'Photogrammetric Week 01' D. Fritsch & R. Spiller, Eds. Wichmann Verlag, Heidelberg 2001.

Sensor integration and data fusion in praxis

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ABSTRACT

Fotonor AS was one of the first aerial photography company to integrate an Applanix POS/AV system with a RC30 camera from LH Systems. This paper describes how this integration is done and what considerations we have taken into account to improve the accuracy of the POS solutions.

1. INTRODUCTION

Fotonor was established in 1985. Fotonor currently operates 3 Piper Navajo's with 2 RC30 camera's, one ALTM1210 Lidar and Magnetic sensors used by TGS-Nopec.

First time we used GPS/INS technology during aerial photography was in 1998, where an Applanix POS/AV 310 was tested for a certain project called NIJOS 3Q. For this project the accuracy of the orientation is specified to 60 cm.

As a consequence of our results at the 3Q project in 1998, Fotonor purchased an Applanix POS/AV 510 system in 1999. The system was initially planned to be used at forestry and agricultural applications, but the interest for using the technology in ortophoto and technical mapping applications is increasing.

For projects were Applanix POS has been used, the accuracy of the GPS/INS processed orientation has normally been specified to be within 0,5 - 1,5 meters. According to the relative strict specifications, all projects are based on post-processing of the GPS and IMU observations, with a demand for the GPS trajectories to be solved with fixed ambiguities.

This paper focuses on various topics that have to be taken into account when using Applanix POS/AV for aerial photography with Leica RC30 cameras . It has to be emphasised that this paper does not focus at the position and orientation accuracy's for the Applanix POS/AV, but on what additional errors that occurs due to the installation/integration with the RC30, and the used flight procedures.

2. INSTALLATION APPLANIX POS/AV 510 LEICA RC30

The Applanix POS/AV 510 is at the moment mounted in a *Piper Navajo* aircraft reg. no. LN-NAB. The Applanix IMU *(Inertial Measure Unit)* is directly mounted at the RC30 drive unit.

Sensors and aerial photography equipment installed for aircraft LN-NAB:

- Leica RC30 camera with 153 m
- Leica PAV30 gyro stabilised camera mount
- Ashtech MIRA-ZA, with photogrammetric option

- Applanix POS/AV 510 (Applanix PCS and IMU, Novatel Millenium GPS receiver with aerial GPS antenna)
- Tracker Camera control and Navigation System.

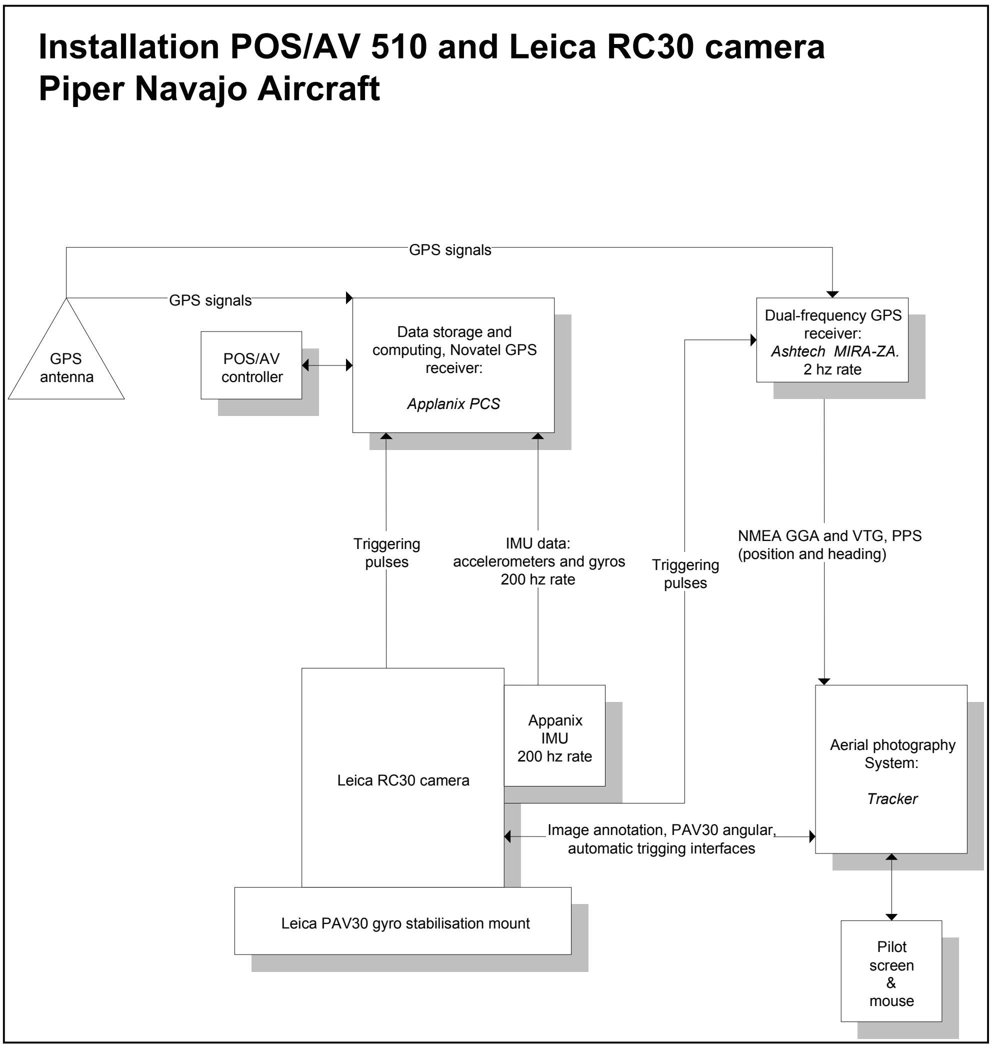

Figure 1: Sensor fusion and data flown

2.1. Mount of IMU at Leica RC30 camera

The IMU needs to be mounted such that no rotation changes between the IMU reference frame and the camera reference may occur.

To avoid changes and movements for the IMU mount, a separate platform is attached by bolts into the skeleton of the camera drive unit. Some adjustments at the Leica RC30 had to be made, because the RC30 was never of course designed to have an IMU mounted to it.

The consequence of a rotation change between the IMU mount and the camera can be dramatic, IMU misalignment causes attitude errors with factor one to one (1:1).

3. SYSTEM PERFORMANCE AND CALIBRATION

Typical RMS values for POS/AV 510 are according to Applanix :

POS/AV 510 Absolute Accuracy Specifications

Element	Post-Processed[1]
Position (m)	0.05 - 0.30
Velocity (m/s)	0.005
Roll & Pitch (degrees)	0.005
True Heading* (degrees)	0.008

[1] ***for typical mission profiles,source: Applanix Corp. website.***

Using the above given accuracy specifications, photo scale 1:12000 and camera lens 0.153 meter, the expected orientation accuracy should be approx. *40 cm*, (other errors not taken into account).

The listed specifications does not include additional errors caused by the camera/POS integration, the camera and the other hardware. These errors will be addressed in the following.

For every installations the IMU needs to be calibrated.

The delta angels between the IMU sensor frame and camera frame are searched. These angels are often noted "Misalignment angels". Additional parameters like *Trigging Camera Pulse Delay* and *Corrected Camera Constant* can also be estimated in the same calibration.

3.1. Calibration of misalignment angels (boresight calibration)

The "Misalignment angels" are estimated by Least Squares Method taking into account Exterior Orientation elements from the Applanix POS and from Aerial Triangulation.

Fotonor AS perform boresight calibrations once or twice a year. Since 1998 Fotonor has tried several kinds of block designs, depending on which unknowns that are searched.

Calibrated parameters: *delta omega*, *delta phi* and *delta kappa*.

3.2. Calibration of offset Camera Trigging Pulses

Time delay between triggering pulse at RC30 and time for the registration as a camera event at the GPS receiver . The magnitude of the parameter is due to hardware delay, unprecise measured pulse edge and so on.

This value needs to be calibrated within a few microseconds.

Propagation of positions along track caused by timing offset:

$$\Delta x = v \cdot \Delta t$$

where	Δx	: position error along track
	v	: velocity aircraft
	Δt	: timing offset

3.3. Camera constant

The accuracy of direct orientation from GPS/INS technology is directly influenced by the calibrated focal length of the camera.

Errors in the focal length will be propagated proportionally by the given photo scale / altitude. For example; an error of 10 microns will be a 20 cm height error on ground for image scale 1:20000.

Propagation of camera constant error:

$$\Delta h = \Delta c \cdot \frac{h}{c}$$

where	Δc	: error camera constant
	c	: camera constant
	h	: flying height
	Δh	: error ground heights

A proper calibrated value for the focal length is a must while using GPS/INS technology for aerial photography. This has been investigated by Fotonor during aerial triangulation letting the focal length being a parameter in the aerial triangulation computations. The computed focal length had no statistically significant changes to the one given in the camera calibration certificate.

3.4. GPS lever arm

The GPS lever arm is the eccentricity between the camera reference point and the GPS antenna phase centre. The lever arm is measured by terrestrial survey methods (teodolites) with an accuracy within 3 cm. A precise measured GPS lever arm is of vital importance for troubleshooting, accuracy, strengthen GPS solution and for the performance of the Kalman filter.

3.5. Effects of using gyro-stabilised camera mount

The effect of using PAV30 compensation of angular movements can lead to systematic errors at the GPS/INS attitudes. During tests we have found that kappa compensation at line entrance may result in large kappa biases at the start of a line. The effect for kappa compensation is shown below.

The errors converge in 3-5 minutes to acceptable values. Similar (analogue) effects can be found for omega and phi compensations.

It can also be shown that these effects will increase proportional with the length of the GPS lever arm.

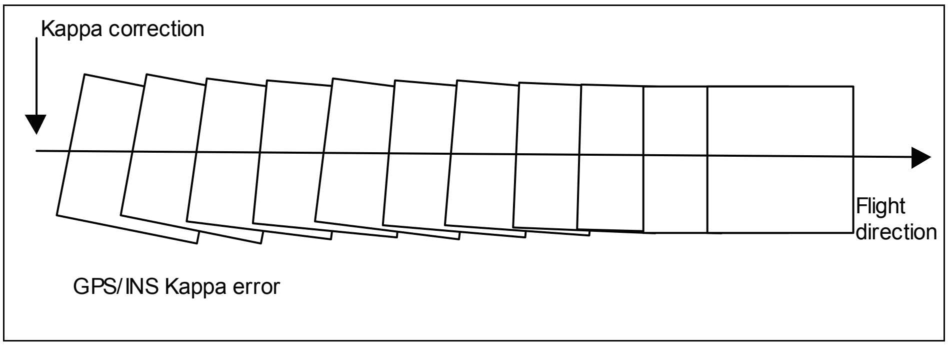

Figure 2: Kappa error due to PAV30 kappa compensation.

At the moment the POS/AV system does not take angular camera movements under consideration during post processing, but Applanix and LH-Systems are developing new interfaces to solve this problem. (reading the recorded PAV30 angles into POS).

3.6. Calibration flights – flight plan design

A couple of flight plans has been tested over a part of "Testfelt Fredrikstad", were a number of GCP's have been computed using static GPS.

Taking into account you want to capture a minimum of images still being able to estimate the extra parameters in a block adjustment, the following design is used :

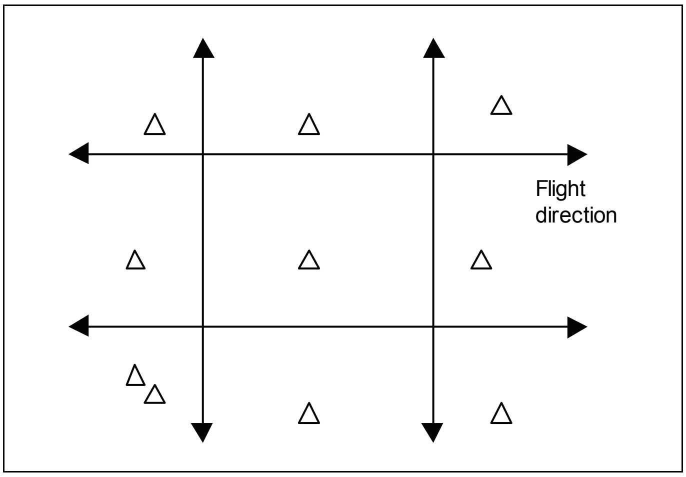

Figure 3: Typical calibration block design

Each line has 6 images with 60% overlap, sidelap is 20%. Image scale has been 1:5000 (last year also 1:10000 was used). The number of GCP's are 11.

4. LIMITATIONS, PROS AND CONS

Use of a POS like Applanix POS/AV gives benefits : money is saved, the EOS can be found in short time after flight. Also some projects are undertaken which earlier were unrealistic to due to the high costs of establishing GCP's.

4.1.1. Advantages by using POS in photogrammetry

- Direct georeferenced images represented by exterior elements x_O, y_O, z_O, ϖ, φ and κ (Exterior Orientation Elements EOE's)
- No need for Ground Control Points (GCP's).
- No need for aerial triangulation
- The real time PO (Position and Orientation) solution can be used to control the kappa drift.

4.1.2. Some limitations compared to normal photo missions :

- The accuracy of "raw" exterior elements are still not good enough for many technical purposes.
- GPS and IMU datagaps during a flight means You will either have to perform a reflight or start to post identify ,and survey, ground control points.
- The distance to nearest GPS reference station has to be less than 100 km during the whole flight. In areas where permanent GPS network does not exist, or is to sparse, the crew will have to set up their own GPS station.
- The integer ambiguities have to be fixed and more than 5 common GPS SV's for the whole flight.
- Compared to normal photo missions the chances you run into technical problems has increased.
- Change of camera lens requires a new calibration .
- Flight procedures has to be changed to make sure the IMU drift is under control. You may therefore spend longer time in air for a specific photo mission compared to a normal mission without POS.

5. PROJECT EXAMPLE USING GPS/INS

As mentioned in the introduction, we have used the GPS/INS on a project in Norway (3Q).

The project consists of 1500 spots, which will be completed in 5 years (approx. 300 single photogrammetric model (2 images). All spots are flown at photo scale 1:12000 with the 153 mm lens.

The accuracy of the Direct Orientation is specified to be within 60 cm.

For this particular project a procedure to control the orientation data has been established. A number of "fully determined" models (spots) are established with 5 to 6 GCP's. These models are referred to as *Masterspots*. None of the other spots have a distance exceeding 100 km from the closest *Masterspot*.

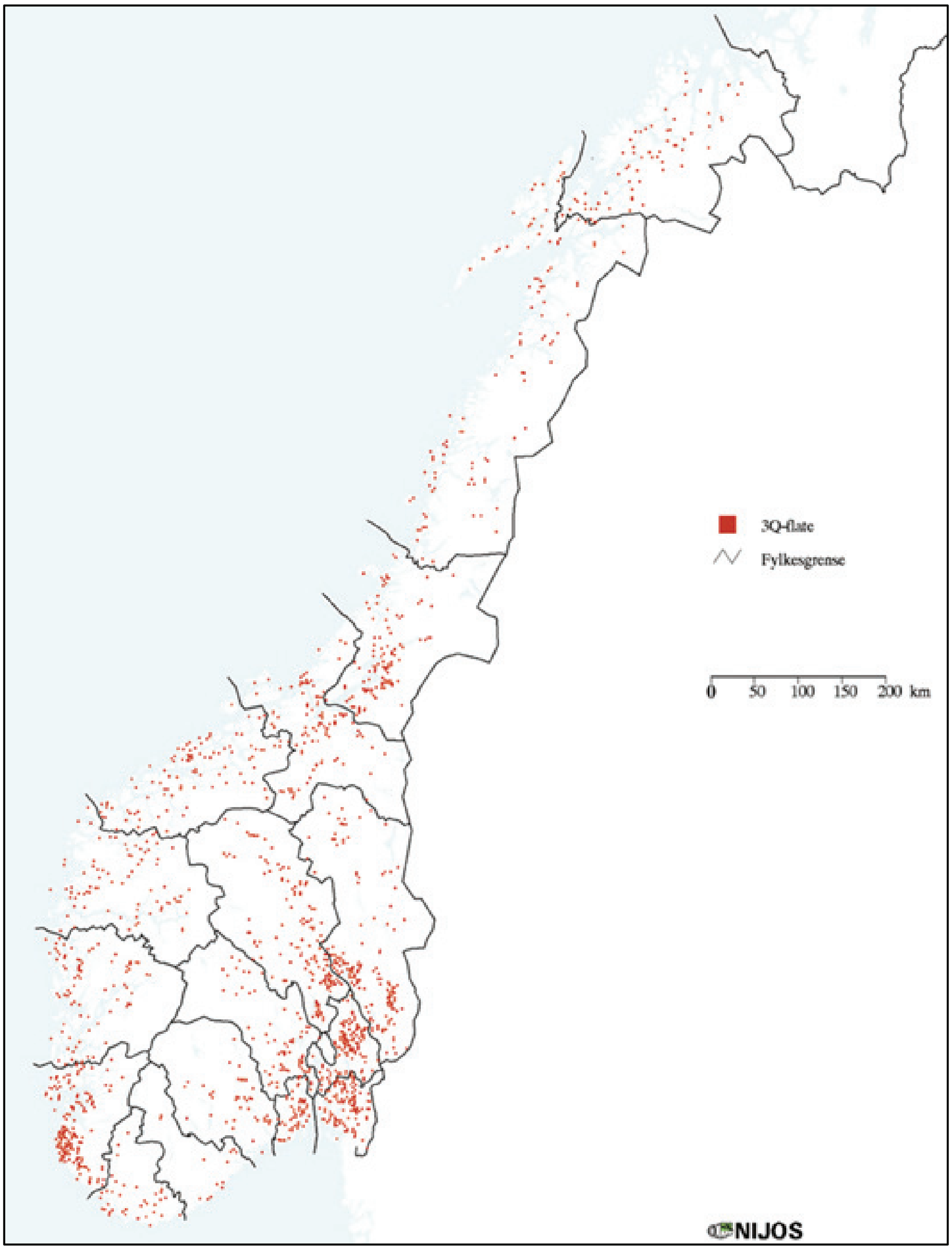

Figure 5: Spot locations 3Q project 1998-2002

At the masterspots the GCP's are measured with an Analytic Plotter where the model has its orientation parameters from POS. By comparing these measurements with the GPS measured GCP's, the accuracy of the GPS/INS orientation is quantified.

A masterspot is flown twice during a flight after the following procedure:

- in direction from east to west, or west to east, at start of photo mission
- in opposite direction to the first photography after flight mission

The below figure shows a typical "fully determined" masterspot.

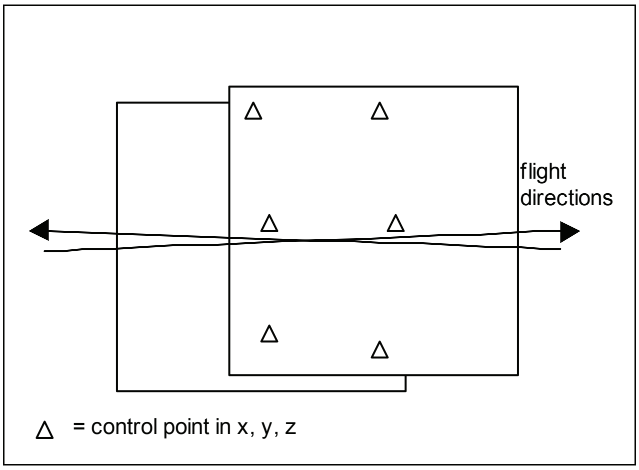

Figure 6: Flight procedure and GCP location 3Q project.

5.1. Results from measurements of Ground Control Points

In the following list some control measurement results are given : Standard deviation, systematic errors and magnitude of the y parallaxes (in microns)

All images are captured during the NIJOS 3Q 2000 project, and we expect these results to give good indications of the expected accuracy's at this photo scale (1:12.000, wide angle lens).

Master-spot	Date of flight	Standard deviations					Systematic errors			y parallaxes
		Easting (m)	Northing (m)	Height (m)	EN (m)	***ENH (m)***	Easting (m)	Northing (m)	Height (m)	(microns)
1170	10.07.00	0.54	0.10	0.33	0.55	*0.64*	0.53	0.00	0.01	0-8
1170	10.07.00	0.38	0.17	0.48	0.42	*0.63*	0.33	-0.08	0.39	20-40
1103	11.07.00	0.09	0.30	0.42	0.32	*0.52*	0.04	0.29	0.29	-
1103	11.07.00	0.18	0.07	0.38	0.19	*0.42*	-0.17	0.03	0.36	-
3279	13.07.00	0.29	0.37	0.25	0.47	*0.53*	0.29	0.31	0.05	-
3279	13.07.00	0.13	0.22	0.73	0.26	***0.78***	-0.07	0.17	0.66	20
3348	25.07.00	0.13	0.51	0.19	0.53	*0.56*	-0.12	-0.49	0.09	-
3348	25.07.00	0.16	0.27	0.22	0.31	*0.38*	-0.03	-0.24	0.01	8-30
3239	25.07.00	0.44	0.13	0.69	0.46	***0.83***	-0.14	-0.07	0.62	-
3348	26.07.00	0.16	0.21	0.25	0.27	*0.37*	0.07	-0.18	-0.02	8-30
3348	26.07.00	0.35	0.44	0.28	0.56	*0.62*	-0.32	-0.43	0.05	0-40
1103	27.07.00	0.18	0.16	0.46	0.24	*0.52*	-0.12	0.00	0.36	0-40
1103	27.07.00	0.22	0.24	0.48	0.33	*0.58*	0.21	0.24	0.40	0-8
1131	27.07.00	0.40	0.18	0.38	0.43	*0.57*	0.39	0.12	0.19	-
1131	27.07.00	0.26	0.17	0.52	0.31	*0.61*	0.23	-0.15	0.47	-
1131	28.07.00	0.44	0.52	0.48	0.68	***0.83***	0.09	-0.37	0.43	20-60
1131	28.07.00	0.47	0.25	0.40	0.53	*0.67*	0.42	-0.04	0.31	0-50
1170	29.07.00	0.55	0.28	0.37	0.62	***0.72***	0.21	-0.20	0.05	20-40
1170	29.07.00	0.62	0.10	0.33	0.62	***0.71***	0.61	-0.06	0.19	0-35
1014	15.08.00	0.29	0.47	0.77	0.55	***0.94***	-0.16	-0.43	0.73	0-40
1014	15.08.00	0.29	0.52	0.81	0.60	***1.00***	0.14	-0.50	0.76	40-60
1014	15.08.00	0.26	0.68	1.05	0.73	***1.28***	0.00	-0.66	0.99	0-50
1014	15.08.00	0.22	0.33	0.69	0.40	***0.80***	-0.05	-0.25	0.62	0-35

1) Derivation: ε = *GCP with GPS/INS orientation – GCP " ground truth"*

2) Systematic error: $\bar{\varepsilon} = \frac{\sum_{i=1}^{n} \varepsilon_i}{n}$,

3) Standard derivation: $s = \sqrt{\frac{\sum_{i=1}^{n} (\varepsilon_i - \bar{\varepsilon})^2}{n-1}}$

4) ENH : $\sqrt{(sE^2 + sN^2 + sH^2)}$

5.2. Conclusion

Column ENH in the table above includes datum problems, photogrammetric errors (operator, interior orientation etc). Due to photogrammetric errors the 3Q project specification is changed to 70 cm (60 cm from POS and 10 cm from photogrammetry).

9 of 23 master spots were rejected due to errors exceeding 70 cm.

As shown, according to Applanix the performance at 1:12000 scale should be approx. 40 cm RMS. Our results are on the average 0.67 cm RMS (extreme values included). The result is also influenced by datum shift, geoid model errors and photogrammetric errors. The calibration issues from chapter 4 do also have influence on the results.

6. REFERENCES

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