# IMPACT OF AN OPTIMIZED POSITION AND ORIENTATION SYSTEM ON THE FINAL ACCURACY OF LIDAR DATA

M. Boba [*a], V. Ussyshkin [a], M. Slater [a], M. Sitar [a], W. Szameitat [a]

[a]Optech Incorporated, 300 Interchange Way, Vaughan, Ontario, Canada L4K 5Z8,-
mariuszb@optech.ca

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## ABSTRACT:

Airborne (or mobile) laser scanning is used to generate high-accuracy data for various mapping and remote sensing applications. In recent studies by Optech Incorporated, Optech's Airborne Laser Terrain Mapper (ALTM) system has demonstrated the capability to achieve sub-centimetre accuracy in spatial data even under operating conditions including highly variable signal dynamic range. However, the best achievable data accuracy of a lidar system is very often critically influenced and limited by the performance of the integrated GPS/INS system.In this paper, we will examine the contribution of errors in geo-positioning data, generated by a GPS/INS system, to final lidar data accuracy by analyzing position and orientation (POS) data collected by Applanix's GPS/INS system and lidar data acquired by the ALTM system in various pre-determined flight conditions. POS data processed with two different versions of Applanix's POS post-processing software, and their impact on lidar data accuracy, are thoroughly compared and analyzed. Results show that recent advancements in the POS post-processing software, through the use of new, more robust algorithms for creating Smoothed Best Estimate Trajectories (SBET), can significantly improve POS data accuracy and may consequently enhance lidar data accuracy and reduce production costs. The virtual base station, another recent advancement in post-processing technology that can potentially be an economic alternative to user-installed GPS base stations, is also described in this paper.

## 1. INTRODUCTION

Over the past several years, lidar systems of increasingly competitive specifications have been introduced to the airborne surveying industry. With fast-paced technological advancement that pushes mechanical and electronic capabilities to the extreme, the source of error in lidar data accuracy and the impact of such errors are becoming more difficult to identify and estimate. Increasing laser point resolution multiplies the effects of data volume, data acquisition and processing, and associated errors. To continue to achieve the required data results, lidar manufacturers must rapidly adapt, optimize, and sustain the development of all aspects of a system's overall process flow.

This paper presents Optech's continued efforts at testing and integrating the latest technological advances to achieve the best possible results for lidar system users. Such efforts involve incorporating Applanix's latest release of the POSPac 5.0 software package into daily airborne lidar operations and identifying the benefits of the new software through first-hand observation. Despite the many capabilities of POSPac 5.0, this paper will focus only on the basic achievable data accuracy and a few other new features. In particular, the results and analysis of a comparison between POSPac 4.4 and POSPac 5.0 will be discussed and presented in this paper.

## 2. BACKGROUND

### 2.1 Role of POS in lidar data accuracy

The position and orientation system (Applanix POS AV or any other GPS/INS system) continually monitors and records the current time-stamped geo-referenced position and orientation of an aircraft, that is, the lidar platform. The POS system accomplishes this task by taking information from GPS satellites for the aircraft's position and from the internally mounted inertial measurement unit (IMU) for the aircraft's orientation in space. Any errors from the GPS and IMU data will ultimately affect the resulting POS data quality and thus may critically influence the quality and accuracy of lidar data.

### 2.2 Comparison: POSPac 4.4 vs. POSPac 5.0

To date, POSPac 4.4 has been the industry standard for GPS/INS systems. To minimize or mitigate POS errors, POSPac 4.4 users have been routinely required to consider several factors during mission pre-planning:

- Whether the location of the GPS base station is within 20 km of the survey site: Increasing this distance will increase errors
- The number of satellites consistently within view during the survey: Proper pre-planning will present optimal times to conduct a survey
- The requirement to maintain less than 20° rolls of the aircraft during turns: Rolling more than 20° reduces the number of satellites available
- The requirement to obtain optimal data that contains no GPS data gaps
- The requirement to collect optimal data that is free of synchronization errors.

After a mission, a Smoothed Best Estimate Trajectory (SBET) of the aircraft flight path and movement is derived from the POS data collected during the flight, using post-processing software. Applanix provides customers with such post-processing software through their POSPac series. The method in which this software calculates SBET files significantly affects the resulting POS and overall lidar data accuracy.

While POSPac 4.4 routinely requires the user to account for the factors listed above, the newly released POSPac 5.0 contains new algorithms and new methodology for handling and processing the POS data that potentially eliminate such pre-planning requirements. This paper will focus on several new capabilities implemented in POSPac 5.0, the first of which is the basic achievable data accuracy that this software can provide if the data is collected under normal flight condition and if the GPS data quality is deteriorated. Another recently implemented advance is a new capability that allows greater banking angles during a survey, which reduces survey time and ultimately makes the entire project more cost-efficient.

In this paper, we will compare the test results for the datasets collected from routinely planned flights to those collected in flights with steep banking angle trajectories. In either case, POS data are comparatively processed by the POSPac 4.4 and POSPac 5.0 software.

### 2.3 Expected accuracy of the Applanix POS AV-510 system

Integrated with Optech's ALTM/Gemini airborne lidar system, Applanix's POS AV system is a direct geo-referencing system that provides differential GPS measurements and orientation data. The Applanix POS system has four main components (Mostafa *et al.*, 2001b):

- Differential dual frequency GPS receiver (DGPS)
- Integrated inertial measurement unit (IMU)
- Computer system real-time control (PCS)
- Post-processing software suite, POSPac.

The heart of the system is the Integrated Inertial Navigation software, which is implemented in real time on the POS computer system (PCS), and in post-processing mission through the POSPac software. In this software, the GPS measurements are integrated with the IMU output to produce a blended position and orientation solution that retains the dynamic accuracy of the inertial navigation system and has the absolute accuracy of GPS (Toth *et al.*, 1998).

The absolute position accuracy of the POS AV smoothed position is characterized in the system performance specification sheet as 5-30 cm RMS. However, in our previous study on achievable POS accuracy, we showed that it is typically less than 5 cm for our typical test flight conditions (Ussyshkin *et al.*, 2006).

The orientation accuracy of the POS AV system is specified by the manufacturer as absolute and relative accuracy. Table 1 and Table 2 present the post-processed position and orientation accuracies of the Applanix POS AV-510 V5 system (Mostafa *et al.*, 2001a). With relative orientation accuracy being a function of the gyro random walk noise and the gyro drift, the absolute accuracy in the POS RMS error in roll, pitch, and heading angles is specified as noise and drift parameters.

| **Position (m)** | **Roll and Pitch (deg)** | **Heading (deg)** |
|---|---|---|
| 0.05-0.3 | 0.005 | 0.008 |

Table 1. Post-processed Applanix POS AV 510 V5 data, absolute accuracy

| | |
|---|---|
| **Noise (deg/sqrt(hr))** | < 0.01 |
| **Drift (deg/hr)** | 0.10 |

Table 2. Post-processed Applanix POS AV 510 V5 data, relative accuracy

## 3. CASE STUDY

### 3.1 Objective

The study presented in this paper had the following objectives:

Investigate the impact of POSPac 5.0 on position and orientation data accuracy in comparison with POSPac 4.4
Investigate the impact of POSPac 5.0 on the overall lidar data accuracy, both vertical and horizontal
Check the robustness of the new software tool through the processing of datasets with PDOP spikes
Compare the data quality and accuracy between datasets collected in flights with typical banking angle (less than 15°) and steep (35°- 45°) banking angles.

### 3.2 Methodology: Data collection and processing

The data selected for this study was collected from eight different missions on eight different days from eight different systems, while various flight regimes were used to check the impact of these alterations on the quality of the processed data. Six of the eight datasets were collected by Optech's ALTM Gemini systems, and two other datasets, by ALTM 3100 Enhanced Accuracy systems. To ensure successful missions, established procedures were rigorously followed. Established procedures included 5-minute static GPS logging at the beginning and end of a mission, a minimum of one GPS base station logging at the minimum frequency of 1 Hz, prior GPS PDOP (satellite constellation quality) planning, a base line maximum of 40 kilometres, a minimum of one hour of system on time, system configuration for specific target type, and flat or shallow turns. In standard test flights, the data were usually collected over four distinct targets with altitudes varying from 500 metres to over 3500 metres above ground level. Targets included flat water, segments of power lines, a large unobstructed flat surface (airport runway), and a building.

To explore the new capabilities of POSPac 5.0 for this study, we selected four datasets collected over runways at flying altitudes of about 1 km. Of the four remaining missions, two were flown with steep banking angle of more than 35º, and two collected data through a poor PDOP situation. The time spent on the steep-banking flights was reduced by a factor of 1.2 to 1.6. The amount of time saved depends on pilot training and what the operator is comfortable with; for example, an extreme banking angle of 45º over a long survey may be difficult for some to achieve. Data gathered in the four flights with steep banking angles or with poor PDOP was compared to data from the four standard test flights with banking angles of 15º or less. General flight characteristics are summarized in Table 3.

| **System & flight** | **Flight condition** | **System & flight** | **Flight condition** |
|---|---|---|---|
| System 15 _ 07008 | Standard test | System 10 _ 03808 | Steep banking |
| System 25 _ 06408 | Standard test | System 06 _ 06408 | Steep banking |
| System 01 _ 05208 | Standard test | System 02 _ 07708 | PDOP spike 10.4 |
| System 07 _ 22007 | Standard test | System 15 _ 07608 | PDOP spike 490 |

Table 3. Flight characteristics for the datasets used for position and orientation error comparison

### 3.3 Results: Comparing POS data accuracy

To address the objectives of this study, we performed comparative processing on the eight datasets described above using two different versions of the POS post-processing software: POSPac 4.4 and POSPac 5.0.

For comparison of position and orientation data accuracy, the following errors were calculated using both POSPac versions (Figure 1 to Figure 6):

- North position RMS error
- East position RMS error
- Elevation position RMS error
- Roll RMS error
- Pitch RMS error
- Heading RMS error.

Based on the results presented in Figure 1 to Figure 6, we calculated the average percentage of observed improvements in the position and orientation data:

**Observed improvements in position error**

| | |
|---|---|
| Northing Position: | Improved by 38.2% |
| Easting Position: | Improved by 49.0% |
| Height Position: | Improved by 39.9% |
| Overall Position: | Improved by: 42.3% |

**Observed improvements in roll, pitch, and heading**

| | |
|---|---|
| Roll: | Improved by 0.09% |
| Pitch: | Improved by 0.36% |
| Heading: | Improved by 2.87% |
| Overall Orientation: | Improved by 1.10% |

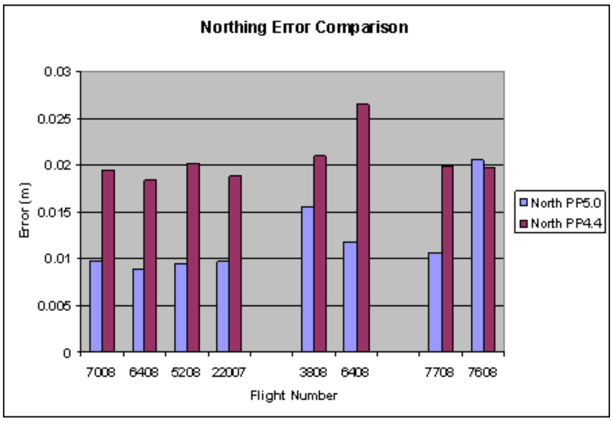

Figure 1. Comparison of northing error for POSPac 4.4 and POSPac 5.0

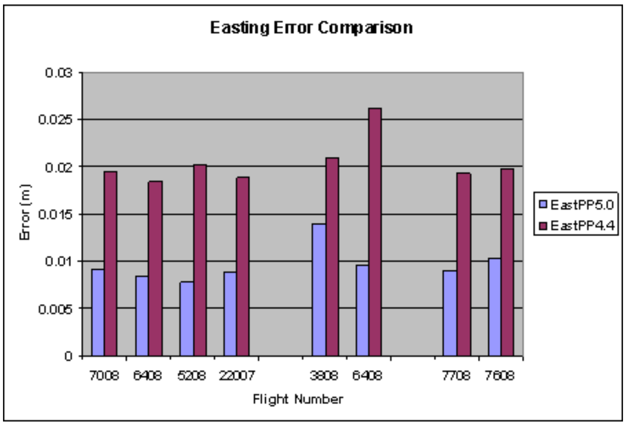

Figure 2. Comparison of easting error for POSPac 4.4 and POSPac 5.0

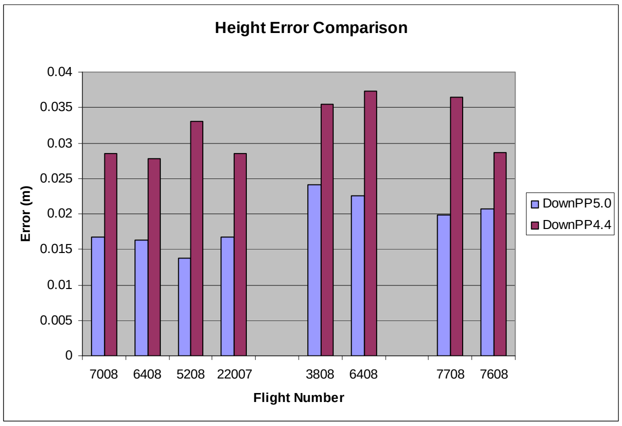

Figure 3. Comparison of elevation error for POSPac 4.4 and POSPac 5.0

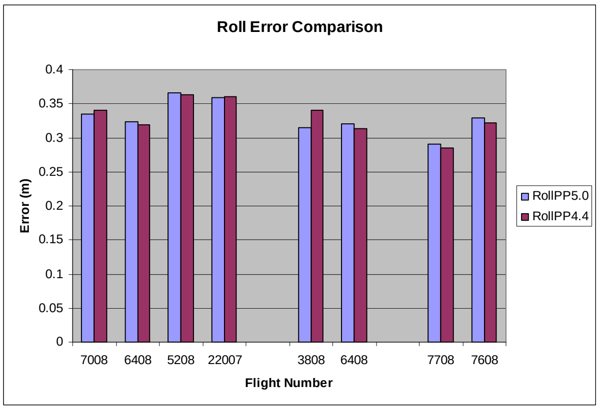

Figure 4. Comparison of roll angle error for POSPac 4.4 and POSPac 5.0

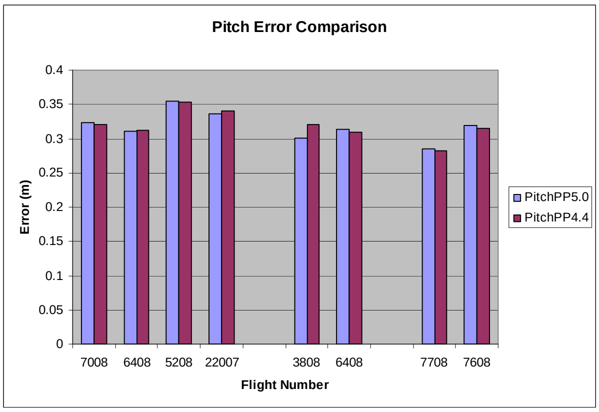

Figure 5. Comparison of pitch angle error for POSPac 4.4 and POSPac 5.0

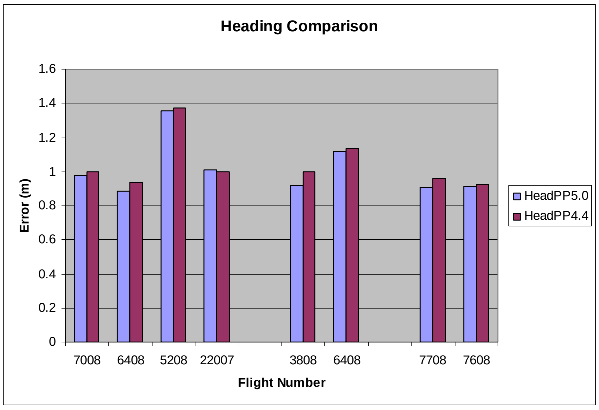

Figure 6. Comparison of heading error for POSPac 4.4 and POSPac 5.0

**Deriving lidar data accuracy**: To compare overall lidar data accuracy, we followed the methodology described in detail in our previous studies on vertical accuracy (Lane, 2005) and horizontal accuracy (Ussyshkin *et al.*, 2008). Since all data were collected over flat uniform terrain, the coupling between horizontal and vertical positional errors was minimized. The main characteristic of data accuracy, RMSE, was calculated by ACalib, Optech's automated software application that separates RMSE calculations in vertical and horizontal planes. The elevation accuracy characteristics, z-RMSE and z-STDEV, were calculated with respect to the airport runway surveyed by traditional methods with sub-centimetre accuracy. The horizontal accuracy characteristics, XY-RMSE and xy-STDEV, were obtained by calculating horizontal coordinates X and Y of a reference target, a man-made linear feature (building edges) densely surveyed by traditional methods with sub-centimetre accuracy as an absolute reference.

It is very important to note that ACalib calculates RMSE using imported flight data and imported control reference data with respect to the real points without applying spatial interpolation, smoothing, or any other data optimization algorithms to the XYZ data through internal or third-party software. Thus, this analysis, as well as the lidar data accuracy numbers in the ALTM specification sheet, represents the very basic accuracy of the lidar data points.

**Possible impact on processing efficiency and lidar data accuracy**: Figure 7 shows the observed improvement in the standard deviation of elevation data where POS data was processed by POSPac 5.0 versus POSPac 4.4.

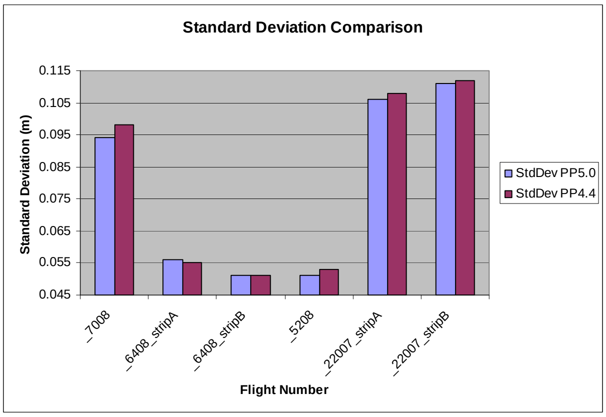

Figure 7. Comparison of z-STDEV calculated for datasets where POS data were processed by POSPac P5.0 versus POSPac 4.4

These results show that the standard deviation has improved in five out of six datasets; in the one case where accuracy was reduced, the reduction was only marginal. Further investigation is necessary to determine the source of this error. Overall improved efficiency in processing with POSPac 5.0 was observed in all cases in comparison to the time spent processing with POSPac 4.4. More detailed analysis of overall lidar data accuracy is to be continued in the near future.

Data from flights with PDOP spikes were handled by POSPac 5.0 much better than by POSPac 4.4. With POSPac 5.0, data accuracy was not compromised despite the reduced quality of GPS data. Data collected during the flight with high PDOP spikes showed reduction by 41.7% in overall positioning error when processed with POSPac 5.0.

## 4. THE VIRTUAL BASE STATION APPROACH

Although airborne lidar surveys are very cost-effective because of their high area coverage rate when compared to traditional technologies, cost effectiveness may often be limited by the short baseline restriction of a GPS base station. To eliminate such restrictions and increase coverage area, a dense infrastructure of multiple GPS reference stations must be established by the user, once again increasing production cost.

On the other hand, the virtual base station is a new feature of Applanix's POSPac 5.0 software that may enable the user to work around the current limitations of using high-accuracy carrier phase differential GNSS for airborne mapping. Provided by the integrated SmartBase$^{TM}$ software module and Applanix IN-Fusion technology$^{TM}$, the virtual base station draws upon existing publicly available base stations such as CORS (Continuously Operating Reference Stations) to create a virtual base station at the centre of the project survey area (Figure 8). Thus, it can potentially alleviate the costly requirement of setting up dedicated GPS base stations.

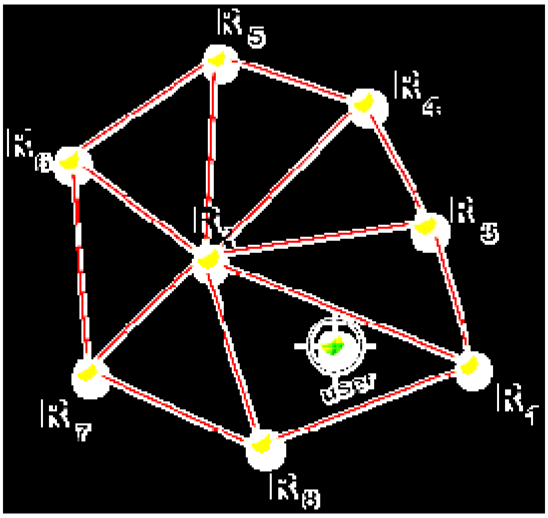

Figure 8. Schematic example of a base station network

In addition, the virtual base station approach has the following advantages:

- Distance to the nearest reference station can be extended well beyond 30 km
- Time to fix integer ambiguities is significantly reduced
- Overall reliability of fixing integer ambiguities is increased
- Survey cost is reduced by eliminating the need to set up dedicated base stations
- No special processing is required in the Real-Time Kinematic (RTK) engine, unlike the case of a centralized multi-base approach.

During the case study, the results of which are partially presented above, we also studied the effects of using a virtual base station compared to the current standard procedure, which requires operators to establish the user's own base station located in the general area of the survey but not necessarily at the centre of the survey. The preliminary results of this comparison (Boba *et al.*, 2008) allow us to expect that the virtual base station approach, without requiring a dedicated station located close to the survey area, can provide equally reliable POS data and lidar data accuracy. The extent to which this accuracy has improved is under continued investigation.

## 5. CONCLUSION

The new post-processing software tool POSPac Air 5.0 has demonstrated a number of advantages over its previous counterpart. During airborne data collection, the new technological solutions incorporated in POSPac 5.0 enabled the ALTM system to accommodate extreme banking angles without compromising data accuracy. Moreover, steep-banking flights decreased overall airborne lidar survey flight times by a factor of 1.2 to 1.6. Also, the improved workflow in POSPac 5.0 reduced processing time by a factor of 2 to 3, resulting in a shorter turnaround time from data collection to end-product deliverables. In handling degraded GPS data quality or PDOP spikes over the course of a survey, this new software tool is capable of maintaining reasonably stable data accuracy, turning data that would previously be unacceptable into data of acceptable quality. In short, POSPac Air 5.0 significantly increases the efficiency and robustness of airborne lidar data collection, improves the accuracy of position and orientation data, and potentially enhances overall lidar data accuracy.

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