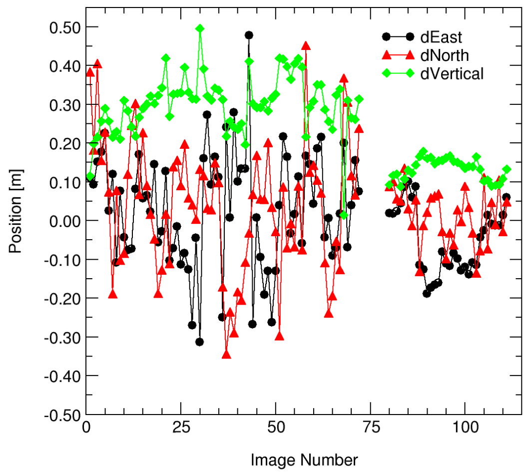

Figure 3, Position variations of direct geo-referencing compared to AT

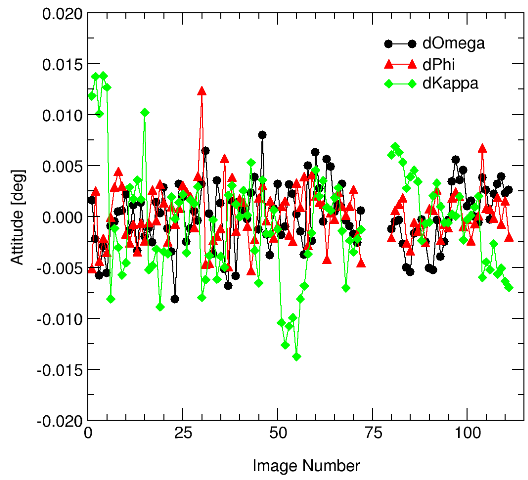

Figure 4, Attitude variations of direct geo-referencing compared to AT

Direct georeferencing

To assess the overall georeferencing performance of the complete sensor system, 142 points were re-computed from image coordinates using direct exterior orientation from POS/DG (S2 solution) and compared to the object coordinates of reference points. The achieved accuracy and maximum deviations for the 1:13000 imagery are given in Table 2. The tests were performed using all images (Version 1), each block separately (Version 2 and 3) and three long strips individually (Version 4-6) to investigate systematic drift errors and the influence of block geometry. The results are very consistent. The RMS values are about 8-9cm for the horizontal and 10-25cm for the vertical components. Version 1 shows the best results: The maximum deviations did not exceed 40cm. With a reduction in the number of used images, the accuracy slightly deteriorates, due to the reduced image overlap. Considering one strip separately, only two to three folded image points are used for point determination, whereas up to 22 to 30-folded points could be used in version 1. This shows the positive effect of strong block geometry.

Vers.	Ima-ges	Check-points	East [cm]		North [cm]		Vertical [cm]	
			RMS	Max.Dev.	RMS	Max.Dev.	RMS	Max.Dev.
1	72	142	5.0	19.5	7.0	30.5	12.1	36.8
2	36	135	6.4	20.0	9.0	31.9	15.7	37.1
3	36	133	9.0	24.9	8.2	30.5	15.0	63.0
4	7	84	15.0	30.8	13.9	47.3	23.9	63.7
5	7	95	7.1	22.8	16.1	35.2	25.2	59.0
6	7	92	9.9	37.6	21.1	70.8	24.9	91.5

Table 2, Accuracy of direct georeferencing (POS/DG solution from S2, 1:13000 imagery)

Concluding remarks

This test shows the high potential of direct exterior orientation using a commercially available integrated GPS/inertial system in combination with a standard aerial camera. Using 1:13000 imagery in cross pattern an accuracy of object point determination of about one to two decimetres (RMS) is obtained. These values are slightly worse when only single strips are considered. Using direct georeferencing proper system calibration becomes an issue of major importance. From this point of view, the integration of the GPS/inertial exterior orientations in a combined AT provides the most flexible approach. This combination allows the control of the whole process by increasing the reliability of the system and gives the possibility for self-calibration of the camera, which is necessary for highest photogrammetric accuracy demands. Additionally, the misalignment between IMU and camera can be optimally estimated for each image block using the combined AT approach.

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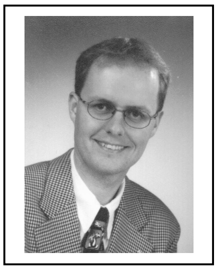
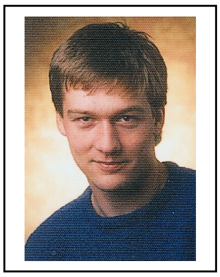
Biography of the author



Michael Cramer received his diploma in surveying from the University of Stuttgart in 1993. From 1993-1995 he was employed in the special research group "SFB228 - High precision navigation" in the field of attitude determination using multi-antenna GPS and low-cost INS. His work is currently focussed on direct exterior orientation of airborne sensors. Since 1998 he has been head of the research group "Sensor Integration".



Norbert Haala received his diploma in surveying from the University of Stuttgart in 1990. He started as a research associate at the Institute for Photogrammetry, Stuttgart University working in the field of automatic image interpretation and finished his Ph.D. thesis in 1996. From 1995 to 1998 he was the head of the research group "Sensor Integration", since 1998 he is deputy director at the Institute for Photogrammetry and head of the division "Photogrammetry and Remote Sensing".

Affiliation

Dipl.-Ing. Michael Cramer and Dr.-Ing. Norbert Haala
Institute for Photogrammetry (ifp), University of Stuttgart
Geschwister-Scholl-Str. 24D, 70174 Stuttgart, Germany
phone: 49 711 121 4118
fax: 49 711 121 3297
email: Michael.Cramer@ifp.uni-stuttgart.d