Ground Accuracy from Directly Georeferenced Imagery

Investigating the accuracy of GPS/Inertial/Photogrammetry

By Dr. Mohamed Mostafa, Mr. Joseph Hutton, Mr. Erik Lithopoulos, Applanix Corporation

Reduction of the time and cost involved in photogrammetric mapping has been the subject of extensive research over the past two decades. The development of GPS-assisted aerotriangulation with minimal ground control was one of the important results of this research. The drawback of this technique is the lack of measuring image orientation information and, thus, “blocks” of images are always needed for solving for each photo’s orientation in 3D space.

The Applanix’s POS/AV™ system integrates GPS data with an Inertial Measurement Unit (IMU), which allows for measuring the camera exposure station position and image orientation angles for each single photo. Therefore, mapping may be done using a directly georeferenced photo steoreopair as the mapping element. This ultimately eliminates the aerotriangulation step from the mapping process. Using the POS/AV™ system, results in flexible configurations of imaging that may be used as image strips or small image blocks - a very common resource in mapping and forestry applications. In contrast, such applications cannot be attained when using GPS-assisted aerotriangulation, unless special GCP distribution is implemented, since image blocks with some geometry strength are always needed to compute image orientation.

This solution ultimately eliminates the aerotriangulation step

The POS/AV™ system has been widely used with most airborne imaging sensors. These include multispectral and hyperspectral scanners, LIDARs, Synthetic Aperture Radar (SAR), along with film and digital cameras. In this paper, a summary of a theoretical/practical study is presented. These investigations were carried out to evaluate the accuracy of positioning ground objects when using the POS/AV™ in conjunction with a frame digital or film camera. The accuracy specifications for the family of POS/AV™ systems are listed in Table 1.

Single Photo Case

In traditional photogrammetric mapping, the determination of the 3D position components of a ground object is done using photo stereopairs. This is the tried and tested way, to compute the point-based scale factor using the so-called 3D space intersection concept. However, if the scale is provided for each image point by an extra piece of measurement

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
True Heading (Deg)	0.080	0.035	0.015	0.008

Table 1: Post-processed POS/AV navigation parameter accuracy

Published in GIM International Vol.14 N.12 December 2000

such as a laser range, processing a single photo would be faster and more cost-effective (although maybe less accurate).

Another possibility for processing single photos is by using an available Digital Elevation Model (DEM) of the mapped area. In this case, the computation of the height component of the ground object 3D position is mainly driven by the DEM and the 3D space intersection is done between one image and the DEM. This approach is an attractive option - especially for applications wherein the available or specially created DEM can be used along with digitally acquired images to produce digital orthophotos in a short time frame.

Typical DEM sources include existing topographic maps, aerial photography, and more recently LIDAR In the study at hand, this approach is simulated using error propagation techniques to analyse the theoretical accuracy of ground object positioning with the different POS/AV™ models. Figure 1 shows the ground point accuracy in horizontal (DRMS) for different POS/AV™ models and image scales. A 9” x 9” format camera, equipped with a 6” lens is used in this simulation. Image precision is taken as 5 mm. To emphasize the exterior orientation accuracy effect on ground positioning accuracy, the errors due to camera calibration, boresight calibration, and DEM are not considered.

Stereo Model Case

This case represents the classical ‘model set-up’ scenario, where a pair of photos or digital frame images can be used to determine the 3D object point coordinates using the space intersection concept. By using the

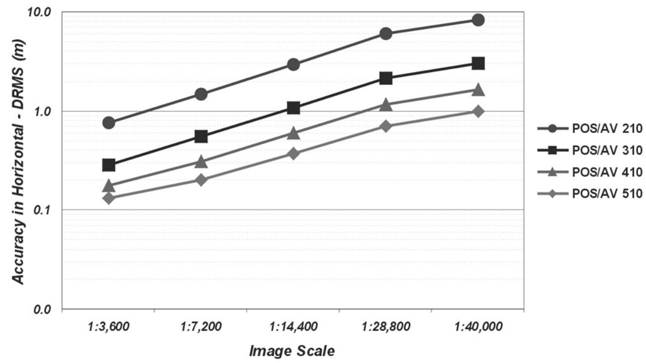

Figure 1: Ground horizontal accuracy (DRMS) - The Single Photo + DEM Case

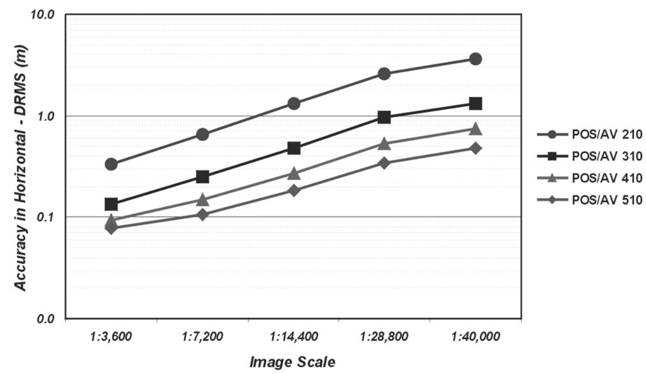

Figure 2: Ground horizontal accuracy (DRMS) - The Model Case

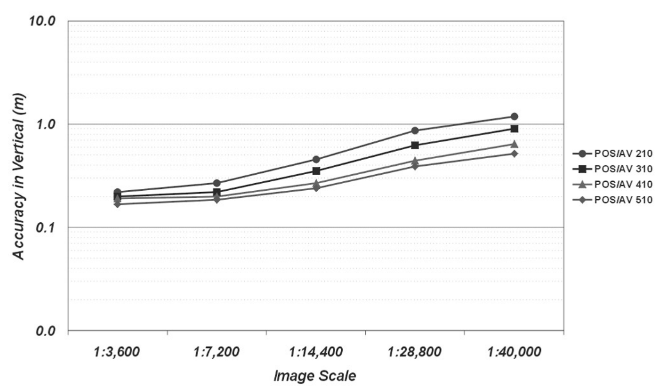

Figure 3: Ground object height accuracy - The Model Case

POS/AV™ data, the aerotriangulation step is bypassed. This results in immediate map production from the raw image data and post-processed POS/AV™ data. The result is a significant reduction in the time and cost for the mapping process. Using the standard error propagation techniques, the effect of GPS/IMU accuracy on ground positioning accuracy is studied. Figure 2 shows the ground point accuracy in horizontal (DRMS) for different POS/AV™ systems and for different image scales. Again, a 9" x 9" format camera equipped with a 6" lens and a 5 mm image precision is used in this simulation. To emphasize the exterior orientation accuracy effect on ground positioning accuracy, the errors due to camera calibration, and boresight calibration, are not considered in this study. Figure 3 shows the ground point height accuracy for different POS/AV™ systems and for different image scales.

In the stereo model case, the use of the entry-level POS/AV™ 210 and POS/AV™ 310 models would result in satisfying ground positioning accuracy for some applications. However, they may also produce a non-satisfactory y-parallax in the model that would make stereovision more difficult than if using a higher end system such as the POS/AV™ 410 or POS/AV™ 510. There is an ongoing study at Applanix, to provide the necessary knowledge for multi-sensor system design purposes.

As previously mentioned, some calibration issues have not been considered in the study presented herein. Two calibration parameters are important, namely, camera calibration and boresight calibration. The former is the determination of the camera interior geometry (principal point offsets and focal length) as well as lens distortion parameters, which are lab-calibrated. The latter is the orientation offset between the image coordinate system and the IMU coordinates system (which is done using a target ground field). Residual errors of these two calibration parameter sets should be kept to a minimum - usually by checking them on a regular basis, especially for the boresight.

Flight data was analyzed to confront the theoretical studies

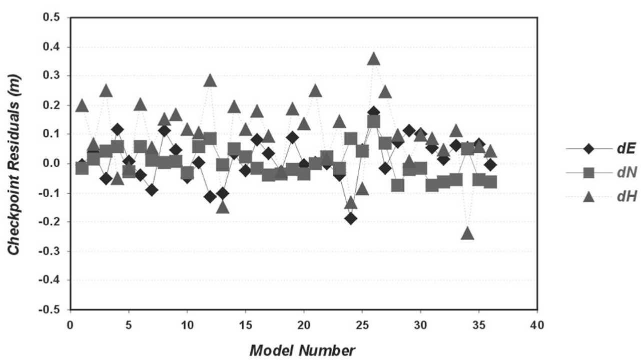

Figure 4: On-the-ground accuracy computed by comparing the coordinates derived from POS/AV 410 with the coordinates derived from land surveying

Error Analysis of Flight Data

A flight data set was analyzed to confirm the theoretical studies presented in the aforementioned sections. HJW of Oakland, California, provided the image data, the precisely surveyed GCPs, and the GPS-assisted aerotriangulation reference. The Applanix POS/AV™ 510 system was used in this flight together with a Zeiss RMK Top camera. A 1: 6000 medium scale, four-strip flight (flown in opposite direction with minimum banking angles to avoid GPS cycle slips) resulted in a block of 4 strips of 11 images each (a 44-image block). A total of 27 well-distributed GCPs were included in the block. Using the POSPac™ post-processing package, a smoothed best estimate of the trajectory was produced. Then, the interpolated camera exposure station positions and image orientation angles at the moment of exposure were extracted for each photo from the trajectory coordinatized in the US state plane mapping frame using the POSEO™ package.

Comparing the camera station

positions and image orientation produced independently by aerotriangulation and by the POS/AV™510, verified the POS/AV™ 510 system specifications listed in Table 1. The boresight was computed from processing the block without GCPs. The available GCPs were used as checkpoints. In this way the effect of boresight is canceled from the data, so that the practical error analysis could be compared to the theoretical one.

To determine the absolute accuracy of the direct georeferencing approach without GCPs, 36 models were processed individually using only one image point (with known ground coordinates) per model. In each model, the exterior orientation data derived by POS/AV™ were used along with the image point coordinates on both model photos, to determine the conjugate ground point position using the space intersection concept. The determined ground coordinates were then compared to the reference land-surveyed values. The checkpoint residuals are shown in Figure 4, while their statistics are depicted in Table 2. It is obvious from the checkpoint residuals that the accuracy of direct georeferencing using POS/AV™ 510 is similar to the theoretical accuracy presented in Figures 2 and 3 for the model case.

Min	-0.19	-0.08	-0.24
Max	0.18	0.14	0.36
Mean	***0.02***	***0.01***	***0.09***
Std. Dev.	0.07	0.05	0.13
RMS	**0.08**	**0.05**	**0.16**

Table 2: Statistics of checkpoint residuals

Conclusions

In this paper, a theoretical and a practical error analysis have been presented. The main objective of the theoretical error analysis is to present the POS/AV™ system accuracies in mapping terms. This has been done under variant conditions, for the different POS/AV™ systems, for various image scales and with dissimilar data acquisition/processing scenarios. The practical error analysis confirmed the validity of the theoretical one. The theoretical accuracy plots presented herein can be used for designing a multi-sensor system for data acquisition, such as a LIDAR/Digital camera system.

Acknowledgement

HJW, Oakland, California, is gratefully acknowledged for providing image data, precise GCP data, and AT reference for the analysis presented here.

Dr. Mohamed Mostafa obtained a Ph.D. in Geomatics Engineering from The University of Calgary in 1999. He is responsible for R&D in Airborne Applications at Applanix. He has worked extensively in the area of kinematic Geodesy and digital Photogrammetry.

Mr. Joseph Hutton obtained a Master of Applied Science in Aerospace Control from the University of Toronto in 1991. He has been with Applanix since 1991 as Product Manager if Airborne Applications. He has worked extensively in the area of inertial/GPS sensor integration for airborne survey and mapping applications

Mr. Erik Lithopoulos obtained a Master of Applied Science in Electrical Engineering from the University of Toronto in 1981. He is responsible for exploring and developing new markets for Applanix's GPS/Inertial products and technology. He has been with the company since 1991 as Manager of Business Development.