# ISAT Direct Exterior Orientation QA/QC Strategy Using POS Data

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## ABSTRACT

This paper describes the quality assurance and quality control (QA/QC) tools currently planned and under implementation in the Z/I ImageStation Automatic Triangulation (ISAT) product for imagery acquired by an aerial camera and Applanix POS/AV$^{TM}$ navigation system. First, a description of the ISAT product with its user interface with the Applanix POSEO package is given. Then, a description on using the EO data in mapping applications is presented. Instead of using the full capabilities of an automatic aerial triangulation, the QA/QC procedure is designed to lessen the amount of work needed to check the quality of the GPS, IMU, and GCP data using different schemes, such as performing a statistical analysis on image/object space intersection using digital images and the GPS/IMU data. Numerical results of using the ISAT's QA/QC strategies on the OEEPE data set are also presented.

## 1. INTRODUCTION

In an aerial triangulation process, the image coordinates of all tie, control, and check points appearing on all photographs are measured and then a least squares bundle adjustment is performed. This process ultimately provides exterior orientation parameters for all photographs and three-dimensional object coordinates for all measured image points. Until recently, all photo measurement was done manually. Furthermore, the block adjustment was a completely separate step (Madani, 1996).

New advances in digital photogrammetry permit automatic tie point extraction using image-matching techniques to automate the point transfer and the point mensuration procedures. Automatic Aerial Triangulation (AAT) is already in production rather successfully. The AAT solution has reached the accuracy level of a conventional aerial triangulation. It has been proven, that the AAT solution is much more economical than a conventional one. However, like any new products, AAT systems need to be improved to fit increasing demands of the users (Schenk, 1996).

In 1997, the European Organization for Experimental Photogrammetric Research (OEEPE) and the International Society for Photogrammetry and Remote Sensing (ISPRS) initiated a test of different existing commercial and experimental AAT systems to study the stability of the block geometry, the accuracy of the tie points and the derived orientation parameters, and the limitations of the products (Heipke, Eder, 1998). Results of the OEEPE-ISPRS test showed that the existing AAT systems have some limitations; therefore, any new AAT approach must incorporate following features:

- Embedding reliable and efficient mechanisms to detect and eliminate blunders in the tie point measurements
- Increasing the number of multi-ray points and ensuring an even point distribution to guarantee a stable block geometry
- Applying combined approaches of image matching to improve both the computation time and the accuracy of point measurement
- Including special techniques to process poorly textured areas by increasing the success rate of automation
- Including an intuitive and instructive interface for the operators who must intercede in the case of automation failure
- Keeping the tuneable procedure control parameters to the very minimum or, even, to achieve an autonomous operation.

GPS photogrammetry has already helped to improve the accuracy/performance of the conventional aerial triangulation process. Directly derived exterior orientation parameters using combined GPS and high-performance INS systems offer the possibility of eliminating conventional aerial triangulation in the long run. Consequently, these changes significantly impact all the steps of the data reduction and measurement processes. For example, the possible elimination of a complete aerial triangulation process will result in substantial savings while increasing the need for more sophisticated quality control procedures.

The early experiments with GPS/INS-derived exterior orientation data were related to analytical plotters. The objective was to set up models very quickly for map compilation without the usual orientation process. Now that GPS/INS technology has evolved, interest is already shifted toward softcopy systems too.

The use of GPS and INS systems in photogrammetry can, on the one hand, support the existing aerial triangulation (AT) packages by providing highly accurate exterior orientation parameters from the beginning and improve the quality and reliability of the orientation results. It is also possible to perform camera and/or self-calibration and simplify the point measurement process of automatic aerotriangulation by reducing the number and necessary tie points and the distribution of the tie point areas. On the other hand, AAT solutions operate as a method where camera, GPS, IMU and ground control observation are checked for consistency, gross errors, and statistical properties.

Cross flights introduced into many GPS supported AT projects served just for the determination of additional drift parameters caused by various factors. Using the INS-derived image orientation angles as additional orientation information helps to reduce and eliminate the necessary cross flights for aerial triangulation projects. This has resulted in an important cost reduction for many GPS supported AT projects.

So the question is raised if the aerial triangulation (AT) will soon become obsolete? The determination of the exterior orientation parameters by the GPS/INS systems has been significantly improved. However, these parameters are not still accurate enough to be used directly in large scale and engineering photogrammetry applications (Greening, et al, 2000). There are still good reasons to keep AT or AAT:

- The self-calibrating block adjustment serves to compensate for systematic image errors based on available tie points;
- The condition of ray intersections which underlies the AT as well as the image plotting serves to be the geometric constraint for compensation of both random and systematic errors in an image. Errors in the parameters of interior orientation can also be compensated for by the exterior orientation. Thus, the orientation parameters determined by an AT could best fit the image for further processing;
- IMU (Inertial Measurement Unit) system alignment based on ground control points (GCP) is essential for the GPS/INS application;
- GPS-derived camera exposure station coordinates are not always available at the precision required for mapping.
- Geodetic consideration regarding underlying coordinate system and datum bias.

Nevertheless, the GPS/INS technology benefits the AT and thus the next generation of AAT systems. Therefore, they should be used in a combined block adjustment.

Facing these new technical challenges Z/I Imaging, as a photogrammetry system provider, has recently upgraded and enhanced its existing AAT system (Madani, 2001).

This paper describes the main features, the major functionality, and the workflow of the newly developed ImageStation Automatic Triangulation (ISAT) product. A number of QC/QA methods are designed to let the operators very quickly evaluate the quality of the directly derived EO parameters (GPS/IMU data) for a particular application and scale. Numerical results of using the ISAT's QA/QC methods on the OEEPE data set are also presented.

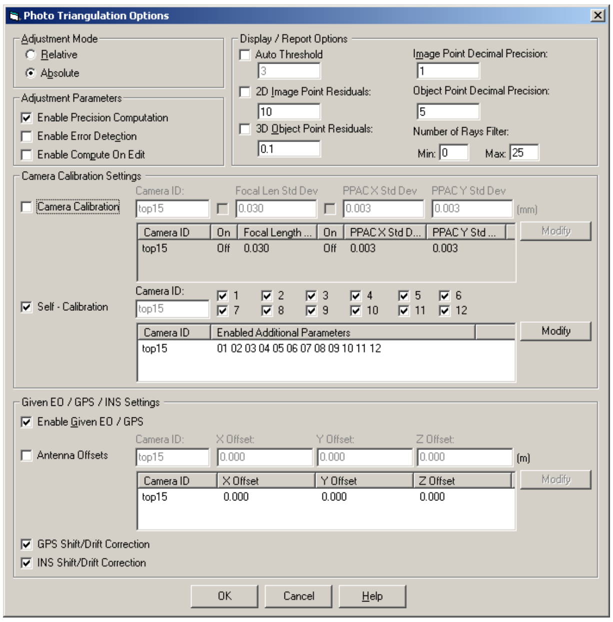
## 2. ISAT MAIN FEATURES

Special emphasis has been given to the ISAT's user friendliness, reliability, and integration. Some of the main features of the ISAT product are (Madani, et al, 2001):

- Comprehensive and flexible photogrammetric project set-up
- Footprint selection, which lets the user graphically select footprints of photos/models/blocks
- Unlimited project size through division into sub-blocks
- Several Import/Export translators and raster utility options for photogrammetric data
- Automatic and interactive image manipulation and enhancement tools
- Automatic and manual Interior Orientation and Relative Orientation
- Single Photo Resection and Absolute Orientation
- Multiphoto measurement in monoscopic and/or stereoscopic modes
- Semi-automatic and manual tie point measurement in a Multiphoto environment
- Real-time panning for image movement in mono and stereo and dynamic coordinate system read out
- Well-connected image block by high-quality multi-ray points
- High performance image matching by using efficient algorithms and by restricting tie points to a reasonable limit
- Automatic weak-area detection and interactive handling mechanism
- Comprehensive bundle block adjustment utilizing (see Figure 1)
    - Relative ("free network") and Absolute bundle block adjustments
    - Robust estimators for blunder detection
    - GPS/INS data processing – It is tightly integrated with the Applanix POSEO system (see Figure 2)
    - Camera and self calibration capability
    - Variance-covariance (precision) estimation
- Display of vector residuals (image/object) to facilitate the error analysis process
- Several easy-to-use editing tools for image measurements
- Merging and editing sub-blocks to allow users to merge multiple blocks into a new block
- On-line bundle block adjustment with and without control points (relative and absolute modes)

## 3. GRAPHICAL ERROR ANALYSIS

ISAT provides graphical displays and error analysis tools to facilitate detection of blunders, weak areas, and problem photos after an AAT run and a bundle adjustment. These graphical displays consist primarily of vector residual displays that interact with the operator:



Adjustment Mode
○ Relative
● Absolute

Adjustment Parameters
☑ Enable Precision Computation
☐ Enable Error Detection
☐ Enable Compute On Edit

Display / Report Options
☐ Auto Threshold: 3
☐ 2D Image Point Residuals: 10
☐ 3D Object Point Residuals: 0.1
Image Point Decimal Precision: 1
Object Point Decimal Precision: 5
Number of Rays Filter: Min: 0 Max: 25

Camera Calibration Settings
☐ Camera Calibration — Camera ID: top15; ☐ Focal Len Std Dev: 0.030; ☐ PPAC X Std Dev: 0.003; PPAC Y Std Dev: 0.003 (mm)

| Camera ID | On | Focal Length ... | On | PPAC X Std D... | PPAC Y Std ... |
|---|---|---|---|---|---|
| top15 | Off | 0.030 | Off | 0.003 | 0.003 |

☑ Self - Calibration — Camera ID: top15
☑ 1 ☑ 2 ☑ 3 ☑ 4 ☑ 5 ☑ 6
☑ 7 ☑ 8 ☑ 9 ☑ 10 ☑ 11 ☑ 12

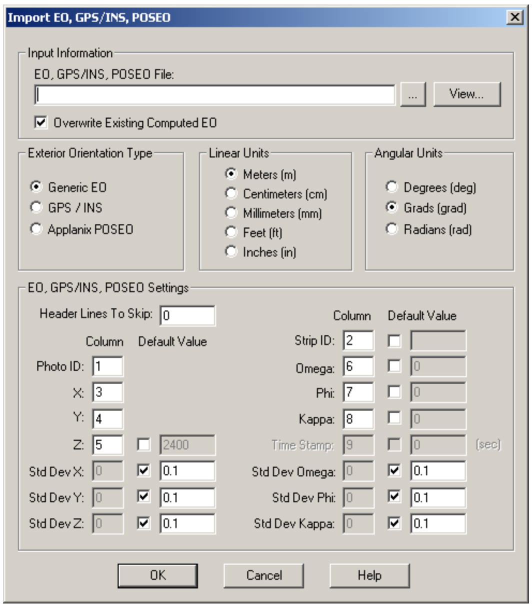
| Camera ID | Enabled Additional Parameters |
|---|---|
| top15 | 01 02 03 04 05 06 07 08 09 10 11 12 |

Given EO / GPS / INS Settings
☑ Enable Given EO / GPS
☐ Antenna Offsets — Camera ID: top15; X Offset: 0.000; Y Offset: 0.000; Z Offset: 0.000 (m)

| Camera ID | X Offset | Y Offset | Z Offset |
|---|---|---|---|
| top15 | 0.000 | 0.000 | 0.000 |

☑ GPS Shift/Drift Correction
☑ INS Shift/Drift Correction

Figure 1. Bundle Block Adjustment Options



Input Information
EO, GPS/INS, POSEO File:
☑ Overwrite Existing Computed EO

Exterior Orientation Type
● Generic EO
○ GPS / INS
○ Applanix POSEO

Linear Units
● Meters (m)
○ Centimeters (cm)
○ Millimeters (mm)
○ Feet (ft)
○ Inches (in)

Angular Units
○ Degrees (deg)
● Grads (grad)
○ Radians (rad)

EO, GPS/INS, POSEO Settings
Header Lines To Skip: 0

|  | Column | Default Value |
|---|---|---|
| Photo ID: | 1 |  |
| X: | 3 |  |
| Y: | 4 |  |
| Z: | 5 | ☐ 2400 |
| Std Dev X: | 0 | ☑ 0.1 |
| Std Dev Y: | 0 | ☑ 0.1 |
| Std Dev Z: | 0 | ☑ 0.1 |

|  | Column | Default Value |
|---|---|---|
| Strip ID: | 2 | ☐ |
| Omega: | 6 | ☐ 0 |
| Phi: | 7 | ☐ 0 |
| Kappa: | 8 | ☐ 0 |
| Time Stamp: | 9 | ☐ 0 (sec) |
| Std Dev Omega: | 0 | ☑ 0.1 |
| Std Dev Phi: | 0 | ☑ 0.1 |
| Std Dev Kappa: | 0 | ☑ 0.1 |

Figure 2. Import EO, GPS/INS, POSEO

- Display vector residuals of control, check points, and photo positions
- Display vector residuals of image points per photo and per block
- Display image systematic errors using significant additional parameters derived by self calibration
- Allow the user to threshold the display to show only vector residuals above a known value or based on number of rays
- Allow the user to scale the magnitude of the vector residuals on the graphical display
- Display dynamic readouts of point ids, XY, and Z residuals
- Display dynamic readouts of photo ids when photo footprints are displayed along with the vector residuals
- Allow the user to perform all the basic viewing commands on the vector residual (Zoom In, Zoom Out, Fit, Pan)

- The numerical point list and the graphical vector residual display will interact. Selecting a point in the list will highlight the point in the graphic display. Selecting a vector in the graphic view will select that point in the listview and scroll to it in the view
- Double-clicking a vector residual will do a window centre about that point and select it in the listview
- Double-clicking a vector residual will drive the image views to that point in the Multiphoto environment
- Error analysis dialog provides pre-filter values to limit the number of points displayed in the list and in the vector display
- Display photo position residuals residual vector between computed and given EO parameters

## 4. WORKFLOW DESCRIPTION

In general, the user will typically perform following steps, shown in Figure 3, when running ISAT.

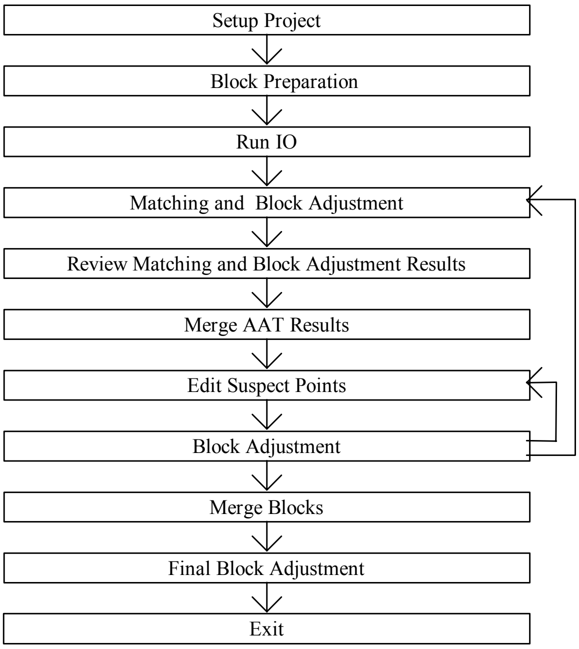


Figure 3: ISAT Workflow

The user sets up a project. This will involve setting up project, strip and camera parameters and optionally entering control coordinates (but not necessarily measuring the control before the automatic tie point generation), GPS/INS data (exterior orientation parameters), if available, and other specific project and users defined parameters.

The user may wish to run image matching and block adjustment on only part of the project. ISAT allows the user to create a sub-block for AAT processing. This will be via a graphical interface that shows flight lines with photo centers, from which the user can select the photos to include in the block. ISAT allows the user to use photo and block footprints to create, edit, delete, and measure blocks. Creating, editing, and merging blocks can be done in a variety of ways: graphically by selecting photo footprints or existing block footprint, by selecting photos or existing blocks from list, or by any combination of these. Later in the workflow the user will be able to tie overlapping blocks together (Merge Blocks).

After performing automatic interior orientation, ISAT's image-matching module generates optimized and well-distributed tie points for the selected images. At the end of image matching, an internal bundle adjustment is called to check the quality of the extracted tie points and to remove blunders using a robust estimator technique.

The user is able to review all the weak areas where insufficient matched points were not generated by AAT. The AAT dialog includes a graphical view for these weak areas. The user may manually measure additional points in those images that do not have strong connections with the overlapping images. After the user has measured new points in weak areas, he will need to run a block adjustment to incorporate these changes into the solution. The user is able to review all the statistics from the image matching and block adjustment steps. In addition to the usual block adjustment statistics, this includes statistics from the point matching procedures. The statistical information also includes a graphical view (vector residuals) of point statistics on the Photo, Object, and Point tabs of the dialog. From this, the user determines whether the adjustment succeeded or failed.

If multiple sub-blocks are run, their measurements may be merged into "master block". This command allows the user to merge multiple blocks into a single block. This allows the user to work with blocks of a manageable size to perform the sub-block matching and block adjustments and ultimately merges all blocks together into a single large block. A final post processing bundle block adjustment is then performed without any further matching.

## 5. HOW THE POS/AV$^{TM}$ SYSTEM WORKS

The key component of the POS/AV$^{TM}$ system is the Integrated Inertial Navigation (IIN) software. This software runs in real-time on the POS Computer System (PCS) and in post-processing in the POSPac$^{TM}$ software suite, and performs the integration of the inertial data from the IMU with the data from the GPS receiver. The functional architecture of the software is given in Figure 4. For details see, Mostafa and Hutton (2001b). For details on GPS-aided inertial positioning and attitude determination, see Scherzinger (1997), Schwarz et al (1993), Hutton et al (1998) and Reid et al (1998). The software consists of the following components:

- Strapdown inertial navigator
- Kalman filter
- Closed-loop error controller
- Smoother (POSPac$^{TM}$ only)
- Feed forward error controller (POSPac$^{TM}$ only)
- In-flight Alignment

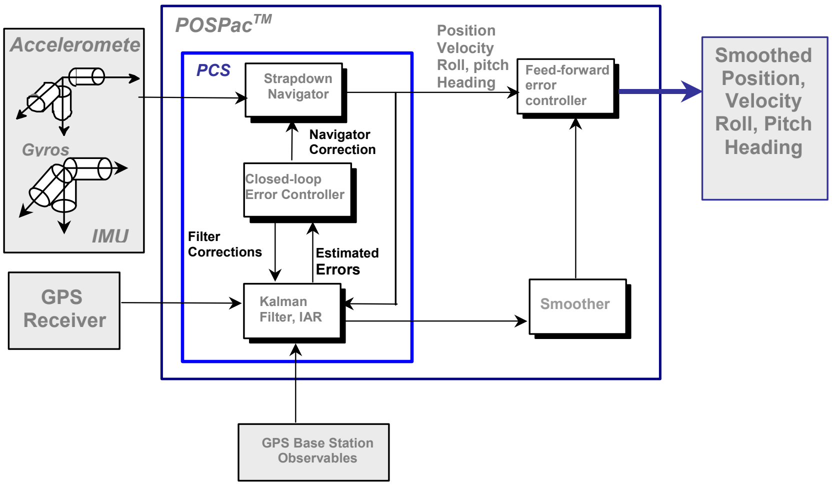


Figure 4. Functional Architecture of the POS/AV System

## 6. DIRECT EXTERIOR ORIENTATION DETERMINATION

As shown in Figure 5, Photo positioning and attitude data is processed using POSPAC$^{TM}$ in an Earth-Centred Earth-Fixed (ECEF) frame of reference, typically WGS84, to produce a smoothed best-estimated trajectory (SBET). Then POSEO$^{TM}$ is used to interpolate the position and attitude information at each image exposure time, calibrate the boresight, and determine the exterior orientation parameters in a local mapping frame of reference that is required for map compilation. Figure 6 shows POSEO$^{TM}$ interface, while Figure 7 shows the POSEO$^{TM}$ data output options, which includes a special format option for Z/I Imaging ISAT (see also Figure 2).

## 7. DIRECT EO QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

The quality of the exterior orientation data generated by a POS/AV system becomes directly apparent when it is combined with the imaging system data. On the other hand, the mapping process using directly measured exterior orientation parameters is different from the traditional one (c.f., Jacobsen, 2001). Therefore, generally, the entire process of quality control becomes a process of managing each step in the data acquisition and post-mission processing phases to achieve a consistent and reliable quality assessment. Consequently, the process of quality control of directly measured exterior orientation data by POS/AV is categorized into two main categories which are done sequentially, namely, quality control using navigation data and quality control using navigation and imaging data simultaneously by ISAT. In the following, each of these will be discussed in some detail.

### 7.1 QA/QC Using Navigation Data

Proper mission planning goes a long way towards obtaining repeatable results. Once the mission begins, the POS/AV system must be monitored frequently for GPS dropouts or other data acquisition failures. A severe failure such as loss of GPS data for an extended time period may be grounds for aborting the mission. Once the aircraft has landed, the recorded data should be checked for outages and other immediate indications of bad or missing data. This allows the mission to be re-flown possibly the same day.

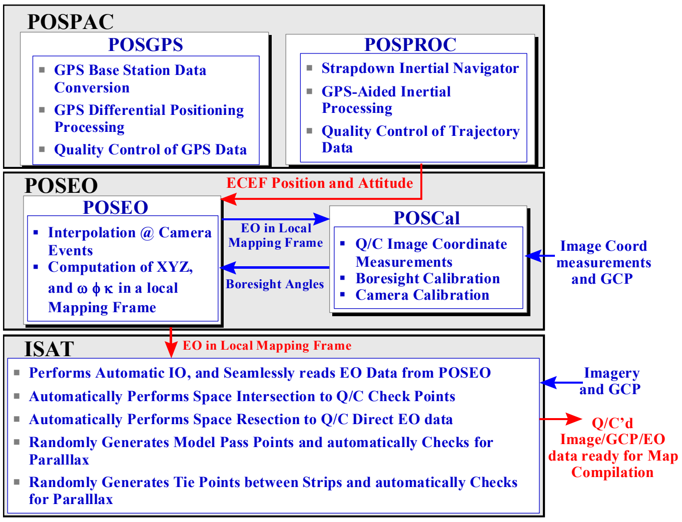
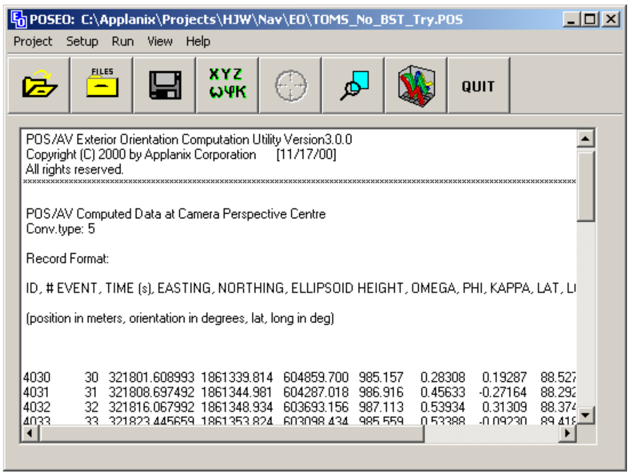
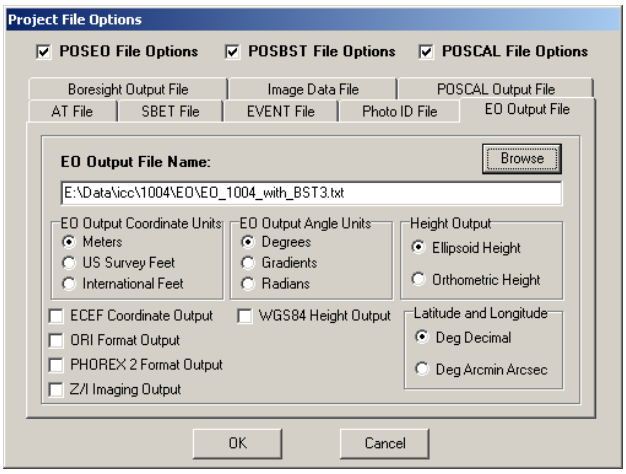


Figure 5. General Processing and Q/C Data Flow



```
POS/AV Exterior Orientation Computation Utility Version3.0.0
Copyright (C) 2000 by Applanix Corporation      [11/17/00]
All rights reserved.
*****************************************************************************************************************


POS/AV Computed Data at Camera Perspective Centre
Conv.type: 5

Record Format:

ID, # EVENT, TIME (s), EASTING, NORTHING, ELLIPSOID HEIGHT, OMEGA, PHI, KAPPA, LAT, L

(position in meters, orientation in degrees, lat, long in deg)



4030      30  321801.608993 1861339.814  604859.700  985.157   0.28308   0.19287  88.527
4031      31  321808.697492 1861344.981  604287.018  986.916   0.45633  -0.27164  88.292
4032      32  321816.067992 1861348.934  603693.156  987.113   0.53934   0.31309  88.374
4033      33  321823.445659 1861353.824  603098.434  985.559   0.53388  -0.09230  89.41
```



☑ POSEO File Options ☑ POSBST File Options ☑ POSCAL File Options

EO Output File Name: E:\Data\icc\1004\EO\EO_1004_with_BST3.txt

EO Output Coordinate Units: ● Meters ○ US Survey Feet ○ International Feet

EO Output Angle Units: ● Degrees ○ Gradients ○ Radians

Height Output: ● Ellipsoid Height ○ Orthometric Height

☐ ECEF Coordinate Output
☐ WGS84 Height Output
☐ ORI Format Output
☐ PHOREX 2 Format Output
☐ Z/I Imaging Output

Latitude and Longitude: ● Deg Decimal ○ Deg Arcmin Arcsec

Figure 6. POSEO™ Software Interface

Figure 7. POSEO™ Output File Including Z/I Imaging Output

If the recorded data are seemed to be acceptable, then the data are handed over to post-mission processing. POSPAC™ has several quality assessment indicators. The most basic of these are the inertial-GPS residuals. These are the corrected differences between the inertial and GPS position solutions at each GPS epoch, and indicate the consistency between the solutions. The residuals will appear to be random in a successful inertial-GPS integration, indicating that the integration process has removed all sources of bias errors in the data. The processing software will typically perform a statistical analysis on the residuals and report a simple quality indicator to the user (c.f., Scherzinger, 1997).

### *7.1.1 Mission Planning*

The absolute accuracy of the blended position of a GPS/inertial system is limited to the absolute positional accuracy of the GPS. Hence it is important that proper mission planning be conducted to ensure that the best possible GPS accuracy is achieved. The best GPS positioning accuracy (5 to 15 cm) is achieved using carrier phase DGPS techniques. To obtain this accuracy, a mission must be planned to provide conditions for reliable ambiguity resolution throughout the mission. Error sources that can prevent maintenance or re-fixing of integer ambiguities include ionospheric delays, multipath, and poor satellite geometry. Even if the correct ambiguities are found and maintained for the entire mission, these error sources can, if not properly managed, still degrade the accuracy of the solution. Airborne mission planning should therefore include the following components.

### *7.1.2 Static Data Collection*

A mission should begin and end with a static data acquisition each lasting a minimum of 5 minutes. The static data allows the GPS post-processing software uses the constant position information to obtain the correct initial and final ambiguities with high probability of success.

### *7.1.3 Minimizing Multipath*

Multipath reflections can be a major source of position error and cause for integer ambiguity resolution failures. All base receivers should use antenna choke rings or ground planes to attenuate low elevation signals, and should be mounted at least 100 m away or above all reflecting surfaces.

### *7.1.4 Limiting Baseline Separation*

If the mission requires the 2-10 centimetre position accuracy that a kinematic ambiguity resolution solution can provide, then the maximum baseline separation must be limited to 10 to 50 km depending on the diurnal and seasonal solar activity. This allows the GPS processing software to recover fixed integer ambiguities following cycle slips or loss of phase lock at any time during the mission. For missions with flight lines greater than 100 kilometres, multiple base receivers must be used to ensure the maximum separation between the aircraft and any base receiver is less than 50 kilometres. Currently, POSGPS$^{TM}$ processing software package processes data from multiple base receivers to produce an optimal combined solution (c.f., Mostafa and Hutton, 2001a).

### *7.1.5 Planning for PDOP*

The mission should be planned during times of good satellite coverage so that PDOP is 3 or less throughout the mission. At the time of writing, the GPS constellation comprises 29 satellites, which provides for a poor PDOP relatively infrequently. A simple satellite prediction software tool provides the information needed to plan for best PDOP. Figure 10 shows the double differenced PDOP during an aerial photography flight. Flight missions should be planned to avoid such spike centred at GPS time of 390,000 for about 10 minutes, although the PDOP is less than three (< √9). In that case, the pilot could have been instructed to fly away from the mapping area during that ten-minute period of time to avoid the resulting inconsistent GPS accuracy.

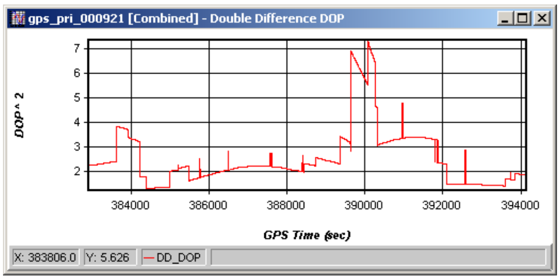


Figure 8. GPS DD-PDOP During an Aerial Photography Flight

### *7.1.6 Inertial Navigator Alignment*

POS/AV can align itself while stationary or in motion. In fact, the in-air alignment is accelerated and the quality of the alignment improved if the aircraft performs an accelerating manoeuvre such as take-off or a turn. An in-air alignment requires about 3 minutes of nominally straight and level flight to allow POS/AV to compute an initial roll and pitch, followed by a series of turns to align the heading. Thereafter POS/AV improves its alignment with every manoeuvre. A typical zigzag survey pattern provides the manoeuvres required by POS/AV to maintain a high quality alignment. Figure 9 shows a frequently changed velocity of an aircraft due to manoeuvres and Figure 10 shows the total acceleration due to such manoeuvres.

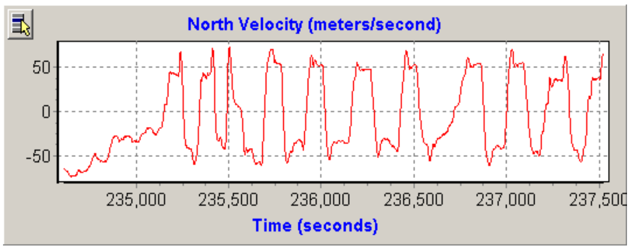


Figure 9. North Velocity Frequent Changes During Manoeuvres

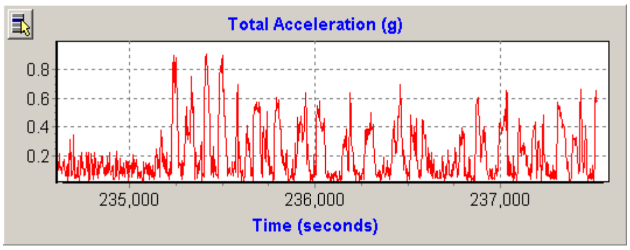


Figure 10. Total Acceleration Frequent Changes During Maneuvers

### 7.2 QA/QC Using Navigation/Imagery Data – The DLC$^{TM}$ Concept

Detection, Location, and Correction (DLC$^{TM}$) is the concept behind the direct EO QA/QC process in ISAT. POS (GPS/IMU) data, project aerial imagery, and available GCP (control/check points) are simultaneously used to efficiently perform DLC. By ‘detection’ we mean, to automatically detect whether or not there is a perfect fit (according to some predefined threshold) between the directly derived EO parameters, the images, and the available GCP. If there is no perfect fit then ‘Location’ is performed, where ISAT tries to automatically identify the location and possibly the reason for erroneous EO parameters. ‘Correction’ is where the erroneous (inaccurate for some reason) EO parameters are corrected.

Figure 11 shows the DLC workflow in the ISAT product. Typically, the raw GPS and IMU data are processed in POSGPS, POSProc, and POSEO, where the derived trajectory parameters are translated into camera exposure station coordinates and image orientation angles with respect to a local mapping frame. ISAT then reads the information where it first performs the automatic interior orientation (IO) then checks in the POSEO output file whether or not the EO parameters have high standard deviations. If the standard deviations are higher than what is suitable for the project at hand, then it will issue a warning to the operator that the EO data should be improved by reprocessing the GPS data.

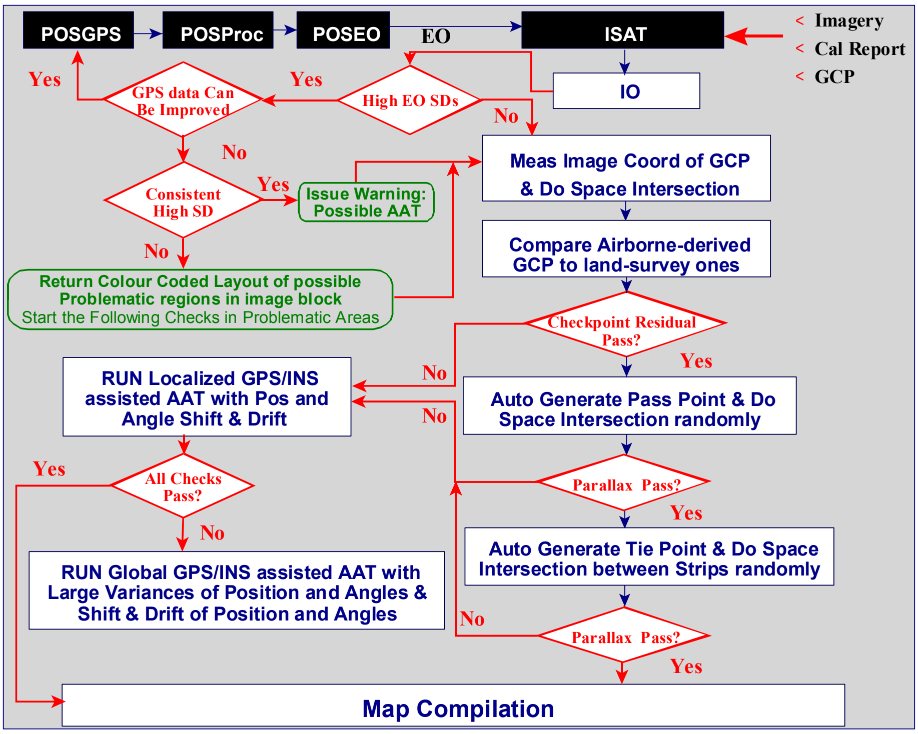


Figure 11. Detection, Location, and Correction Concept (DLC$^{TM}$)

The operator is then becomes responsible to improve the GPS data processing quality, then run the data through POSProc and POSEO, respectively and import the improved X, Y, and Z and ω, φ, and κ, data in ISAT. If the GPS data cannot be improved, ISAT will check whether the standard deviations are consistently too high for the project at hand or not. If the data is consistently high, then ISAT will issue a warning that there might be a possibility to use a ISAT's automatic aerotriangulation engine to its fullest. If the EO standard deviations are not consistently high, ISAT will then return a colour-coded footprint of the project layout to show and distinguish the problematic areas in the project. Then, ISAT will run the following checks on those areas of the project that have high EO standard deviation.

1. ISAT will manually or semi-automatically measure image coordinates of the ground points (check points). The user can then revisit the ground point locations manually to make sure that they are precisely located on the imagery.
2. ISAT will then perform the space intersection using the given EO data and the image coordinates of all available checkpoints.
3. ISAT will compare the computed checkpoint coordinates with the given values. If the checkpoint residual test passes, ISAT will issue a statement that all checkpoint residuals are within the required accuracy.
4. If checkpoint residual testing did not pass, ISAT will issue a warning and let the user decide on running a local automatic aerial triangulation using GPS/INS assisted triangulation concept applying the shift and drift parameters.
5. If the checkpoint residual test passed, ISAT will automatically generate model pass points and performs space intersection to check analytically if model pass points have any parallax. If parallax is evident, the user is given an option to eliminate the parallax by using the localized GPS/INS-assisted AAT option.
6. If the pass point test passed, ISAT will move on to automatically generate tie points between strips. These points will be used again in the space intersection mode to determine whether or not there is remaining parallax between the image strips. If no parallax is discovered, then the software will issue a statement that no errors are found in this project and the EO data can then be used directly in the map compilation mode.
7. If parallax is evident, the user is given an option to eliminate the parallax by using the localized GPS/INS-assisted AAT option.
8. Each time there is any need to run a localized GPS/INS-assisted AAT, all the check listed in steps 1 to 7 will be checked again. If all those checks are passed, ISAT will issue a statement that all errors found in this project are fixed and the EO data can then be used directly in the map compilation mode.

If any of the check failed, the user will be given the option to run the entire project using ISAT's GPS/INS-assisted automatic aerotriangulation engine, to fix the remaining problems.

## 8. EXAMPLES OF NUMERICAL RESULTS

### 8.1 Test Data Description

The 1:10,000 photo scale data of the Fredrikstad, Norway test field, flown by Fotonor AS using a wide angle Leica RC30 camera equipped by an Ashtech GPS receiver and the Applanix POS/DG system, was used in this study (for detail, see Heipke, et al, 2000). This test field is about 5 x 6 km$^2$ and has 51 well distributed signalized control points with the accuracy of about 0.01 cm. The control point coordinates and raw and refined direct EO parameters were given in UTM/EuroRef80 coordinate system with ellipsoidal heights. This data set is comprised of five parallel strips and two cross strips and 13 control points (Figure 12).

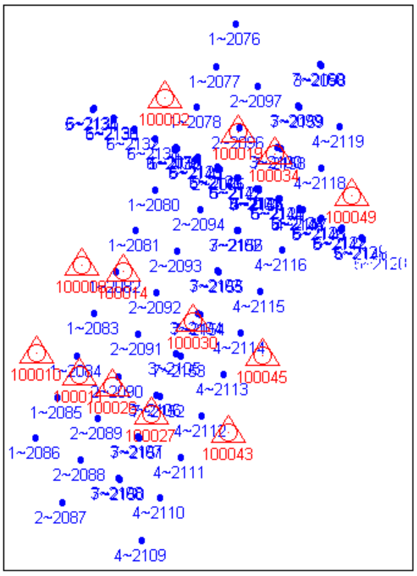


Figure 12: Calibration Flight in Southern Norway, Image Scale 1:10,000

Applanix POSEO data, uncorrected and corrected for boresight (misalignment between camera IMU coordinate frames) computed in the phase one of the OEEPE study, along with the provided control points coordinates and the image coordinates of all 85 photos were used to investigate the results obtained by the ISAT bundle block adjustment and its DLC capability for analyzing the quality of the derived EO parameters.

For quality control purposes, error detection is experimented using the 1:10,000 block of photos. The purpose of examining this scenario is to investigate the following:

1. Can the boresight errors be detected using the shift and drift parameters in ISAT?
2. What is the effect of block geometry in detecting any boresight errors?
3. What is the effect of boresight errors on camera exposure station coordinates and orientation angles if a block is adjusted using the boresight-corrupted exterior orientation data ignoring boresight errors

Therefore, POSEO was used to produce an exterior orientation file for the block with boresight angles set to zeros. This is done this way to simulate a scenario where the calibrated boresight values were not input to the software by mistake. Then, the corrupted exterior orientation data files were read in ISAT. The entire block was triangulated using the original photo coordinate measurements, the boresight-corrupted exterior orientation data and all available ground control points. The whole 85 photos were used in this scenario. Angular shift and drift option was used to answer the first question on the previous list. The standard deviations of the camera exposure station coordinates and orientation angles were set to the POS system specifications, namely 0.1 m for each component of the camera exposure station coordinates and 0.005º, 0.005º, 0.008º for image $\omega$, $\varphi$, and $\kappa$, respectively. This implies that the intentional boresight error is not accounted for in the standard deviations of image orientation angles. This is done on purpose in order to simulate a production environment.

The computed shift angles were very close to the boresight angles. In other words, ISAT was capable of absorbing almost all the intentional boresight errors by the angular shift parameters. The computed exterior orientation parameters were then compared to those given by POSEO. Figures 13, 14, and 15 show the difference in camera position in X, Y, and Z components, respectively. In these Figures the difference is shown twice, once in red diamonds where no angular shift and drift were used, and the other time in blue squares where the angular shift and drift option was used. It is clear that any boresight error will affect the camera exposure station coordinates if the data is triangulated neglecting the boresight error without properly choosing the necessary math model required to recover the boresight error. . Figures 16, 17, and 18 show the differences in image orientation angles in ω, φ, and κ, respectively. Note that the same observation can be made in Figures 16-18, too Although it is evident that ISAT will absorb the boresight errors, it will issue a warning that there is possible calibration issue and the operator should go back and double-check entering the correct boresight values in POSEO. Tables 1 and 2 show the statistics of the differences presented in Figures 16 - 18. Although it is evident that ISAT will absorb the boresight errors, it will issue a warning that there is possible calibration issue and the operator should go back and double-check entering the correct the boresight values in the POSEO.

Table 1. Statistics of Image Orientation Differences from POSEO Using ISAT With INS Shift and Drift Option to recover a Boresight-Corrupted Data - Full Block 1: 10,000 photo Scale

| | Omega (deg) | Phi (deg) | Kappa (deg) |
|---|---|---|---|
| Minimum | -0.019 | -0.006 | -0.020 |
| Maximum | 0.003 | 0.013 | 0.011 |
| Mean | -0.008 | 0.003 | -0.002 |
| Std Dev | 0.005 | 0.005 | 0.005 |
| **RMS** | **0.010** | **0.005** | **0.006** |

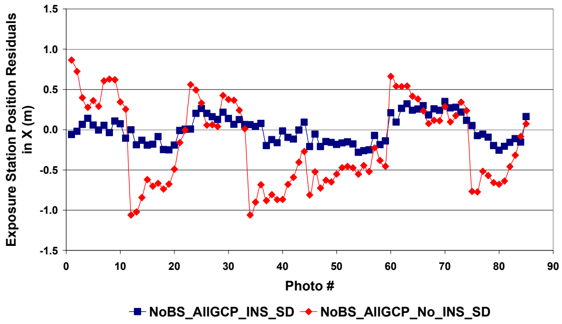


Figure 13. Exposure Station Position Residuals (X Component) Using ISAT With and Without INS Shift and Drift Option to Recover a Boresight-Corrupted Data - Full Block 1: 10,000 photo Scale

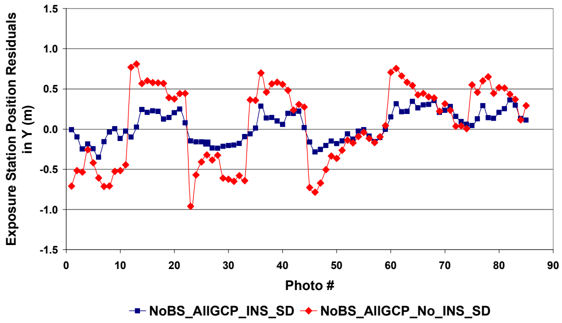


Figure 14. Exposure Station Position Residuals (Y Component) Using ISAT With and Without INS Shift and Drift Option to Recover a Boresight-Corrupted Data - Full Block 1: 10,000 photo Scale

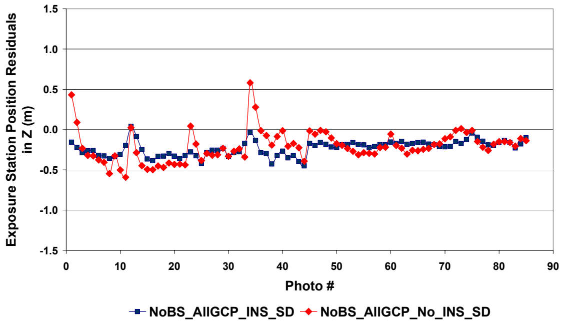


Table 2. Statistics of Image Orientation Differences from POSEO Using ISAT Without INS Shift and Drift Option to recover a Boresight-Corrupted Data - Full Block 1: 10,000 photo Scale

| | Omega (deg) | Phi (deg) | Kappa (deg) |
|---|---|---|---|
| Minimum | -0.042 | -0.028 | -0.041 |
| Maximum | 0.037 | 0.027 | 0.005 |
| Mean | -0.008 | -0.002 | -0.013 |
| Std Dev | 0.017 | 0.015 | 0.009 |
| **RMS** | **0.019** | **0.015** | **0.015** |

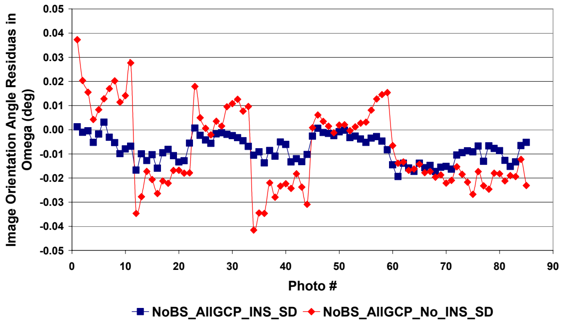


Figure 16. Image Orientation Residuals (in Omega) Using ISAT With and Without INS Shift and Drift Option to Recover a Boresight-Corrupted Data - Full Block 1: 10,000 photo Scale

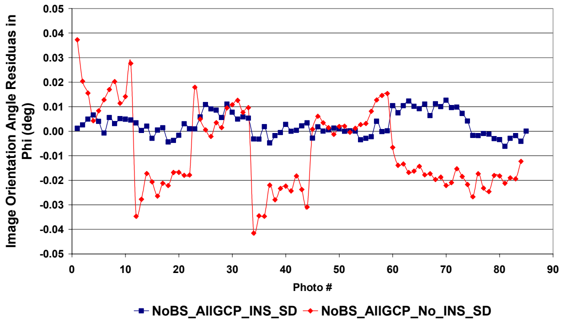


Figure 17. Image Orientation Residuals (in Phi) Using ISAT With and Without INS Shift and Drift Option to Recover a Boresight-Corrupted Data - Full Block 1: 10,000 photo Scale

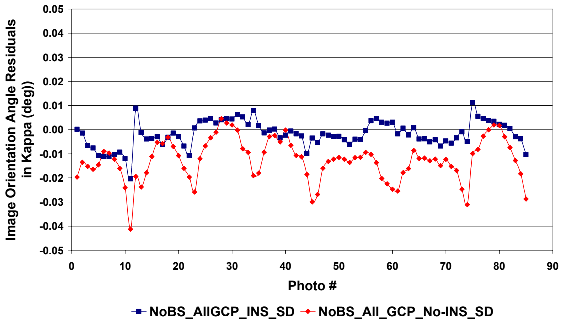


Figure 15. Exposure Station Position Residuals (Z Component) Using ISAT With and Without INS Shift and Drift Option to Recover a Boresight-Corrupted Data - Full Block 1: 10,000 photo Scale

Figure 18. Image Orientation Residuals (in Kappa) Using ISAT With and Without INS Shift and Drift Option to Recover a Boresight-Corrupted Data - Full Block 1: 10,000 photo Scale

The second scenario is similar to the aforementioned one, except that error detection is experimented using only two image strips. This is to investigate whether or not a two-strip image block is geometrically stable enough to detect any boresight errors by ISAT. ISAT was then used to run the two-strip block using the angular shift and drift option. This required the use of four ground control points. ISAT was able to absorb the intentional boresight error by the shift parameters for the two sets of data. The refined image angles by ISAT were then compared to those derived by POSEO (where the boresight angles are accounted for). The results are shown in Figure 19 for the strip 1 and 2 block, and in Figure 20 for the strip 1 & 4 block.

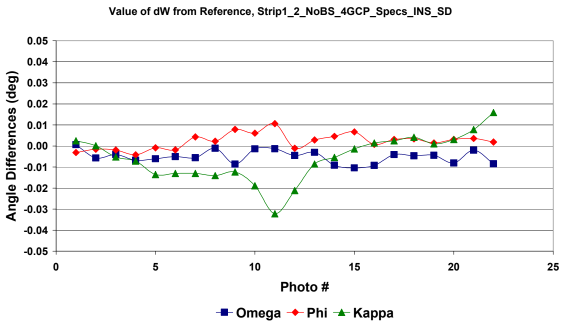


Figure 19. Image Orientation Difference Between POSEO and ISAT using INS Shift and Drift for Boresight-Corrupted Data Strip 1 & 2 Photo Scale 1: 10,000

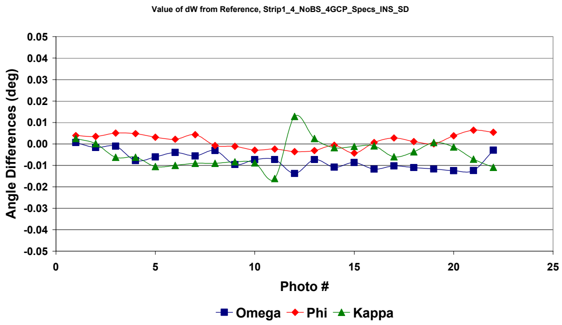


Figure 20. Image Orientation Difference Between POSEO and ISAT using INS Shift and Drift for Boresight-Corrupted Data Strips 1 & 4 Photo Scale 1:10,000

Tables 3 and 4 show the statistics of the differences shown in Figure 19 and 20. It is clear from Tables 1 and 2 that ISAT absorbed almost all of the boresight error by the angular shift parameters. More importantly, ISAT detected the boresight error. Typically, the next step in the ISAT data processing chain in such a scenario is to warn the user to go back and correct for that boresight mistake in POSEO.

Table 3. Statistics of Attitude Differences using Strips 1 & 2

| | Omega (deg) | Phi (deg) | Kappa (deg) |
|---|---|---|---|
| Minimum | -0.010 | -0.004 | -0.032 |
| Maximum | 0.001 | 0.011 | 0.016 |
| Mean | -0.005 | 0.002 | -0.006 |
| Std Dev | 0.003 | 0.004 | 0.011 |
| RMS | 0.006 | 0.004 | 0.012 |

Table 4. Statistics of Attitude Differences using Strips 1 & 4

| | Omega (deg) | Phi (deg) | Kappa (deg) |
|---|---|---|---|
| Minimum | -0.014 | -0.004 | -0.016 |
| Maximum | 0.001 | 0.006 | 0.013 |
| Mean | -0.008 | 0.001 | -0.004 |
| Std Dev | 0.004 | 0.003 | 0.006 |
| RMS | 0.009 | 0.004 | 0.008 |

## 10. CONCLUDING REMARKS

Directly observed EO parameters from a well-planned mission and correctly operating GPS/IMU systems are accurate enough to be used in many photogrammetric applications. However, the critical issue is the QC/QA of the data. If images are to be processed in stereo then AT followed by bulk model orientation is essential in order to solve the parallax problem. Check points measured in AT provide information on the quality of the direct EO data. Performing AT also permits modeling the unaccounted systematic errors using self-calibration techniques.

The DLC concept currently implemented in ISAT is an attempt to reduce or eliminate remaining errors. In that sense, the function of AT can be viewed as changing from the determination of EO parameters to the QC/QA of direct EO data. For large-scale engineering surveys, it is still the case that ground control points are necessary in order to achieve the required accuracy in the AT.

- The ISAT product covers all the mandatory requirements for automated aerotriangulation, and avoids those drawbacks found in the OEEPE-ISPRS report.
- The ISAT product delivers fully and automatically the best-matched multi-ray tie points, without blunders. This is achieved by a robust built-in bundle block adjustment during all phases of the image matching operation.
- ISAT contains improved search algorithms to find sufficient and well-distributed tie points in the overlapping regions.

- ISAT has s number of tools for the QC/QA of the directly measured EO parameters by Applanix POS/AV system. These tools and methods allow the operator to analyze very quickly the accuracy of the directly derived EO parameters.
- Since the quality of the EO parameters depend on the quality of the GPS data (e.g., number and distribution of satellites, etc.) the IMU data (the quality of the inertial navigator alignment), the quality of lever arm calibration, and boresight calibration. ISAT is currently being augmented by the necessary tools to automatically isolate the EO errors due to any of the aforementioned reasons, to eventually inform the operator about the possible reason of any EO errors
- The DLC concept is introduced briefly, where ISAT will automatically to answer the following questions 1) where is the error? Of which magnitude is the error?, and What is the most probable reason of that error.
- The OEEPE Phase I data of the 1:10,000 flight was used to analyze one part (boresight errors) of the new DLC concept, namely the automatic detection and isolation of the boresight error and then correcting it.

## 11. FUTURE WORK

ISAT will be augmented with numerous tools to aid the operator control the quality of the directly measured EO data by Applanix POS/AV system.

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