# PERFORMANCE ANALYSIS OF INTEGRATED SENSOR ORIENTATION

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**ABSTRACT:**

Integrated multi-sensor systems, with their major progress in terms of sensor resolution, data rate and operational flexibility, have become a very attractive mapping tool over the last decade. In the aerial mapping application, for example, exterior orientation parameters (EO) for the imaging sensors are required. Using Differential Global Positioning System (DGPS) with Inertial Measurement Units (IMU), direct determination of the EO parameters can be obtained from the inertial/GPS navigation solution. This process is referred to as Direct Georeferencing (DG). Direct Georeferencing provides substantial benefits over the indirect determination method of estimating EO parameters from conventional aerial triangulation (AT) techniques using block of images with sufficient number of known control points. These benefits include the ability to map remote and inaccessible regions, and by replacing tie point measurements/matching and AT, significant cost-savings can be obtained for projects that do not require stereo models (such as projects with existing DEM, single image or strip/corridor mapping). The accuracy of Direct Georeferencing however, is limited by the accuracy attainable by the DGPS, IMU and any residual datum calibration errors. These can typically be as large as 10 cm RMSE, which is not sufficient for some large scale mapping applications. However, by combining the direct EO data in a traditional block adjustment, AT techniques can be used to remove the residual errors in the solution. This technique is known as Integrated Sensor Orientation (ISO). It has several advantages over traditional AT, primarily since; the stable geometry provided by direct EO can reduce the number of required GCP and tie-point to a minimum. At the same time, ISO provides an excellent means to QA/QC the EO from a DG system.

This paper will examine the factors that determine the system performance for ISO. In addition, an example will be given to illustrate the expected accuracy of an aerial mapping project using ISO under different qualities of DGPS/IMU data.

## 1. INTRODUCTION

During the recent revolution in aerial mapping, two major components have undergone rapid research and development. The first is the development of digital imaging sensor and the second is the determination of exterior orientation parameters (EO) using integrated navigation systems. Digital imaging sensors considerably reduce the data processing effort by eliminating the digitizing step. They also open the way towards new and flexible designs of the processing chain, making ample use of mathematical software tools readily available. In the form of digital frame cameras, they are inexpensive enough to make redundancy a major design tool. Precise integrated navigation systems, in the form of DGPS/IMU, has developed to a point where it can provide the solution of the exterior orientation problem without the use of ground control points (GPC) or block adjustment procedures. The also open the area for new mapping sensors, such as line scanners, SAR and LIDAR, where EO cannot be obtained using the traditional AT techniques. This paper will focus on the second component; the determination of EO parameters for full frame digital imagining sensors.

There are two basic approaches for computing the EO of an imaging sensor, they are:

- Determine the EO *directly* using suitable position and orientation sensors
- Determine the EO *in-directly* by extracting them from a block of images with a sufficient number of known ground control points.

The fist approach is known as Direct Georeferencing, most commonly achieved using an integrated DGPS/Inertial system. Such systems have been well studied and implemented commercially, such as Applanix's Position Orientation System for Airborne Vehicles (POS AV). The second approach uses AT, which relies on a network of tie points in a block of *frame* imagery with a sufficient number of known ground control points.

When the availability of ground control points is in question, such as in forest and desert areas or along a coastline, the ability of resolving the EO parameters *in-directly* is limited. Often these areas are also very important when an emergency response has to be taken. Such application requires fast orthophoto generation, and there is insufficient time and resource to extract EO parameters using traditional AT. In addition, some projects only require a single strip or single photo orientation, such as in the case where there is an existing Digital Elevation Model or DEM, Here the use of traditional AT to determine EO parameters is unpractical because it

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requires excessive ground control points and additional overlapping photos. Hence in many applications direct georeferencing is either the only practical solution, or the most cost effective solution.

In traditional, large area mapping projects however, there always exists a block of images with side and end-lap. Having such a block of images, it is possible to combine the advantages of both; direct georeferencing system and aerial triangulation by using assisted AT or Integrated Sensor Orientation (ISO). Integrated Sensor Orientation has been discussed widely in the last few years, most extensively by the OEEPE test in 2001 (Heipke et al, 2001). This paper will discuss the use of Integrated Sensor Orientation on blocks of images, and will investigate the level of accuracy that EO can be estimated from the direct georeferencing and ISO approaches.

## 2. DIRECT GEOREFERENCING

### 2.1 Benefits of Direct Georeferencing

Before investigating ISO an understanding of the benefits and capabilities of Direct Georeferencing is required. The OEEPE test results showed that the high-end direct georeferencing systems can achieve an accuracy of 5 – 20 cm in horizontal, and 10 – 25 cm in vertical for conventional aerial film cameras by using direct georeferencing without performing bundle adjustment (Cramer et al, 2000, Cramer 2001). This accuracy is good enough to perform mapping for reduced accuracy requirement applications such as fast orthophoto production (Kruck et al, 2001), and is ideal for projects such as corridor and single photo orientation where it is unpractical to collect numerous ground control points required for AT. An example of a high-end direct georeferencing system is an Applanix POS AV 510. Direct georeferencing also allows the generation of the so-called “fast orthomosaic”, by allowing automatic Digital Terrain Model (DTM) extraction and subsequent orthomosaic generation without AT and little operator intervention.

### 2.2 Direct Georeferencing for Large Scale Mapping Projects

The accuracy on the ground when using a direct georeferencing system is dependent upon the DGPS accuracy for position, and the IMU accuracy for orientation. The orientation error produces a position error on the ground as a function of flying height (or scale). With dual frequency differential processing and over short baselines (<20Km), DGPS accuracies are usually within 5 - 10 cm RMS. For traditional large scale mapping projects, the ground accuracy becomes dominated by the DGPS position error (Moatafa, 2001). Therefore, for large scale mapping (> 1:1000) projects requiring sub-centimeter accuracy, direct EO estimation from DG system will be marginal for film camera system. To overcome this problem, further research to improve DGPS accuracy is currently being underway. However, using aerial triangulation to improve the GPS accuracy has long been considered by researchers as an acceptable solution, and has been introduced in OEEPE tests as Integrated Sensor Orientation (ISO).

## 3. INTEGRATED SENSOR ORIENTATION

### 3.1 Benefits of Integrated Sensor Orientation

Assisted AT or ISO combines benefits from both Direct Georeferencing and traditional Aerial Triangulation especially *when the imagery is flown in a block configuration with sufficient overlap*. By using the EO parameters from direct georeferencing systems as initial approximate for aerial triangulation, only a limited number of tie points in the overlapping area are needed, and ground control points are only required to check for datum shifts and correct for systematic residual errors in the DGPS. Furthermore, using the direct EO in the tie-point matching process reduces the computational time and numbers of blunders, making the entire process truly automatic.

**3.1.1 Using ISO as a Quality Assurance/Control Tool for Direct Georeferencing**: One of the key assumptions in Direct Georeferencing is that the calibrated system parameters are constant over the mission. These system parameters include GPS/IMU lever arm offset, boresight mis-alignment and the camera’s internal geometry. The first can be estimated by Kalman filtering during DGPS/INS post-processing, and the last two can be calibrated terrestrially and/or via a flight calibration. For quality assurance/control purpose, one could run a terrestrial and flight calibration before every direct georeferencing mission to check the values of the boresight and camera calibration parameters. However, this is not practical due to the time and cost these processes can take. Instead ISO can be used to run a cost efficient Quality Assurance (QA) / Quality Control (QC) procedure using actual photos from part of the mission (if flown in a block), or from a small QA/QC block flown before or after the mission. By running Integrated Sensor Orientation, boresight values can be refined and self-calibration can be performed for the camera. In addition, if one or two ground control points are available in the projects area, datum shifts in the mapping frame can also be determined. Notice that the QA/QC procedure does *not* refine the EO parameters; it is only used to refine the calibration parameters.

**3.1.2 Reduce System Cost**: Except for large scale engineering projects which are limited by the accuracy of DGPS, a high end direct georeferencing system is sufficiently accurate to perform all types of projects: corridor mapping, single photo orientation, mapping in remote areas, or large area mapping. This total solution provides the flexibility of being able to do any project without the limitation of requiring to fly in a block configuration. However, it useful to understand if a lower accuracy direct georeferencing system, and hence lower cost system, can achieve similar accuracy to a high end system when ISO is used. Since ISO requires a block of images, it has most benefit to the user who only flies projects that contain a block of images.

**3.1.3 Achieving Maximum Accuracy**: While a direct georeferencing system allows direct determination of exterior orientation parameters with high accuracy and reliability, there exist some projects which require sub-centimetre accuracy. Such projects will require the direct EO parameters to be refined before they can be used for further mapping procedure.

The following sections will investigate these benefits of ISO using actual flight test data from a high accuracy direct georeferencing system, plus simulated data from a lower accuracy system. The analysis will focus on the effects of different direct EO accuracy only, and will not look at the contributions of system calibration errors.

## 4. TEST DATA PREPARATION

The ISO investigation was performed using real-flight test data from a high-end Applanix POS AV 510, and a simulated data from a less-accurate POS AV 310 for the same flight. To simulate the performance of the less accurate system, the IMU data from the POS AV 510 was degraded using statistical error models based upon Applanix Corporation's proprietary simulations tools. This method allows a direct comparison between two datasets for the same operating conditions: identical ground coverage, number of photos and flight trajectories.

### 4.1 Reference System Description

A RMK Top film camera data equipped with Applanix POS AV 510 system was selected for the test. The data parameters are listed in Table 1. The published accuracy specifications for the POS AV 510 system are presented in Table 2.

| | |
|---|---|
| Location | University of Kentucky, United States |
| # of Strips | 4 |
| # Photo / Strip | 8 |
| Flying Height (m) | 900 AGL |
| Scale | 1 : 6000 |
| Photo Scan Resolution (um) | 15 |
| Forward / Side Overlap | 60% / 20% |
| Mapping Projection | StatePlane Zone 1601 |
| Datum, Height | WGS84, Orthometric |
| # of Check Points | 18 |
| DGPS/INS System | Applanix POS AV 510 |

Table 1. Dataset Information

| Post-Processed Accuracy | Absolute Value |
|---|---|
| Position (m) | 0.05 – 0.3 |
| Roll & Pitch (deg) | 0.005 |
| True Heading (deg) | 0.008 |
| Noise (deg/sqrt(hr)) | 0.02 |
| IMU Drift (deg/hr) | 0.1 |

Table 2. Specification of POS AV 510 System

To simulate as much as possible a perfect system calibration, any residual boresight errors were removed using the Quality Control/Quality Assurance procedure documented by Applanix Corporation with its POSCal$^{TM}$ (IMU/Camera Calibration Software). The original camera calibration from U.S.G.S. is used and assumed to be correct.

### 4.2 Less Accurate Direct Georeferencing Data Simulation

To investigate the performance of ISO using a lower accuracy DGPS/IMU system compared to a high accuracy POS AV 510 system, the POS AV 510 data was degraded to simulate the performance of a POS AV 310 system. A POS AV 310 system was chosen since it achieves approximately 3 times lower orientation performance than the 510 system. Table 3 presents the published specifications of the POS AV 310.

| Post-Processed Accuracy | Absolute Value |
|---|---|
| Position (m) | 0.05 – 0.3 |
| Roll & Pitch (deg) | 0.013 |
| True Heading (deg) | 0.035 |
| Noise (deg/sqrt(hr)) | 0.15 |
| IMU Drift (deg/hr) | 0.5 |

Table 3. Specification of POS AV 310 System

The primary difference in system performance between POS AV 310 and POS AV 510 system is the orientation accuracy, which is directly a function of the IMU. Therefore, the raw 510 IMU data was brought into a simulation tool and purposefully degraded. The simulation tool superimposes additional random noise, bias, scale factor, and mis-alignment errors on both the accelerometer and gyro data. After running through the tool, the degraded IMU data was then post-processed with the original unaltered GPS data using the Applanix's POSPac$^{TM}$ software (Post-Processing Package). The simulated POS AV 310 solution was then differenced with the original POS AV 510 solution and the RMS differences in both position and attitude were computed. To statistically validate the simulation, a Monte Carlo Analysis was performed and ensemble RMS on both position and attitude difference was determined. Table 4 presents the theoretical RMS value for the differences between a POS AV 510 and 310 based upon their specifications. If the simulation is valid, the ensemble RMS of the differences should approach these values. The ensemble RMS differences results from the Monte Carlos analysis are presented in Table 5.

| Navigation Parameters | Ideal RMS Difference |
|---|---|
| Position (m) | 0 |
| Roll & Pitch (arc minute) | 0.72 |
| Heading (arc minute) | 2.04 |

Table 4. Ideal RMS Difference

| Navigation Parameters | Ensemble RMS Difference |
|---|---|
| Northing (cm) | 2.85 |
| Easting (cm) | 2.40 |
| Vertical (cm) | 1.57 |
| Roll (arc minute) | 0.74 |
| Pitch (arc minute) | 0.71 |
| Heading (arc minute) | 2.08 |

Table 5. Ensemble RMS difference of the Simulated 310 Data

From Table 5, the ensemble RMS difference is very close to the ideal RMS difference given in Table 4, which validates the simulation. However, in order to further validate the simulation, each Monte Carlo trial was analysed using the EO Analysis tool from the Z/I ImageStation Automatic Triangulation software (ISAT).

### 4.3 Direct Georeferencing EO Analysis Test

This test is performed to validate the simulated data in addition to the ensemble RMS difference obtained from the Monte Carlo Analysis. The EO Analysis evaluates the quality of exterior orientation parameters by comparing the given coordinates of check points with the intersection of the rays of these points as project it on the overlapping photo pairs by the EO Data. Table 6 lists the EO analysis result for the POS AV 510 data, while, Table 7 lists the ensemble RMS from the Monte Carlo Analysis of the degraded data. Notice that the EO Analysis Results presents the statistics of check point residuals for all check points used in the EO Analysis.

| | Check Point Residuals | | | Parallax |
|---|---|---|---|---|
| | dX (m) | dY (m) | dZ (m) | (um) |
| Min | -0.26 | -0.29 | -0.12 | 3.2 |
| Max | 0.09 | 0.09 | 0.30 | 30.4 |
| Mean | -0.05 | -0.07 | 0.12 | 12.7 |
| RMS | 0.10 | 0.13 | 0.15 | 14.8 |

Table 6. EO Analysis Results for the POS AV 510 Data

| | Check Point Residuals | | | Parallax |
|---|---|---|---|---|
| Ensemble | dX (m) | dY (m) | dZ (m) | (um) |
| RMS | 0.24 | 0.40 | 0.28 | 63.5 |

Table 7. EO Analysis Results for the Simulated POS AV 310 Data (Monte Carlo Analysis)

It is clear form Table 6 that the ground accuracy of a POS AV 510 system is very accurate. The 3D position is < 15 cm and the parallax is less than 1 pixel. In contrast, the simulated 310 data shows a higher check point RMS, and the parallax is quite significant, which is expected for a lower accuracy system. To validate these results, they were compared with the error budget analysis performed by Applanix Corporation (Mostafa et al, 2001). In this report, the horizontal ground position accuracy of a POS AV 310 was about 2 times poorer than that of 510 system, while the vertical accuracy is about 1.5 times poorer (both for the mapping scale of 1:6000). Although the actual differences are slightly higher than the theoretical values, the error budget analysis is ideal and assumes an error free system other than the error in the direct EO. In the simulated 310 data, the check point RMS include errors such as residual boresight error, check point accuracy and measurement noise. Hence the ensemble RMS derived by the Monte Carlo Analysis can be considered as representative of the performance of a true POS AV 310 system. The performance of the simulated 310 data is summarized in Table 8, which has very similar performance as a POS AV 310 system specifications listed previously in Table 3.

| Post-Processed Accuracy | Relative Value |
|---|---|
| Position (m) | 0.06 – 0.3 |
| Roll (deg) | 0.013 |
| Pitch (deg) | 0.013 |
| True Heading (deg) | 0.036 |

Table 8. Specification of the Simulated 310 Data

### 4.4 Quality Assurance / Control of Simulated Data

A reference boresight calibration has been performed on the POS AV 510 data after the Quality Control / Assurance procedure. Since the simulated 310 data shared the same hardware as the 510 data, and only the raw IMU data has been degraded, the boresight angle of the simulated 310 should be the same as reference. But, in order to understand the behaviour of lower accuracy system, a QC/QA procedure will be performed in the simulated data. Since the Monte Carlo Analysis creates 10 sets of simulated data, only one set of data will be picked for the rest of the tests in this paper. The selection of such dataset is based on the ensemble RMS difference and the ensemble check point RMS from EO analysis.

**4.4.1 Direct Georeferencing EO Analysis Test on QA/QC' Simulated POS AV 310 Data**: After removal of the boresight mis-alignment error in the simulated 310 data, the refined EO parameters is brought to ISAT and another EO analysis was performed. This is mainly to validate the simulated data with the error budget analysis by comparing the EO analysis against the POS AV 510 system. The result is shown in Table 9.

| | Check Point Residuals | | | Parallax |
|---|---|---|---|---|
| | dX (m) | dY (m) | dZ (m) | (um) |
| Min | -0.67 | -0.47 | -0.39 | 1.1 |
| Max | 0.63 | 0.50 | 0.80 | 85.6 |
| Mean | -0.06 | -0.03 | 0.13 | 38.6 |
| RMS | 0.22 | 0.27 | 0.27 | 46.2 |

Table 9. Results of EO Analysis on QA/QC'd Simulated POS AV 310 Data

From Table 9, and by comparison to Table 7, it can be seen that horizontal accuracy has been improved with the boresight mis-alignment error being minimized. Such improvement has brought the simulated data closer to the ideal ratio difference in the error budget analysis. This again validates the simulated data that can represent the POS AV 310 performance.

## 5. INTEGRATED SENSOR ORIENTATION TEST

After validating the simulated data and proper QA/QC procedure, further test can be carried on to analysis the performance of low cost GPS/INS system using Integrated Sensor Orientation technique. In addition to the simulated data, the ISO test will also focus on applying assisted triangulation on POS AV 510 data, which is a high performance DGPS/INS system. Accuracy improvement of such data will be reviewed and compared with the performance when ISO is applied on the simulated data. The assisted-triangulation is performed in ISAT after automatic tie point collection is performed. Notice that no ground control point is used in the assisted-triangulation.

### 5.1 ISO Test on Simulated Data

The test will begin with the simulated data. The test will focus on the assisted triangulation result and compare the result with the reference data, the POS AV 510 Direct Georeferencing data, as shown in Table 6. Starting with using 1 strip of data, Figure 1 presents the check point RMS when different point per von grubber (PPVG) values are used.

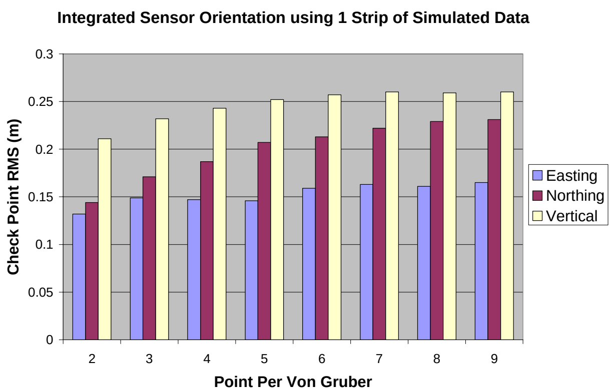


Figure 1. ISO Test Results when using 1 Strip of Simulated POS AV 310 Data

Figure 1 clearly indicate that assisted triangulation using 1 strip of simulated data can improve the check point RMS, but it is unable to reach a similar performance of the POS AV 510 Direct Georeferencing data, especially in the vertical. However it is still acceptable for some lower accuracy requirement projects. Another conclusion that can be drawn from Figure 1 is that an increase in PPVG value can not improve the result of the Integrated Sensor Orientation. Thus, using more tie points in assisted triangulation will actually degrade the performance. To investigate this further, additional strips (2, 3 and 4) were used in the test. Figure 2 presents the ISO test when using 2 strips of simulated POS AV 310 data.

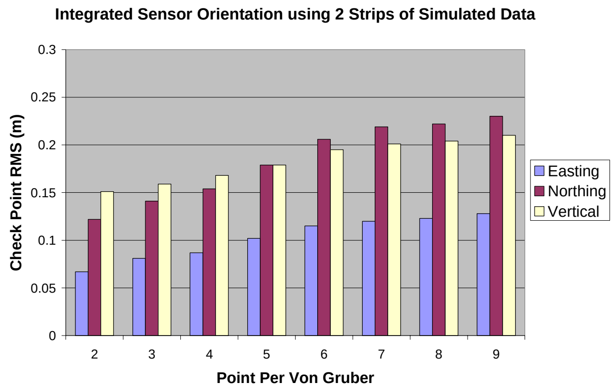


Figure 2. ISO Test Result when using 2 Strips of Simulated POS AV 310 Data

From the above Figure, further improvement in both horizontal and vertical has been achieved. In fact the final accuracy achieved by running the Integrated Sensor Orientation on only 2 strips of the simulated data is similar to the Direct Georeferencing performance of the POS AV 510 system (Table 6.0), and increasing the number of strips in the adjustment does not significantly improve the results. Therefore the minimum requirement for assisted triangulation is only 2 strips. Regardless of the number of strips however, the more tie point that are used, in the assisted AT, the poorer the results are. Further investigation on this behaviour will be given later.

### 5.2 ISO Testing on POS AV 510 Data

Running Integrated Sensor Orientation on the POS AV 510 system will provide an insight into how much an improvement that can be achieved when using a high end Direct Georeferencing system. The test configuration is the same as to run the test using the simulated data. Starting with using 1 strip of the POS AV 510 data, the result is shown in Figure 3.

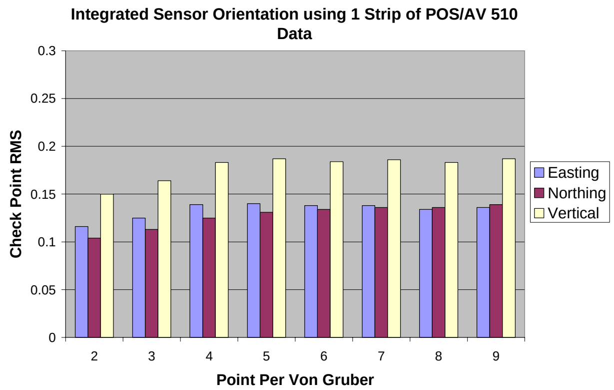


Figure 3. ISO Test Result when using 1 Strip of POS AV 510 Data

From Figure 3, it can be seen that running assisted triangulation using 1 strip of POS AV 510 data did not make any improvement in the achievable final 3D position accuracy (Table 6). Such triangulation in fact *degrades* the performance because of the lack of information in resolving the Omega angle. Solving this will requires a lot of ground control point in the strips, which is not practical for many applications. This explains why a high end DG system is required for single pass corridor flights, for example. In comparison, Figure 4 presents the result when 2 strips of POS AV 510 data is used.

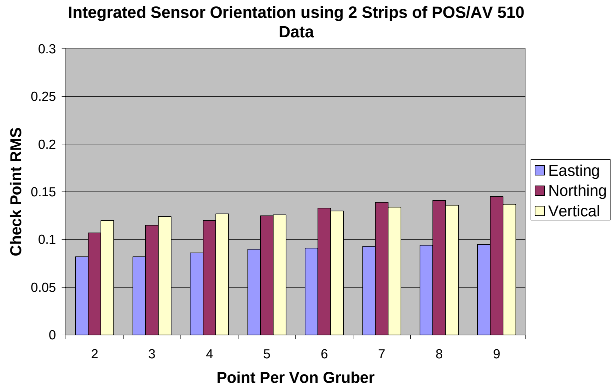


Figure 4. ISO test result using 2 Strips of POS AV 510 Data

Even these results clearly indicates that only slight improvement can be achieved when running assisted triangulation on the POS AV 510 data. This can be explained by the fact that having a scale of 1:6000 and using a high end Direct Georeferencing system, this data set already has highly accurate 3D position accuracy, and it is especially well calibrated system, with boresight and datum shift error being minimized. Therefore, by applying Integrated Sensor Orientation on this dataset, insignificant improvement will be made. Notice that the test is performed without any ground control points. In a case where datum shift might exists in the project, running Integrated Sensor Orientation with 1-2 ground control points would improve the result.

Similar to the simulated data, the ISO test on POS AV 510 data shows a trend that by including more automatic collected tie points into the assisted triangulation, the results are slightly degraded. This can be explained by the fact that by using more tie point in assisted triangulation will create more noise in the adjustment, as there is no guarantee that the tie point collection module can maintain the same level of accuracy all the time. This has been proved when reviewing the parallax for the tie and the check points through EO Analysis using the assisted triangulated EO derived parameters. Table 10 lists the parallax result from the ISO test on 4 strips of simulated data.

| PPVG Value | Point Parallax (um) | | Model Parallax (um) | |
|---|---|---|---|---|
| | Max Value | RMS | Max Value | RMS |
| 2 | 23.2 | 5.2 | 7.7 | 4.3 |
| 4 | 27.3 | 5.5 | 7.5 | 4.4 |
| 6 | 28.3 | 5.4 | 6.3 | 4.2 |
| 8 | 29.5 | 5.4 | 6 | 4.2 |

Table 10. Parallax Result on EO Analysis after running Assisted-Triangulation on 4 Strips of Simulated POS AV 310 Data

From Table 10, it can be seen that model parallax converges as PPVG value increases; this is expected because more tie points allows the adjustment to refine the EO such that tie point residuals can be minimized. However it is also clear the value of parallax is increasing while RMS is kept stable. Thus, higher residual tie points are obtained when PPVG value increases, and the solution is degraded. *Thus, for Integrated Sensor Orientation, using less tie points is better*.

## 6. CONCLUSIONS

This paper reviews several uses of Integrated Sensor Orientation. First, it can be used in conjunction with direct georeferencing as a Quality Assurance / Control Tool to calibrate boresight mis-alignment or any datum shift of the DGPS/INS data. Second, it can be used with a high end direct georeferencing system to achieve better accuracy in large scale mapping projects, where the DGPS position error is not always sufficient to meet the desired ground accuracy. Finally, when flown in a block configuration with a minimum of 2 strips, ISO can be used in conjunction with a lower accuracy system to achieve similar performance of a high end system, all *without the use of any ground control point* and hence lower the cost of direct georeferencing system,

From the EO analysis presented in this paper, it is easy to understand why a less accurate DGPS/INS system is not suitable for high-accuracy direct georeferencing applications: the ground error of a POS AV 310 is 2 times larger than the POS AV 510, and parallax can be as large as 4 pixels RMS versus 1 pixel for the POS AV 510. However, if a block of photos with at least 2 strips is *always* available in the projects, the advantages of Integrated Sensor Orientation can be exploited with the lower accuracy system. Using an advanced automatic tie point collection module such as ISAT by Z/I, highly accurate tie point can be collected instantly using the seeded EO from the DGPS/INS system. Then, without the help of any ground control, assisted triangulation can be performed on the collected tie point to refine the EO data to achieve similar level of accuracy as those obtained form a high end DGPS/INS system. Given the cost difference between the lower accuracy POS AV 310 and high end POS AV510 (about a factor of 1.5 to 2), Integrated Sensor Orientation seems to make sense; however this is only true *if the additional processing time required to do the tie-point matching and ISO can be minimized.* If inefficient software and workflow are used in the ISO process, the cost savings in the system is not realized The results presented above show that the processing time can be optimized with proper use of EO in the tie point matching software (as is done in ISAT), and in the tie point collection strategy. Results from both POS AV 510 and simulated POS AV 310 data shows that having more tie points will in fact degrade the assisted triangulation results. This is due to the fact that more noise from collected tie points is included into the assisted triangulation as number of tie point used increases. This is an important conclusion: only *the minimum* of tie points must be used to perform Integrated Sensor Orientation, which in turn also helps reduce the processing time.

Although the results presented provide a good insight into the use of Integrated Sensor Orientation, further work is required to be performed before any firm conclusions can be made. This includes conducting tests using an actual POS AV 310 system on a film camera

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