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AIRBORNE IMAGE GEOREFERENCING BY GPS-AIDED INERTIAL SYSTEMS: CONCEPTS AND PERFORMANCE ANALYSIS

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ABSTRACT: This paper describes how position and orientation measurement systems are used to directly georeference airborne imagery data, and presents the accuracies that are attainable for the final mapping products. The Applanix Position and Orientation System for Airborne Vehicles (POS/AV^{TM}) has been used successfully since 1994 to georeference airborne data collected from multispectral and hyperspectral scanners, LIDAR's, and film and digital cameras. The POS/AV^{TM} uses integrated inertial/GPS technology to directly compute the position and orientation of the airborne sensor with respect to the local mapping frame. A description of the POS/AV^{TM} system is given, along with an overview of the integrated inertial/GPS processing. An error analysis for the airborne direct georeferencing technique is then presented. Firstly, theoretical analysis is used to determine the attainable positioning accuracy of ground objects using only camera position, attitude, and image data, without ground control. Besides theoretical error analysis, a practical error analysis was done to present actual results using only the POS data plus digital imagery without ground control except for QA/QC. The results show that the use of POS/AV enables a variety of mapping products to be generated from airborne navigation and imagery data without the use of ground control.

1. INTRODUCTION

A direct georeferencing (DG) system provides the ability to directly relate the data collected by a remote sensing system to the Earth, by accurately measuring the geographic position and orientation of the sensor without the use of traditional ground-based measurements (Mostafa and Schwarz, 2000, Reid et al, 1998, Hutton et al, 1997). Examples of where DG systems are used in the airborne remote sensing industry include: scanning laser systems or LIDAR such as the Optech ALTM, Interferrometric Synthetic Aperture Radar systems (InSAR) such as that produced by the Aero-sensing, multispectral and hyperspectral scanners such as the ITRES CASI, the new state-of-the-art digital line scanners systems such as the Z/I DMC and the LH Systems ADS40, and more increasingly small format digital cameras and traditional film cameras such as the Leica RC30 and Zeiss TOP RMK, as shown in Figure 1. The current state-of–the-art direct georeferencing systems such as the Applanix POS/AV^{TM} use carrier phase differential GPS measurements integrated with an Inertial Measurement Unit (IMU). This paper gives an overview of how the systems work, and investigates what ground accuracy is attainable for typical applications such as mapping with a digital camera. This is supported through theoretical and practical results.

Figure 1 IMU Installation on Different Airborne Remote Sensing Sensors

2. DESCRIPTION OF THE POS/AVTM DIRECT GEOREFERENCING SYSTEM

The Applanix POS/AV™ direct georeferencing system (see Figure 1) is comprised of four main components: an IMU, a dual frequency low-noise GPS receiver, a computer system (PCS) and a post-processing software suite called POSPac™. The heart of the system however is the Integrated Inertial Navigation software that is implemented both in real-time on the PCS and in postmission using the POSPac™ software. In POSPac™, the GPS measurements are used to aid the inertial navigation solution produced by integrating the IMU outputs to produced a blended position and orientation solution that retains the dynamic accuracy of the inertial navigation solution but has the absolute accuracy of the GPS as shown in Figure 2.

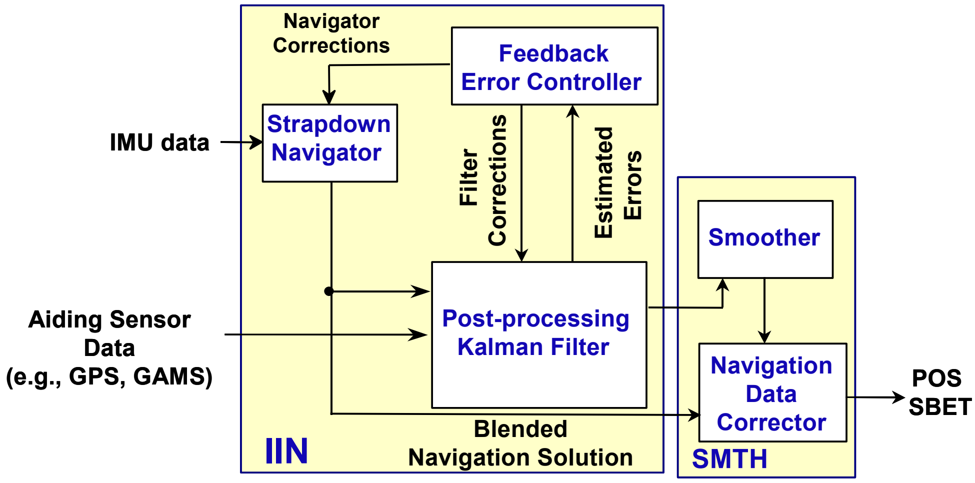

Figure 2 POSPac™ Software Structure

3. Accuracy Obtainable From POS/AV™

3.1 Positional Accuracy

With proper mission planning, careful flight operations to minimize satellite loss of lock, and assuring that the maximum baseline separation between the remote and base receivers are within 10 - 50 km, position accuracies in the range of 5 to 30 cm RMS are achievable using post-processed carrier phase Differential GPS.

3.2 Orientation Accuracy

The orientation accuracy of the POS/AV™ smoothed navigation solution is described best in terms of *absolute accuracy* and *relative accuracy*. The *absolute accuracy* is the total RMS error including the mean, while the *relative accuracy* describes the high frequency sample-to-sample error. It is convenient to do this since in most cases the orientation error is comprised of a slow varying signal with almost no noise, and in some applications it is the accuracy of the change in orientation that is most important (such as that in a digital line scanner). Table 1 shows the absolute accuracy of different POS systems.

Table 1. POS/AV™ Absolute Accuracy Specifications

Parameter Accuracy (RMS)	***POS/AV™ 210***	***POS/AV™ 310***	***POS/AV™ 410***	***POS/AV™ 510***
Position (m)	0.05 –0.30	0.05 –0.30	0.05 –0.30	0.05 –0.30
Velocity (m/s)	0.010	0.010	0.005	0.005
Roll & Pitch (deg)	0.040	0.013	0.008	0.005
Heading (deg)	0.080	0.035	0.015	0.008

4. DIRECT GEOREFERENCING OF DIGITAL IMAGES USING POS/AV^{TM}

Direct digital image georeferencing using POS implies the direct measurement of position and orientation of each single image frame or scan line at the moment of data acquisition. In principal, this allows immediate map production using the photogrammetric unit (either a stereopair of images, or a single image+DEM). Ultimately, this approach totally bypasses the aerotriangulation step with no ground control point requirement, except for Q/A and Q/C. Figure 3 shows the georeferencing concept (Reid et al, 1998), while Figure 4 shows the digital dataflow of orthophoto production.

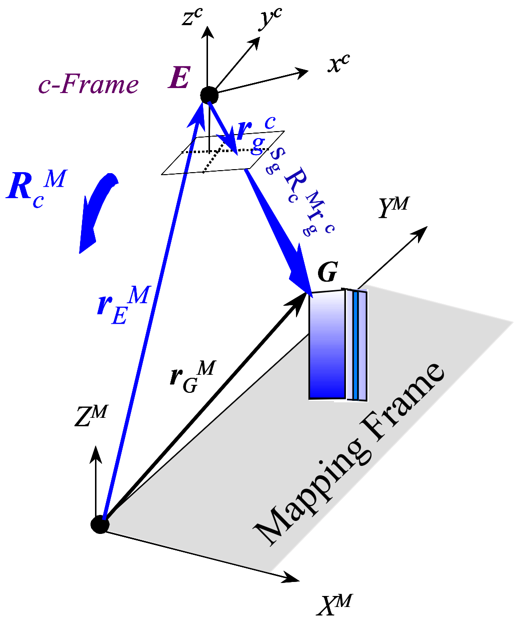

Figure 3 Direct Georeferencing Concept

4.1 Ground Accuracy From Theoretical Analysis

The necessary error models have been developed for two different cases of orthophoto production, namely, using either a single digital image or an image stereopair. Some assumptions have been made to account for different practical aspects (Mostafa and Schwarz, 2000).

As an example of these theoretical studies, a specific case was studied which involved a digital camera of a 3k x 2K CCD chip and a 28 mm lens. This example is presented due to the availability of a real airborne data set to back up the theoretical analysis. Figures 5 and 6 depict the horizontal DRMS theoretical accuracy and the height accuracy, respectively, when using a stereo model of digital images for different Ground Sample Distance (GSD) when using POS/AV^{TM} 210, 310, 410, and 510, respectively (left to right in the graph).

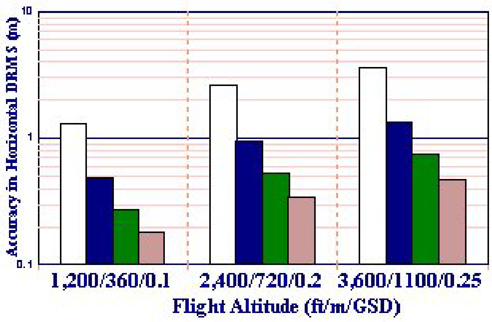

Figure 5 Horizontal Ground Accuracy

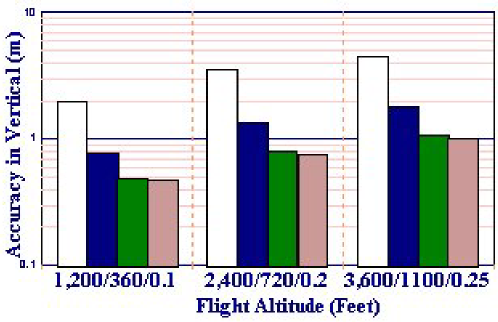

Figure 6 Vertical Ground Accuracy

4.2 Ground Accuracy From Practical Analysis

A flight test data was collected using POS/AV 410 and a digital frame camera of 3k x 2k and 28 mm lens (GSD ~ 0.2m). The digital camera was calibrated to compute the focal length, the principal point offsets, and the lens distortion parameters. Boresight calibration took place to determine the misalignment angles between the IMU body frame and the image coordinate frame. The airborne navigation data was processed in POSPac^{TM}. The image data together with POS data were used to compute the coordinates of the ground control points that appeared in different stereo models. A total of 20 models have been analyzed to account for different point location in the model. The POS-derived ground coordinates were then compared to the land-surveyed ones. The results are shown in Table II. Note that the practical accuracy is a little better than the theoretical one. In other words, the theoretical accuracy is conservative enough.

5. SUMMARY AND OUTLOOK

In this paper, a brief description of the concept of airborne remote sensing without ground control has been introduced through Applanix's POS systems. The basic concepts of inertial GPS integration have been described, along with the accuracy that can be achieved using such techniques. Then the ground accuracy using POS integrated with a digital frame camera was analyzed. The results show that direct georeferencing can be used to obtain digital orthophotos to an accuracy that can meet many remote sensing requirements.

Table 2. Ground Point Accuracy Derived by POS

Model ID	*Easting (m)*	*Northing (m)*	*Height (m)*
1	-0.08	0.10	-0.59
2	0.07	-0.10	-0.11
3	0.13	0.09	0.88
4	0.38	-0.18	-0.02
5	-0.24	0.01	0.71
6	-0.18	-0.32	-0.40
7	0.19	-0.08	0.00
8	-0.07	0.07	-0.45
9	-0.25	-0.05	0.34
10	0.06	0.20	-0.15
11	0.28	-0.10	0.28
12	0.13	-0.37	0.39
13	0.35	-0.20	-0.05
14	0.09	0.17	0.52
15	0.34	-0.02	1.34
16	-0.06	0.06	0.30
17	-0.21	0.15	-0.01
18	-0.04	-0.34	0.53
19	0.21	-0.10	0.03
20	-0.20	-0.11	-0.64
Min	-0.25	-0.37	-0.64
Max	0.38	0.20	1.34
Mean	0.04	-0.06	0.15
Std	0.21	0.17	0.50
RMS	**0.21**	**0.18**	**0.52**

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