Application of GPS/INS-Systems with the HRSC –
A Comparison of APPLANIX POS/AV-510 and IGI AEROcontrol-IId

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Abstract

The airborne HRSC (HRSC-A/AX) is being operated in combination with direct georeferencing methods since 1997 by the German Aerospace Center (DLR). Using a GPS/INS system many scientific and commercial applications achieving accuracies in the decimeter range could be accomplished for the standard products, such as true-orthoimage mosaics and Digital Surface Models. Continuous and high-resolution data acquisition using digital line scanner technology is probably the best tool to evaluate the quality of orientation data derived from GPS/INS systems. HRSC's multi-stereo capability provides additional means for precise 3D-modelling and the investigation of the reliability of external orientation data.

In March 2002 the DLR-Institute of Space Sensor Technology and Planetary Exploration performed a test flight with the HRSC-A in cooperation with BSF LUFTBILD GmbH and IGI mbH using two GPS/INS systems APPLANIX POS/AV-510 and IGI AEROcontrol-IId simultaneously. Results of the investigations of the exterior orientation quality of both GPS/INS systems based on photogrammetric processing of HRSC-A data are presented.

1. Introduction

Since 1997 the digital High Resolution Stereo Camera – Airborne (HRSC-A) is being operated at the German Aerospace Center (DLR), Institute of Planetary Research [4,5,6,7]. Photogrammetric processing of multiple line scanner data requires the recording of precise and continuous position and attitude data. The very stable and well known interior orientation of such a digital line scanner, combined with its high geometrical resolution and its permanent image data acquisition with a scan frequency of 450 Hz, offers the possibility to investigate the quality of GPS/INS systems. In spite of previous tests [1] a first real comparison of the GPS/INS systems of APPLANIX UND IGI under identical conditions could be performed with an ideal sensor for this task.

2. Test Configuration

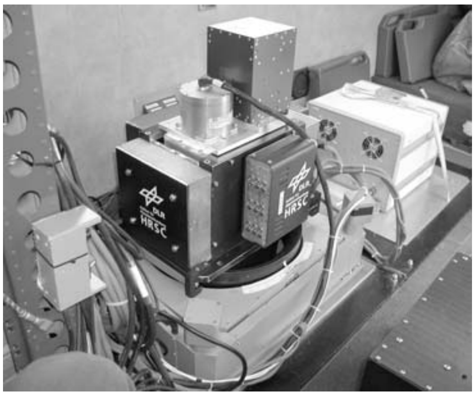

Figure 1: Installation of the HRSC-A with APPLANIX AIMU and IGI IMU-IId.

For the GPS/INS test flight a standard installation of the HRCS-A camera system was used, the camera was mounted in a ZEISS T-AS stabilized platform on-board a twin-engine CESSNA 404 of BSF LUFTBILD GmbH. Both GPS/INS systems, APPLANIX POS/AV-510 and IGI AEROcontrol-IId, were installed for a parallel operation during the test flight. In order to ensure absolutely identical conditions, both systems were adapted to a L1/L2 GPS antenna using a splitter. The antenna position was directly above the camera. Furthermore, both inertial measurement units (APPLANIX AIMU and IGI IMU-IId) were mounted close to each other on a common plate on top of the camera head (see Figure 1). The time synchronization of the HRSC image data with the navigations data was realized using the PPS-pulses (Pulse Per Second) generated by the APPLANIX GPS-Receiver.

The test flight on March 12/13, 2002 over a test field south of Berlin (Königs Wusterhausen, Ragow) was flown with four East-West flight strips (each of approx. 10 km length) and with two North-South flight strips (each of approx. 3 km length). The across-track overlap was chosen to approx. 60 %, the flight altitude was about 1,000 m. Both GPS/INS systems were operated synchronously during the test flight (switch-on, initialization, and switch-off at the same time). A 10-minute static initialization was conducted on ground before take-off. Before the first flight strip an additional in-flight-alignment was carried out. As a reference station a SAPOS GPS station in Wünsdorf was selected. Airport, test field and reference station were within a range of 30 km. The GPS situation during the entire flight was adequate and stable (9-10 satellites).

3. Description of the GPS/INS systems

	APPLANIX POS/AV-510	IGI AEROcontrol-IId
System components	AIMU (dry tuned gyros), PCS-computer (incl. L1/L2 GPS receiver) s/w package: POSPac	IMU-IId (fibre-optic gyros), AEROcontrol-computer L1/L2 GPS receiver s/w package: AEROoffice
Operation in flight	autonomous	via Standard CCNS4
IMU parameters	AIMU	IMU-IId
Size (H x W x L) / Weight	9 x 11 x 11 cm / 1.6 kg	19 x 14 x 13 cm / 3.3 kg
Raw data	200 Hz	64 Hz
Gyro drift	1 deg/h	0.1 deg/h
Gyro drift stability	0.01 deg/sqrt(h)	0.02 deg/sqrt(h)
Absolute Accuracy Spec. (post-processed)		
Data rate	200 Hz	64 Hz
Position (RMS)	5-10 cm	5-10 cm
Attitude (RMS)		
Roll, Pitch	0.005 deg (20")	0.005 deg (20")
Heading	0.008 deg (30")	0.008 deg (30")

Table 1: Comparison of parameters of the navigation systems APPLANIX POS/AV-510 and IGI AEROcontrol-IId.

The navigation systems used for the test flight, APPLANIX POS/AV-510 and IGI AEROcontrol-IId, are integrated GPS/INS systems, designed for the direct determination of position and attitude of airborne sensors. They efficiently combine inertial sensors and GPS technology [2,3]. The technical parameters of both systems are listed in Table 1.

Each system consists of three central components, the inertial measurement unit (IMU), a command unit with a L1/L2 GPS receiver, and a software package for data processing. The main difference between both systems is the IMU component. The APPLANIX AIMU is based on mechanical gyro-technology with 200 Hz scan frequency, while the IGI IMU-IId owns fiber-optical gyroscopes (FOG) with a scan frequency of 64 Hz. The IMU realizes measurements of accelerations and angular velocities, thus recording movements of the camera/IMU system, which could not be compensated by the stabilized platform (ZEISS T-AS). For further processing the time-synchronized IMU and GPS data are recorded during flight on a PC card by the command unit.

4. GPS/INS Data Processing

While the APPLANIX-data were processed at DLR using the APPLANIX software POSPac, processing of IGI data was completely done by IGI, resampling the 64 Hz based IGI navigation solution to 200 Hz. The general processing chain of the recorded GPS and inertial data consist of two phases and is valid for both systems (see Figure 2).

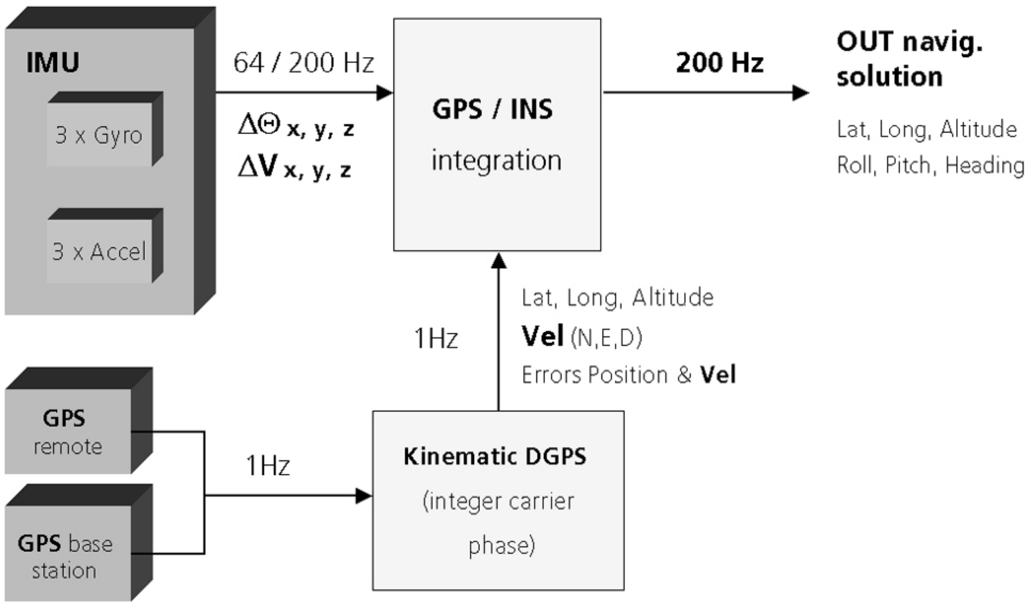

Figure 2: GPS/INS data processing

The first phase contains the pure GPS processing, where GPS data from the airplane are combined with the data of the reference station to a kinematic GPS trajectory. This DGPS solution of 1 Hz describes the position (latitude, longitude, altitude) and velocity (Vn, Ve, Vd) in the WGS84 coordinate system wth a very high absolute accuracy of 5-10 cm for position and few cm/s for velocity). The second phase comprises the GPS/INS integration. There, the inertial navigation algorithm based on the IMU data is stabilized by additional GPS position and velocity information. Because of the fact, that typical errors of inertial navigation and GPS measurements are independent and complementary, it is possible to estimate and compensate these inertial errors within a Kalman filtering procedure. Therefore, the accuracy derived by this integrated GPS/INS solution is conditioned w.r.t. position by the GPS position accuracy and w.r.t. attitude by the quality of the IMU.

5. Analysis of the Navigation Solutions

For further analysis of the HRSC-A test flight the pure DGPS 1 Hz solutions of APPLANIX and IGI as well as the final GPS/INS 200 Hz solutions of March 13, 2002 were available. At first we compared the pure DGPS solutions of APPLANIX (s/w POSGPS 3.0) and IGI, since the GPS position is used as absolute reference for the following GPS/INS integration. Based on the GPS reference station Wünsdorf the maximum difference in position (3D) between both trajectories (w.r.t. the GPS antenna) of 4 cm (RMS 2 cm) showed a high consistency for the entire flight path.

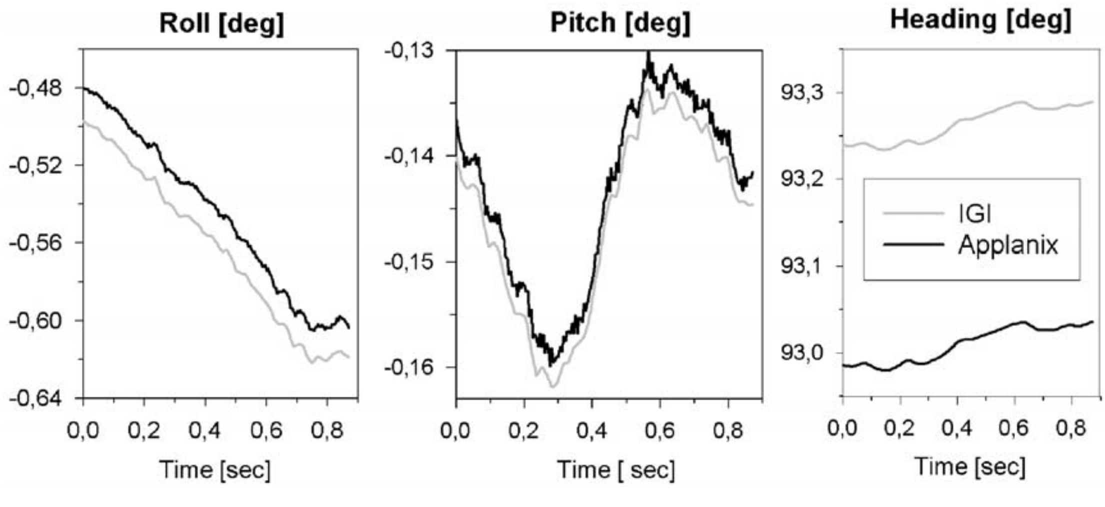

Figure 3: Position difference between both navigation solutions

The integrated GPS/INS solutions refer w.r.t. position to the HRSC-A projection center and w.r.t. attitude to the IMU axes. The direct comparison of both navigation solutions show as attitude differences (Figure 3) the result of the different boresight angles. These angular offsets, as well as possible small time synchronization offsets, can only be determined within an image based photogrammetric analysis (see Chapter 6).

Image data of the HRSC-A are acquired with a scan rate of 450 Hz. The contain movements and vibrations, that affect the camera and which can not be compensated by the stabilized platform. The characteristics of the uncompensated movements depend on different parameters, such as the type of the aircraft, actual turbulences, or platform behavior. A spectral analysis of the attitude date of both navigation solutions shows the following dominant frequencies (Table 2).

Frequency [Hz]	APPLANIX (Roll)	IGI (Roll)	Amplitude [deg]	Remarks
1-2	+	+	approx. 0.02	T-AS platform control circuit
18	+	+	approx. 0.004	
85	+	-	≤ 0.002	air-screw (3 blades) (1700 r.p.m.)

Table 2: Dominant frequencies within the APPLANIX and IGI navigation solutions

These frequencies could also be proved in the image data. Thus, both systems have detected and recorded these high-frequent movements of the camera. An exception is, as shown in Table 2, that the IGI-IMU-IId with its 64 Hz scan rate can not detect, in contrast to the APPLANIX-AIMU with 200 Hz, a frequency of 85 Hz within the roll angles. But because of its small amplitude of less than 0.002 deg (this is below the HRSC pixel resolution) this is of secondary importance.

6. Photogrammetric Analysis of the Navigation Solutions

HRSC-A acquires image data with 9 different CCD lines, where 5 panchromatic channels offer different stereo angles of 0°, ± 12.8°, and ± 18.9°. These stereo channels are used, in contrast to the other 4 spectral bands, within the photogrammetric analysis. Because of its scan rate the ground resolution along-track is about 16 cm. The across-track ground sampling distance is, from a flight altitude of 1,000 m, approx. 4 cm.

Within the test field 18 well defined control points were known with an accuracy of few centimeters due to GPS measurements. The image coordinates of these control points and additional of 87 tie-points in the overlapping region of the 6 flight strips were measured in all five stereo channels with sub-pixel accuracy. Within a numerical optimization procedure at first the boresight offsets for κ und ϕ, and a possible time offset between image and attitude data were determined by optimization of the intersection of all rays, defined in space by interior and exterior orientation of all tie- and control points. In the following step the boresight offset for ω, a possible time offset between image and position data, and potential absolute WGS84 position offsets, were determined with the help of all points in the overlapping regions of the alternating flight strips. This procedure was applied to both navigation solutions. The results of this optimization are shown in Table 3.

		APPLANIX	IGI
Boresight angles:			
	Boresight ω[°]	0.024	0.011
	Boresight ϕ[°]	0.009	0.013
	Boresight κ [°]	-0.017	0.259
WGS84 position offset:			
	ΔNorth[cm] / ΔEast[cm] / ΔUp[cm]	4 / 1 / 4	2 / 1 / 12
Time offsets:			
	Δt Position-Image[ms] / Δt Attitude-Image[ms]	3 / -4	4 / -2
Point accuracy:			
	Relative (strip-wise): 3D-RMS [cm]	8	8
	Strip-to-Strip: 3D-RMS [cm]	14	16
	Absolute: (at GCPs): 3D-RMS[cm]	14	16

Table 3: Results of the photogrammetric analysis of the navigation systems APPLANIX POS/AV-510 and IGI AEROcontrol-IId

The results of Table 3 can be interpreted as follows:

- The different boresight angles are causes by the non-parallel set-up of both IMUs on top of the HRSC-A.
- The WGS84 position offsets in Northing an Easting are not significant. The difference of 8 cm in the height component obviously reflects errors in the assumed lever arms between the camera resp. the IMU and the GPS antenna, as well as its unconsidered slight dynamics introduced by the active stabilization.
- The differenced in time offsets are small (1 - 2 ms). They obviously result from different filter effects during the GPS/INS integration. Especially the time offset between image and attitude data can be considered as significant, because of the sensibility of the determination of the interior strip-wise accuracy using five stereo observations.

The relative and absolute point accuracy derived with both systems are at or below 1 pixel and can therefore not be defined as significantly different.

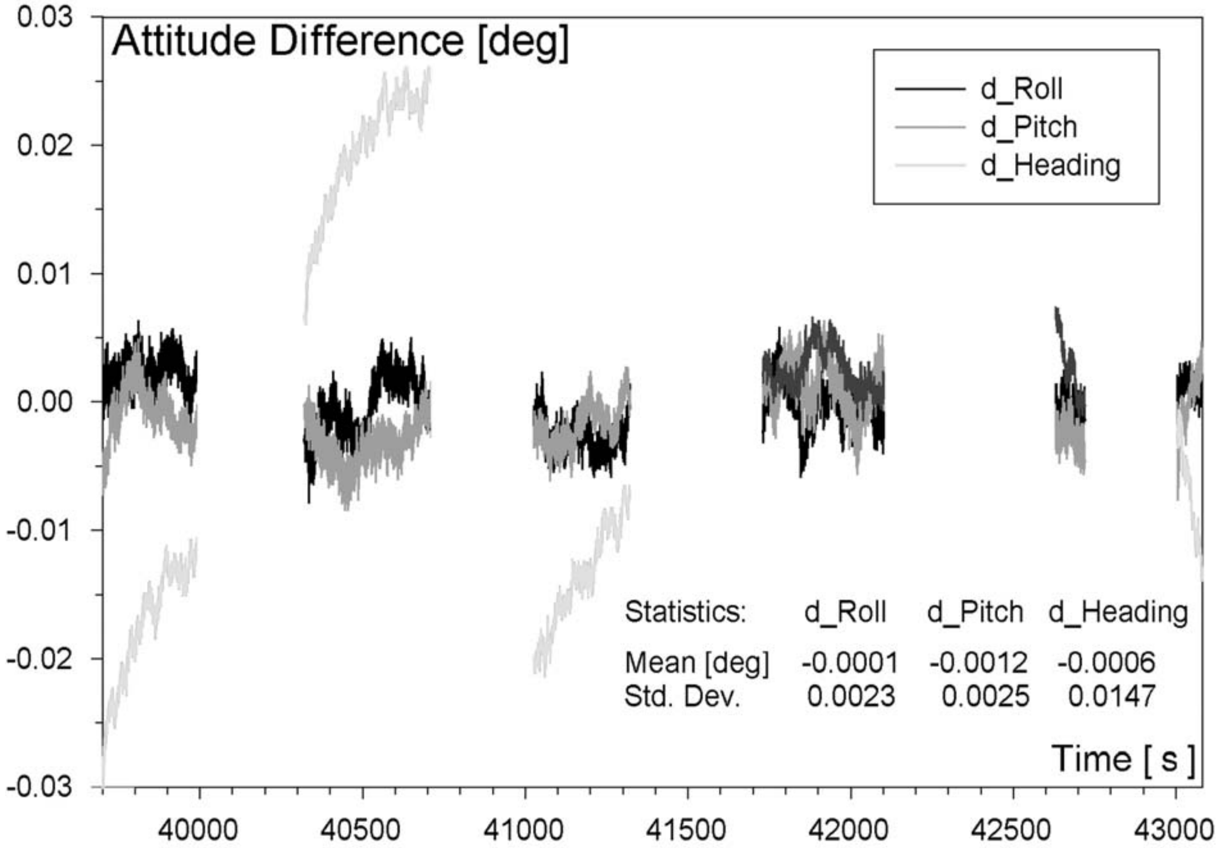

Figure 4: Attitude differences of APPLANIX- and IGI navigation solutions after photogrammetric boresight and time offset correction using 6 flight strips

Based on the calculated time and boresight offsets new attitude data result for both systems, the difference of which are shown in Figure 4 for the entire flight path.

The standard deviations of roll and pitch differences accord with the HRSC-A IFOV of 0.0023°. Effects of an error in heading in the size of 0.0147° depend on the distance to the principle point of the camera. For the near-nadir CCD lines only differences below the pixel resolution arise because of the narrow field of view. The outer four stereo lines are affected by up to 2 pixels, but the symmetrical arrangement of the stereo lines compensates this effect. Thus, the ray intersection accuracy is reduced but the position of the resulting point in object space still remains correct.

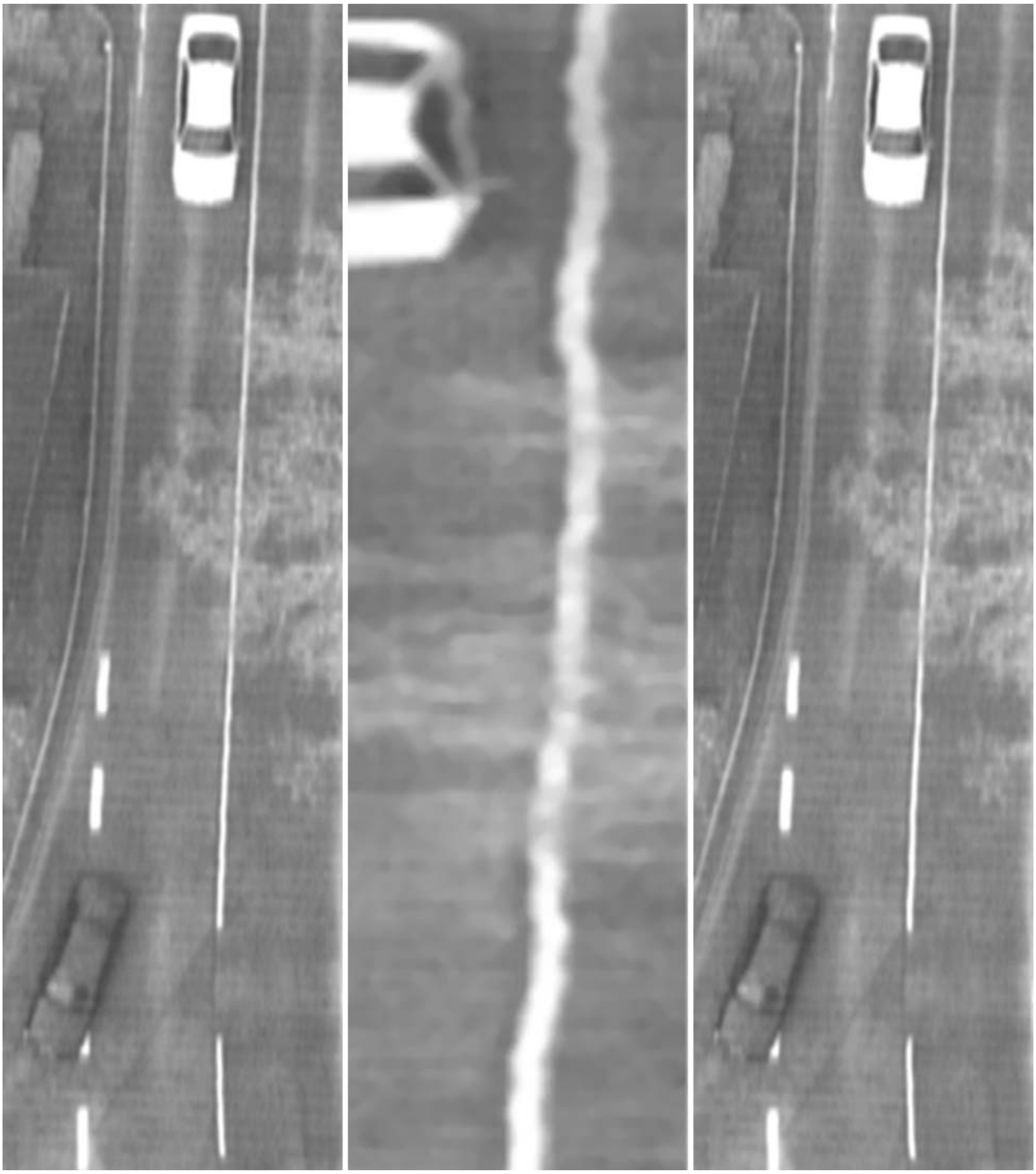

Figure 5: Resampling of HRSC data (middle) with APPLANIX- (left) and IGI (right) navigation solution.

A flight attitude correction of HRSC-A image data using the optimized navigation solutions is shown in Figure 5. According to the previous analysis the difference in the results of both solutions are negligible (below the pixel resolution). Even the in the 64 Hz IGI solution uncompensated effects of vibration are not visible within the corrected image data.

7. Conclusion

During this test at the DLR, using the GPS/INS systems APPLANIX POS/AV-510 and IGI AEROcontrol-IId synchronously with the HRSC-A, both systems delivered navigation solutions that have been checked and optimized w.r.t. offsets for boresight angles, time offsets, and WGS84 flight path offsets, based on the continuous HRSC-A image acquisition. Within a photogrammetric analysis it could be shown that both systems correct for all frequencies, with the exception of the 64 Hz IGI-Systems, that could not detect vibrations of 85 Hz with small

amplitudes of 0.002°. The average differences of both optimized navigation solutions are in or below the HRSC pixel resolution of 0.0023° w.r.t. position, pitch, and roll. The mean differences in heading of 0.0147°, the cause of which can not be determined within this investigation, yield on sub-pixel effects due to the symmetrical arrangement of the HRSC CCD lines and due to the camera's narrow field of view.
As a conclusion and based on these investigations it can be stated, that both systems are at the same stage suitable for use in combination with the HRSC, especially if the IGI system is based on an IMU scan frequency of higher than 64 Hz for the measurement of high frequent vibrations.

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Bibliography

[1] Heipke, C., Jacobsen, K., Wegmann, H. 2001. The OEEPE Test on Integrated Sensor Orientation – Results of Phase I. – In: Photogrammetric Week ´01, FRITSCH/SPILLER (Eds.), Wichmann Verlag, Heidelberg, pp. 195-204.

[2] Kremer, J., 2001. CCNS and AEROcontrol: Products for Efficient Photogrammetric Data Collection. – In: Photogrammetric Week ´01, FRITSCH/SPILLER (Eds.), Wichmann Verlag, Heidelberg, pp. 85-92.

[3] Lithopoulos, E., 1999. The Applanix approach to GPS/INS integration. – In: Photogrammetric Week ´99, FRITSCH/SPILLER (Eds.), Wichmann Verlag, Heidelberg, pp. 53-57.

[4] Neukum, G. & the HRSC-Team, 2001. The Airborne HRSC-AX Cameras: Evaluation of the Technical Concept and Presentation of Application Results after one Year of Operations. – In: Photogrammetric Week ´01, FRITSCH/SPILLER (Eds.), Wichmann Verlag, Heidelberg, pp. 117-130.

[5] Scholten, F., Wewel, F. & Sujew, S., 2001. High Resolution Stereo Camera – Airborne (HRSC-A): 4 Years of Experience in Direct Sensor Orientation of a Multi-Line Pushbroom Scanner. – ISPRS Proceedings Sensors and Mapping from Space 2001: Veröffentl. Inst. f. Photogrammetrie und Geoinformation, Universität Hannover.

[6] Scholten, F., Gwinner, K., Wewel, F., 2002. Angewandte Digitale Photogrammetrie mit der HRSC-A. – Photo-grammetrie, Fernerkundung, Geoinformation, **5**, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, pp. 317-332.

[7] Wewel, F., Scholten, F., Neukum, G. & Albertz, J., 1998. Digitale Luftbildauf-nahme mit der HRSC – Ein Schritt in die Zukunft der Photogrammetrie. – Photo-grammetrie, Fernerkundung, Geoinformation, **6**, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, pp.337-348.