QUALITY CONTROL OF DIRECT GEOREFERENCING DATA

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ABSTRACT:

Quality Control (QC) is a critical step in the mapping process when using Applanix POS AV system in the direct georeferencing mode or in the aerotriangulation mode of mapping. Therefore, in this paper, the necessary steps of quality control of direct georeferencing data is presented in some detail. This is presented through Applanix PSOPAC software package using real mapping data sets. First, a brief description of the quality control steps of POS data is introduced. Then a description of the simultaneous use of navigation/imagery data is presented through the DLC™ Concept.

1. INTRODUCTION

Applanix POS AV™ system has been used successfully since 1994 to georeference airborne data collected from multispectral and hyperspectral scanners, LIDAR's, and film and digital cameras. The POS AV™ uses integrated inertial/GPS technology to directly compute the position and orientation of the airborne sensor with respect to the local mapping frame. For details, see Hutton et al (1997) and Mostafa and Hutton (2001b). In this paper, a description of the necessary quality assurance and quality control (QA/QC) steps to ensure a successful mapping process when using Applanix POS AV system is introduced. The presentation therefore is covering the quality control of direct georeferencing data through the Applanix POS hardware and software. Figure 1 shows the top-level data flow diagram using POSPAC™ software modules.

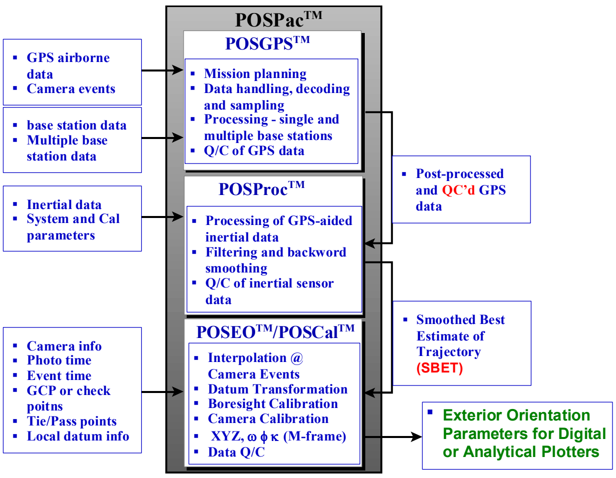

Figure 1: Data Flow in Applanix POSPAC Software

Proper aerial mission planning and quality control goes a long way towards repeatedly obtaining the trajectory parameters of the mapping sensor with the sought accuracy. 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.

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 in softcopy environment. In the following, each of these will be discussed in some detail.

2. GPS FOR AERIAL SURVEYS

During the mid 1980s throughout the 1990s, GPS has been used in kinematic airborne environment as an aiding sensor for photogrammetric aerotriangulation. The entire aerotriangulation process is based on the strength of the network of tie/ground points measured on the images, their measurement precision, distribution, and number. The accuracy of GPS-derived exposure station coordinates was not crucial since aerotriangulation has been designed to handle GPS errors in the form of relative positions together with their associated shifts and drifts from true positions. GPS ambiguity resolution was the reason for that scenario. If satellite signals' ambiguities are computed to be wrong by some cycles, the derived trajectory of the aeroplane will then be shifted by the same amount projected onto 3D components of coordinates. In the meantime, due to the fast change of constellation of satellites with respect to a moving aircraft, the shift tends to turn partially into a drift over time. Photogrammetrists, therefore, introduced new unknown parameters in the aerotriangulation process to absorb those shifts and drifts. These parameters absorbed some other errors such as tropospheric and datum distortion errors because of correlation which indirectly helped improve the exposure station position quality. Modelling shift and drift parameters in the block triangulation process introduced new difficulty which the unwanted ambiguity on the roll angle of different image strips. To sort this out, photogrammetrists suggested flying cross strips of photographs to introduce geometrical strength in the block by tying the parallel strips together again. This approach introduced a solution, which was used as a procedure in the 1990s. The procedure was to fly as many parallel strips of photographs as desired for coverage purposes. Then, fly a cross strip at a regular interval or at least at each end of the block.

The mapping is then done normally using the parallel strips of photos while the cross strips are only used for aerotriangulation to fix GPS errors. In practice, plotter operators were annoyed because of point transfer process between parallel and cross strips (the so-called cross bugging).

In the direct georeferencing mode, however, GPS is used as a primary sensor. The GPS-derived exposure station coordinates and the IMU-derived camera attitude angles are used as absolute Exterior Orientation (EO) parameters together with their associated statistical measures in the mapping process. The absolute accuracy of the blended position of a GPS/inertial system is limited to the absolute positioning accuracy of the GPS. Hence, it is important that proper mission planning be conducted to ensure that the best possible and consistent 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.

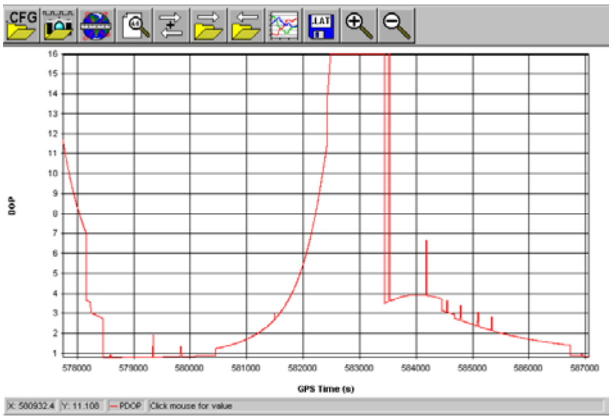

Figure 2: PDOP Plot in POSGPS

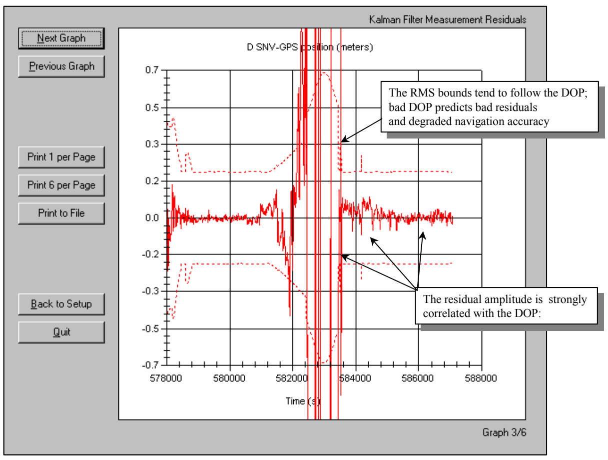

Figure 3: Kalman Filter Measurement Residual in POSProc

2.1 Collecting GPS Static Data

A mission should begin and end with a static data acquisition of the aircraft, 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.

2.2 Minimizing Multipath

Multipath reflections can be a major source of position error and cause for integer ambiguity resolution failures. Antenna choke rings or ground planes are best used to attenuate low elevation satellite signals to minimize multipath. Further, the location should not be in an environment affected by multipath or jamming conditions (e.g., building rooftops, trees, metal structures, transmission towers, large bodies of water, etc.)

2.3 Collecting GPS Base Station Data

The GPS base station should be occupied by a dual-frequency Geodetic Quality GPS receiver to collect raw Code and Phase satellite signals and ephemeris at 2 Hz. Base station operator should start data collection before the airborne GPS unit starts to collect data and stops collecting data after the airborne GPS unit is completely shut off after landing. Antenna height above the control point should be measured according to the GPS receiver manual. An appropriate location should be chosen for the base station such that a clear view from the receiver antenna and the satellites is maintained at all times. If the base station coordinates are questionable, the data collected by permanent tracking networks such as, for example, the CORS in the United States or GEONET in Japan can be used to compute the base station coordinates using the multiple base station approach.

2.4 Planning for PDOP

The mission should be planned during times of good satellite coverage so that PDOP is 3 or less throughout the mission. Currently, the GPS constellation provides for a poor PDOP relatively infrequently. Therefore, A simple satellite prediction software tool provides the information needed to plan for best PDOP. Figure 2 shows a window of time where PDOP was poor (i.e. more than 3) at the beginning of the flight and in the middle of the flight. The GPS accuracy was therefore much worse during the aforementioned time windows than that obtained during the rest of the flight. Figure 3 shows the Kalman filter measurement residuals plotted by POSProc that show evident degraded navigation accuracy during the poor PDOP time windows (Kinn, 2001). In that case, the pilot should pause the mission for that 30-minute poor-PDOP (during GPS time of 581500-583500) to avoid the resulting inconsistent GPS accuracy. On the other hand, for a well-planned mission with a consistently low PDOP during a flight, the Kalman filter measurement noise should be as white and consist as possible. Figure 4 shows, for example, the results in a typical aerial survey well-planned mission. Note that, Kalman filter residuals can be always used as a Q/C tool to capture some errors. Figure 5 shows the measurement residuals, where biases and spikes are evident. Occasional spikes in the residuals may be due to cycle slips in the GPS data; this can be verified by noting the time(s) of the spikes and reviewing the GPS solution.

2.5 Limiting Baseline Separation

If a mapping mission requires the 5-10 centimetre positioning 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. If baseline separation is greater than 100 km, multiple base station approach must then be used.

2.6 The Multiple Base Station Approach

GPS errors propagate directly and indirectly to errors in the mapping product. The direct GPS error propagation occurs by contaminating the lens perspective center location. The indirect propagation occurs by contaminating the inertial data, which results in deteriorating the quality of the inertial-derived image orientation angles. One of the most important errors affecting GPS positioning is the atmospheric error (of both ionospheric and tropospheric effects). These errors tend to be pronounced when the aircraft is flown farther than 30 Km away from the base station. Typically, mapping missions will expand far beyond 30 Km. Therefore, it is strongly recommended to use any available permanent tracking GPS networks such as that of the United States CORS (Continuously Operating Reference Stations). These permanent tracking GPS stations are becoming more common in different parts of the world for marine, car, and other navigation purposes as well as Earth's crustal motion perdition and other geodetic work. Examples of these services can be found in the US, Canada, western Europe, Japan, Hong Kong, Korea, Australia, etc. Figure 6 shows the USA CORS as an example of those permanent tracking GPS network stations. Figure 7 shows the Japanese GEONET network of permanent tracking GPS stations established for the purpose of crustal deformation monitoring. Note that the individual GPS motion in these stations is well within the accuracy required for the base station coordinates for airborne mapping applications.

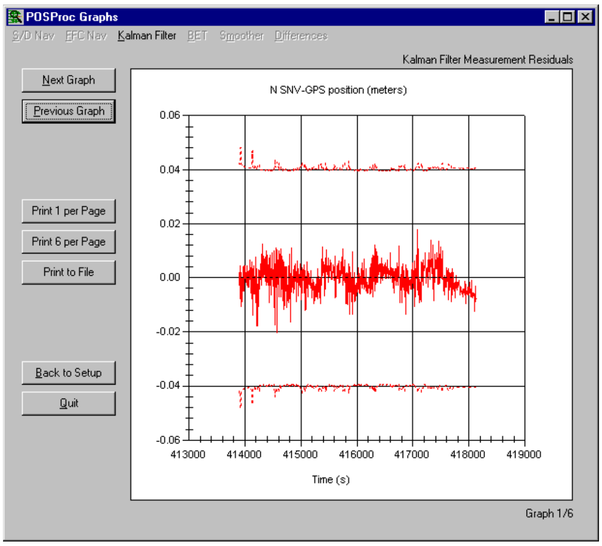

Figure 4: Kalman Filter Measurement Residuals for a Well Planned Mission (Low PDOP)

Recent Studies showed that processing the GPS data using a number of the available base stations improves the quality of the final GPS-derived trajectory which results in a better quality of the exterior orientation parameters (c.f, Mostafa and Hutton, 2001a; Bruton et al, 2001; Mostafa et al, 2002). In summary, using the available CORS stations around the mapping area helps as follows:

- Computation of the dedicated base station coordinates, in case the coordinates are not known or the station is just established at the time of the aerial survey. The new coordinates are computed using the multiple base station approach, which is geometrically similar to geodetic network adjustment
- Computation of a best estimate of the GPS antenna coordinates during the flight. Using multiple base stations yields more accurate GPS results than when using one dedicated base station or in case of loosing the base station data

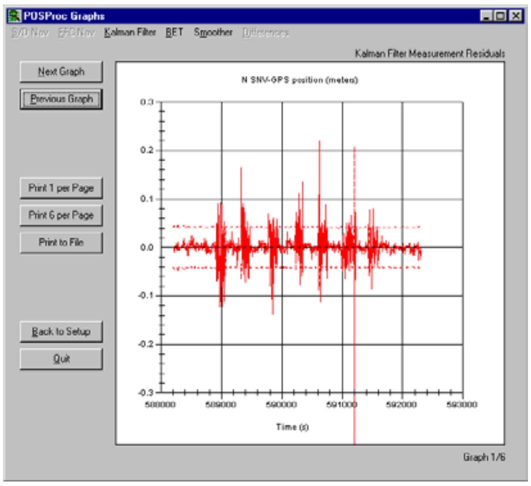

Figure 5: Measurement Residuals Showing Systematic Effect and Spikes Which Indicate Poor Data Quality

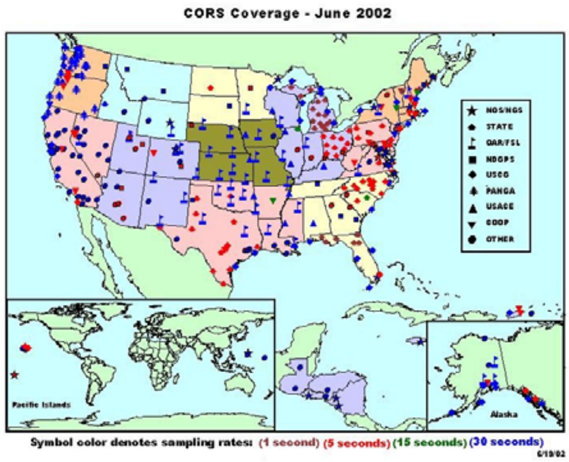

Figure 6: The US CORS (Courtesy of NOAA/NGS)

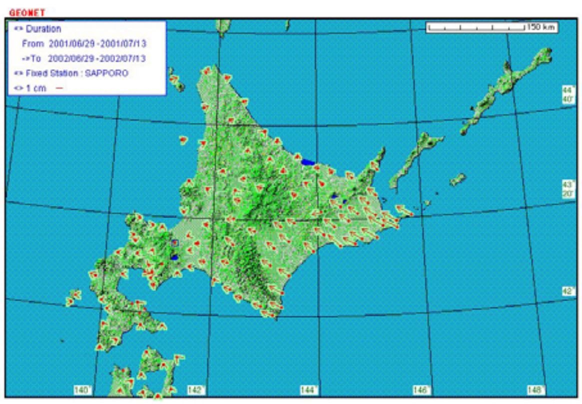

Figure 7: GEONET Network of Permanent Tracking GPS Stations in Japan (Courtesy of GSI)

3. 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 8 shows the heading plot, which normally looks like the path of a bouncing ball. The low points correspond to turns, where the heading error is calibrated. Figure 9 shows the heading error for the same flight after smoothing, which is twice as much accurate as that derived by the forward Kalman filtering. Note that the heading error tends to increase for straight flight lines and therefore, it is recommended to do a manoeuvre if an aeroplane is flown in a straight line for more than 10-15 minutes

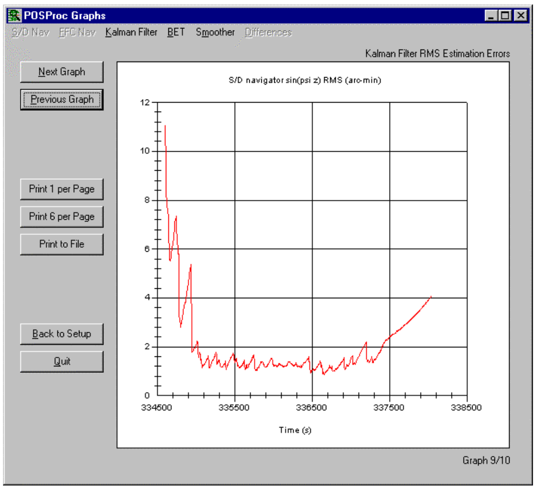

Figure 8: Kalman Filter-derived Heading Error

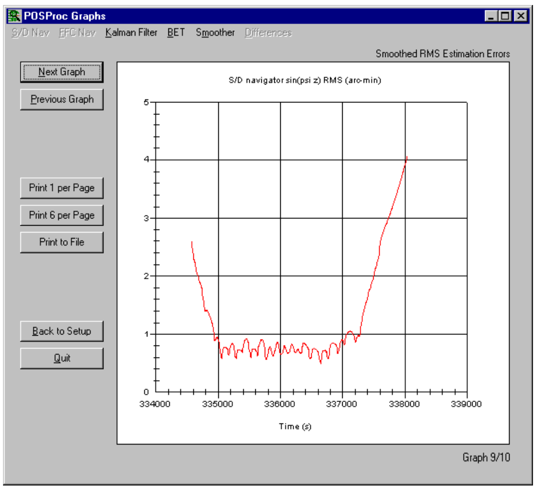

Figure 9: Heading Error After Further Backward Smoothing

4. REAL-TIME QA/QC OF NAVIGATION DATA

Once the aerial 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.

If the recorded data are seemed to be acceptable, then the data are handed over to post-mission processing. POSPAC^{TM} has several quality assessment indicators. The most basic of these are the inertial-GPS residuals, shown previously in Figures 3,4, and 5. 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).

5. SIMULTANEOUS USE OF NAVIGATION & IMAGERY DATA FOR Q/C PURPOSES: THE DLC^{TM} CONCEPT

Detection, Location, and Correction (DLC^{TM}) is the concept behind the direct EO QA/QC process in photogrammetric softcopy (c.f., Madani and Mostafa, 2001). POS AV data, aerial imagery, and available GCP (control/checkpoints) are simultaneously used to efficiently perform DLC^{TM}. By 'detection' we mean, to automatically detect whether or not there is a perfect fit (according to some predefined threshold) between the POS-derived EO parameters, the images, and the available GCP.

If there is no perfect fit then 'Location' is performed, where the SoftCopy 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. The DLC is currently being implemented in Z/I Imaging ISAT software Package.

Figure 10 shows the workflow in ISAT. 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 some 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.

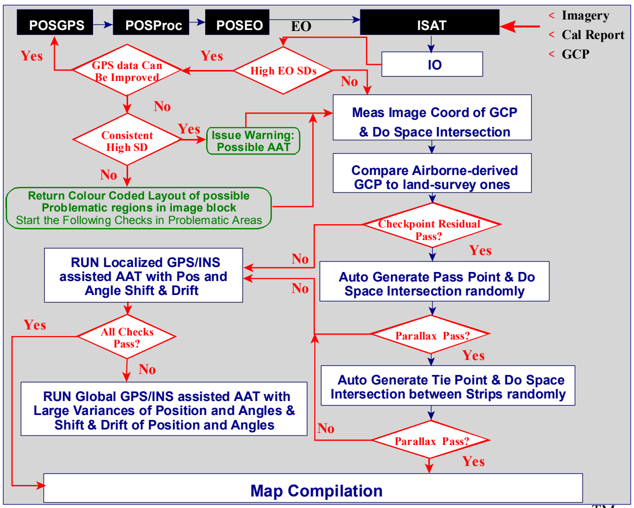

Figure 10: Detection, Location, and Correction (DLC[TM]) Concept

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 w, j, and k, data into the SoftCopy. If the GPS data cannot be improved and the position standard deviations are consistently high, then automatic aerotriangulation may be warranted to recover the mission. If the EO standard deviations meet the requirements, then the following checks should be done for a selection of images throughout the block:

1. Manually or semi-automatically measure image coordinates of 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. Perform space intersection using the given EO data and the image coordinates of all available checkpoints.
3. Compare the computed checkpoint coordinates with the given values.
4. If checkpoint residual testing did not pass, systematically check the system for calibration errors, base station errors and mission planning errors.
5. If the checkpoint residual test passes, generate model pass points and perform space intersection to check analytically if these points have any parallax. If parallax is evident, systematically check the system for calibration errors, base station errors and mission planning errors
6. If the pass point test passes, 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 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, systematically check the system for calibration errors, base station errors and mission planning errors.

Currently, in Z/I Imaging's ISAT, some of the previously mentioned features are already implemented. Figure 11 shows the EO analysis window in ISAT. The upper panel shows the computed (back-projected) image coordinates determined using the POS-derived exterior orientation and the land-surveyed ground control point coordinates. The statistics of the remaining y-parallax are listed at the bottom of the first panel.

This gives a quick indication of the amount of remaining y-parallax in the images that had GCP appearing in them. In the lower panel, the ground control point coordinates are computed using the airborne data (POS AV plus image coordinates). Then, the computed ground control point coordinates are compared to the land-surveyed ones. The differences as well as their statistics are listed in the lower panel and underneath it. This tool is used to judge whether the accuracy achieved by the entire assembly of camera plus POS AV is good enough for the project at hand. If not, the problematic areas should be evident from the lower panel and can be used to locate the problematic area for subsequent analysis.

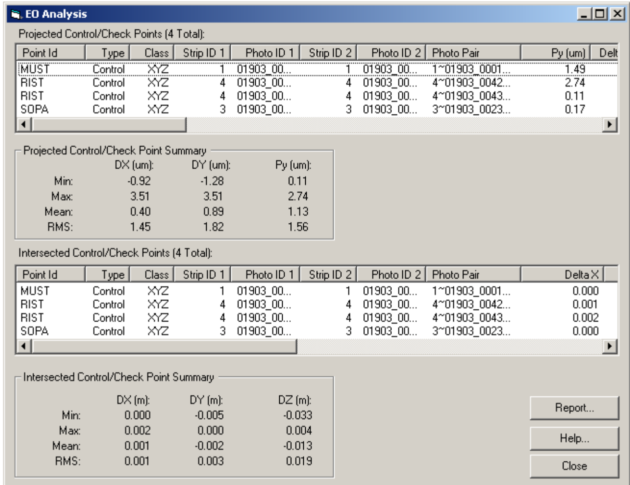

Figure 11: POS AV Exterior Orientation Data Analysis in ISAT

6. ON –THE-FLY DATUM CALIBRATION

All navigation data collected in conjunction with image data is typically realized in an Earth-centred Earth-fixed (ECEF) coordinate frame of reference. However, all photogrammetric work is done in a 3D Cartesian coordinate system. The photogrammetric algorithms are all developed using this concept and, thus, require the input of the exterior orientation parameters to be in some local datum such as a national grid. Therefore, the GPS and IMU data must be transformed into a local datum. The transformation of GPS-derived photo exposure station normally takes place using the available algorithms of coordinate transformation. This is done by converting the latitude and longitude of each GPS-derived position into a Northing and Easting component of a local national grid using map projection concepts. During this transformation process, a scale factor is determined for each point and then applied to the horizontal components only. The height component is however not scaled by such a scale factor. Therefore the GPS-derived height becomes biased by that scale factor. In some other instants, the local datum is distorted and there is a need to compute an average of that. An easy way of doing this is to establish at least three ground control points somewhere close to the mapping area and fly over these ground control points to capture a stereo pair. This photo pair together with POS AV data and the ground control points can be used to compute the datum shifts using a 7-parameter transformation. The exterior orientation parameters can be therefore compensated for such datum transformation parameters. Figure 12 shows the 3D Transformation Adjustment window in POSCal software where a partial or full 7-parameter transformation can be computed and/or applied to a calibration data set.

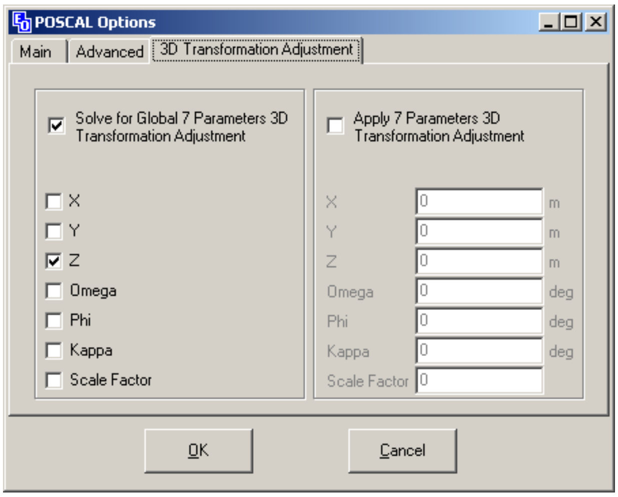

Figure 12: On-The-Fly Datum Calibration

7. COCLUDING REMARKS

Directly measured EO parameters from a well-planned mission and correctly operated POS AV system are accurate enough to be used in many photogrammetric applications. However, the direct georeferencing data has to go through the necessary quality control procedure to ensure achieving the required accuracy of the mapping product. This paper briefly described the necessary Q/C steps in some detail

8. FUTURE WORK

Quality control procedure presented here is a work in progress. Further improvement of the QC procedure is the next challenge. Implementation in different photogrammetric softcopy is also planned.

9. ACKNOWLEDGEMENT

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