

Integrated GPS/inertial and digital aerial triangulation - recent test results

MICHAEL CRAMER, Institute for Photogrammetry (ifp), Stuttgart

ABSTRACT

GPS/inertial systems for direct determination of exterior orientations of airborne sensors are an accepted technology for sensor orientation in the meantime. Their theoretical accuracy potential was proven several times from well designed and controlled performance tests. Nonetheless, results from operational production projects are rarely published till now. Hence, this paper focuses on the investigation of GPS/inertial system performance in true operational environments. Aspects of long-term system calibration are covered also. The results from such production applications quite clearly show the difference between academic tests and results from real projects. The quality of direct georeferencing is worse compared to performance tests, the theoretical maximum accuracy is not achieved in some cases. Especially the quality of GPS/inertial positioning seems to be critical. In such cases the use of integrated sensor orientation offers one possibility to finally obtain the desired accuracy for object point determination. Therefore, the use of GPS/inertial data to aid automatic aerial triangulation (AAT) is investigated in the second part of the paper.

1. INTRODUCTION

Sensor orientation still remains one major task within the photogrammetric processing chain, but new technologies offer alternatives to determine exterior orientation parameters for airborne sensor systems. Besides “classical” aerial triangulation – the indirect way of estimating sensor orientation parameters based on control information in object space – the advent and commercial availability of high-quality integrated GPS/inertial systems allows for direct georeferencing without use of any ground control data – at least theoretically. The accuracy potential of this direct approach to obtain sensor orientation was investigated from different institutions in numerous well controlled and designed test flight scenarios in the last years. Very extensive tests were done in the OEEPE framework (now renamed to EuroSDR), where a special test was dedicated exclusively on the performance of direct georeferencing and integrated sensor orientation (OEEPE, 2002). Parallel to these activities, the estimation of accuracy performance of experimental systems and commercial GPS/inertial products like POS/AV-510 DG (Lithopoulos, 1999) and AEROcontrol-IIId (Kremer, 2001) in combination with different airborne sensors still is a topic at Institute for Photogrammetry (ifp), also. This can be seen from Table 1, where the history of performed test flights starting in 1995 is given. Most of the flights were done in the Vaihingen/Enz test site close to Stuttgart, which is the specially designed test area maintained from ifp. Within this area a sufficient number of signalized ground control points, coordinated from static GPS surveys, serve as independent check point information to estimate the quality of object point determination from airborne sensor data. Besides this a DTM from LIDAR measurements is available for the test site providing reference data to estimate the quality of photogrammetric DTM generation.

The individual test results from these different ifp test series can be found in several publications, i.e. the results from the first GPS/inertial test are given in Škaloud et al. (1996), the results from the pushbroom line scanner test flights with DPA and HRSC-A systems are published in Fritsch (1997) and Haala et al. (2000), whereas the investigations on commercial GPS/inertial system performance can be found in Cramer (1999) and Cramer (2003). The data from the most recent flights with the new digital photogrammetric sensor DMC are under current investigations. Nonetheless, preliminary results are very promising confirming the high accuracy potential of digital sensor systems. In general, from the results of these different test campaigns – focussing on the role of GPS/inertial components as one part of the sensor systems – the following conclusions are drawn.

Test site	Test date (month/year)	Airborne sensor	GPS/inertial components
Hambach	07/95	RMK-A 15/23	University of Calgary, Geomatics Ashtech Z12, Litton LN-90
Vaihingen/Enz	07/95, 08/96 10/96, 11/98	DPA	DPA – system specific Trimble SSE4000, Sagem DPAKSE
Vaihingen/Enz	02/98	HRSC-A	Applanix POS/AV-510 DG Novatel Millenium, Litton LR86
Bedburg	02/98	RMK-Top15	Applanix POS/AV-510 DG Novatel Millenium, Litton LR86
Vaihingen/Enz	12/98	RMK-Top15	Applanix POS/AV-510 DG Novatel Millenium, Litton LR86
Vaihingen/Enz	06/00, 09/02	RMK-Top15	IGI AEROcontrol-IId Ashtech Z-Surveyor/Z-Extreme, IMU-IId
Vaihingen/Enz	04/03	DMC	Applanix POS/AV-510 DG Novatel Millenium, AIMU
Vaihingen/Enz	Summer 03 (planned)	ADS40	Applanix POS/AV tightly integrated with ADS40

Table 1: Performed test flights with different system installations.

- Direct sensor orientation based on GPS/inertial systems provides high flexibility since this method can be used with any type of sensor (frame/line, analogue/digital). There are no longer restrictions on flying regular block structures. Since there is no need for tie point matching this method of image orientation will succeed even in applications where traditional transfer of tie points is problematic like coastlines and dense forest regions. The use of GPS/inertial sensors is essential for later efficient data processing of push-broom line sensor data, like ADS40.
- Direct determination of exterior orientation parameters using high-quality integrated GPS/inertial systems can reach high accuracy fairly close to standard photogrammetry – but only if a correct GPS/inertial data processing (including efficient GPS/inertial error control, correct transformation between different coordinate and mapping frames, datum problems) and an appropriate overall system calibration (including GPS/inertial components and camera self-calibration) is guaranteed for the specific mission site.
- Direct georeferencing without any ground control is possible but highly unreliable since non corrected systematic or gross errors remain undetected and directly deteriorate the quality of sensor georeferencing. Hence, the use of a certain number of check point data in the mission area itself is recommended to provide redundant data for quality assessment and quality control. If errors are present these check points in the test site may serve as control data to compensate the error effects.

Although it is explicitly admitted that direct georeferencing is a powerful technology with wide influence on the georeferencing process the results from such academic performance tests typically suffer from the following points: Due to the lack of separated calibration and mission sites the calibration is performed in the mission area itself, which is different from later practical use. In order to estimate the maximum possible accuracy of GPS/inertial systems these test flights are carefully planned, most often the flight turns are flown with low banking angles to preserve good satellite constellation. In addition to that, highly skilled experts (sometimes the system manufacturers themselves) spend a lot of time for the subsequent data processing and the overall system evaluation. Again, such test conditions are non-typical for the later use of GPS/inertial systems in operational production environments, showing quite clearly that the results from these

performance tests might be too optimistic compared to the results from later practical use. From these points especially in the true production field work there might be a need for an efficient calibration and control tool, which is solved by integrating GPS/inertial data in an (automatic) AT process, so-called integrated sensor orientation.

In order to illustrate this situation, some recent results on the use of GPS/inertial data in operational applications are given within the following Section 2. Since now, field reports from system performance in true operational photogrammetric applications are rarely published, unfortunately. Experiences from such operational projects showed that especially in true production environments the prerequisites of high-quality overall system calibration and data processing could not always be guaranteed which in some cases results in an integrated sensor orientation process to refine system calibration and to finally obtain the aspired accuracy performance. For highest accuracy and reliability requirements there is obviously a need for such integrated orientation approaches based on direct observations of sensor exterior orientation parameters and additional ground control with their assigned corresponding weights. Therefore, the main focus in the second part of this paper is laid on integrated sensor orientation and its realization in commercially available software products for automatic AT (AAT). Section 3 gives a short overview on potential of integrated sensor orientation and some experiences using GPS/inertial exterior orientation data to aid AAT are presented.

2. DIRECT GEOREFERENCING IN OPERATIONAL ENVIRONMENTS

Focusing on the more traditional photogrammetric application field experiences from operational use of GPS/inertial systems in combination with analogue aerial cameras are not well documented. Although a certain number of companies is already using this technology in their daily work, only few publications depicting their experiences are already available. Besides reports from the GPS/inertial system providers itself (i.e. Kremer (2001), Mostafa et al. (2001)), Himle (2001) gives some practical experiences for the operational system calibration and direct orientation of single photogrammetric models based on GPS/inertial data, where the given accuracy specs could be fulfilled mostly. Dreesen (2001) stated the successful generation of mid-scale orthoimagery for forest applications based on direct sensor orientation. Schroth (2003) summarizes the experiences using GPS/inertial based exterior orientations at Hansa Luftbild German Air Surveys like follows: Up to now 30 different projects with 68000 RMK images and one project with the digital camera DMC (350 images) were flown with additional GPS/inertial data, but only one third of those direct exterior orientations were used in later processing. Within the remaining projects the data from integrated GPS/inertial system were recorded only for safety reasons in case traditional processing would fail. For about 5000 images direct georeferencing was done without any need for further processing. Within the orientation of approx. 3000 images further refinement of GPS/inertial data using integrated sensor orientation was necessary. All other GPS/inertial orientation elements were directly handed over to clients and no feed-back on data quality is available. The main application fields for use of GPS/inertial data are within orthoimage generation and processing of low-contrast areas like lakes or coastal zones. No mapping is done with images oriented using integrated GPS/inertial systems. In Tang et al. (2003) the successful introduction of GPS/inertial technology in China is described. Within the projects mentioned there a quality of ~0.2m was obtained for direct georeferencing (large scale blocks). Direct georeferencing had problems in vertical determination, but was still suitable for orthoimage production. For maximum accuracy the approach of integrated sensor orientation with minimal number of ground control points is favoured. In order to further illustrate the quality of GPS/inertial data in operational applications the main results of a large production campaign with several thousands of images flown in Saudi-Arabia are recapitulated in the following.

2.1. The Jeddah calibration flights

The presented results are obtained data from different calibration flights which are only a very minor part of a larger production project in Saudi-Arabia flown by Hansa Luftbild German Air Surveys. Within this project more than 9000 images (scale 1:5500) were captured covering a time span of approximately 2 months. Parallel to the image data recording, GPS/inertial positions and attitude data were continuously provided by the IGI AEROcontrol-IIId system, whose IMU was rigidly mounted at the camera body. During each mission day one fully signalised flight line was flown twice with opposite flight directions for system calibration – typically once in the morning before and once in the evening after mission flight. This calibration strip consists of altogether 21 ground control points (GCP) located in the standard or von Gruber positions of each image resulting in 7 captured images per calibration line. Since almost all images were taken with the same Z/I-Imaging RMK Top30 – GPS/inertial installation, the results from the multiple calibration flight data allow for first investigations on the long-term stability of system calibration. Only these calibration flight data are topic of the following subsections. For a detailed description of the test design and the theoretical aspects of system calibration the reader is referred to Cramer & Stallmann (2002). All tests have been done in a local topocentric coordinate frame to overcome additional aspects due to non-orthogonal mapping frames and map projections (Greening et al. (2000), Ressler (2001), Jacobsen (2002)).

2.2. Long-term performance of overall system calibration

One main result of this test was the analysis of the variation of system calibration parameters over time in such operational environments. In this context three different types of parameters were considered for system calibration: Besides the inherent boresight alignment angle calibration, representing the physical misorientation between IMU and camera coordinate frame, additional camera self-calibration parameters and position offsets are introduced, as far those parameters are estimated as significant values. The results are like follows:

Boresight misalignment angles The correct estimation of boresight misalignment is mainly dependent on a high-quality GPS/inertial data processing – provided that a stable mounting between IMU and camera is realized. Any remaining non corrected effects in GPS/inertial attitudes after performing the GPS/inertial data integration including the internal systematic inertial error control will influence the boresight angle estimation significantly. In our case, at least within two of the investigated 8 calibration flight days larger systematic strip dependent offsets were clearly visible within the κ -angle. Such strip dependent systematic might be due to non optimal calibration of z-gyro scale factor during GPS/inertial data integration. In order to obtain a realistic estimation on long-term boresight angle stability those data sets have to be excluded. Doing so, the estimated variation of boresight angles over longer time periods is within $10''$ - $20''$, which is close to the aspired accuracy potential of GPS/inertial attitude determination. These variations indicate a quite high stability of boresight alignment over several mission flight days. Similar results can be found in Alamús et al. (2001). In Jacobsen (2002) larger variations in boresight angles up to 0.02deg are cited. These results are based on the Jeddah data sets also, but only at a very early stage of data processing.

Position offsets The calibration of position offsets seems to be the most critical component within this data set. Experiences from these operational calibration flights have shown several days with significant position offsets in the vertical component. Similar effects are known not only from other GPS/inertial projects (i.e. Cramer, 1999), but from standard GPS-assisted AT also. Within GPS-assisted AT such effects are typically compensated using the so-called “shift and drift” approach. Nevertheless, when establishing a long-term valid overall system calibration the day-to-day variation of estimated offsets between 10-40cm cannot be corrected in advance and has to be

taken into account when using direct georeferencing for the individual test flight days. Without going into details, reasons for such position shifts are manifold: They might be due to inconsistencies between physical reality of image formation and the assumed mathematical model of central projection (focal length, radial-symmetric effects), remaining errors in the GPS trajectory, its processing or other effects.

Camera self-calibration Finally, for overall system calibration the imaging sensor itself has to be taken into account. Within this context the refinement of camera interior orientation and image distortions modelled by additional self-calibration terms are mentioned. This is the standard way to adopt mathematical model and physical reality. Using a more general model including such additional parameter sets the mathematical representation better fits the given input data. Nonetheless, since there are strong correlations between some of these parameters and the exterior orientation of the sensor itself only a subset of these unknowns can be determined within standard photogrammetric flight conditions. Typically images flown in one image scale and GCPs covering a small vertical range extension only are available. Such data sets do not allow for separation between influence of global GPS shifts in vertical component or change in camera focal length. Additionally, if only single flight lines are used for system calibration strip dependent effects cannot be separated from global effects. A shift in flight direction might be due to the displacement of principal point, a global shift within the GPS trajectory or some remaining errors in time synchronization or lever arms. Nonetheless, the correct calibration of the imaging sensor itself is essential in direct georeferencing, where the refinement of the camera specific parameters (principal point, focal length, lens distortion) typically compensates the main systematic effects. If the data from calibration sites do not allow for the separation between camera specific effects and global shifts, system calibration should be done in the same image scale as the later image flight. Even when using orthogonal polynomials as additional parameters proposed by Ebner or Grün, which are per definition of no or less influence on the estimated exterior orientation parameters, it is questionable whether the parameters estimated in the calibration area are still valid in the mission site. Since those self-calibration parameters are determined as block- or strip wise parameters, site dependent variations have to be considered. This effect is already known from the early days of self-calibrated bundle adjustment and has to be taken into account when using direct georeferencing. From the investigated calibration flights the mean influence of self-calibration is in the range of $10\mu\text{m}$.

2.3. Operational direct georeferencing based on long-term system calibration

It is known that correct overall system calibration is a quite demanding topic. Nevertheless, from the previous section it is obvious that the realization of a long-term valid system calibration is even more demanding and might be questionable in some cases, in especially when the GPS/inertial data integration is not done optimally, which for sure is the difference between very carefully done performance test flights and true operational projects. In our case especially the variation in position components is most critical and will influence the quality of direct georeferencing significantly if this daily effects are not compensated during direct georeferencing and only one set of long-term calibration parameters is applied for the different mission days.

Nonetheless, in order to estimate the performance of long-term system calibration one set of boresight angles was applied for all mission days exclusively to relate the GPS/inertial attitudes to the camera coordinate frame. Other calibration parameters are not considered due to their large variations over time. Such established system calibration for sure is not optimal for individual flight days, hence the quality of direct georeferencing reflects the performance of operational GPS/inertial exterior orientations with long-term calibration parameters, which is a quite interesting topic from users point of view. The results (RMS) from these tests can be seen in Figure 1, where the quality of direct georeferencing (DG) is obtained from analysis of 21 check point differences. Within this test each calibration flight line was considered individually, providing “worst case” geometry with

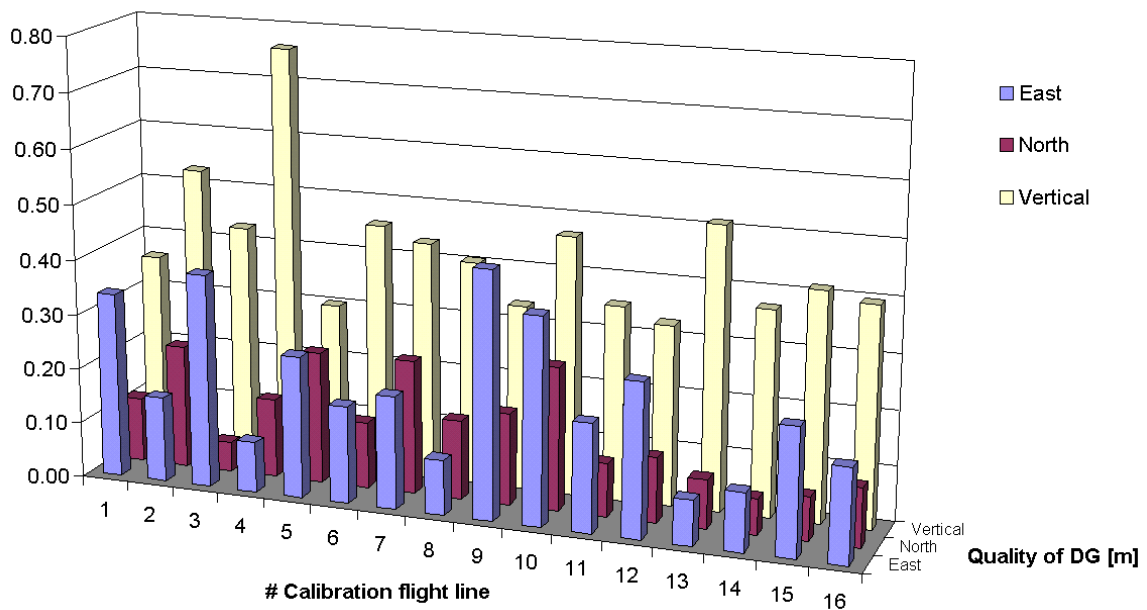


Figure 1: Quality (RMS) of operational DG using long-term boresight angle calibration.

single flight lines with only 3-ray points (max.) available for object point determination. Doing so 16 different flight lines from the 8 calibration flight days are evaluated. The obtained quality (RMS) is given for the three coordinate components separately. As to be expected, the maximum deviations are present in the vertical component. The RMS values raise up to 76cm, the mean RMS is about 4dm. The mean horizontal RMS is about 20cm, whereas in some cases the quality of east components achieves values close to 40cm. Note, that the flights were done over a time window of about 2 months and only one set of boresight angles was applied.

Comparing these numbers to the accuracy obtained from DG with optimal system alignment – typically in the range of 10-20cm for similar image scales (see e.g. results from OEEPE test (Heipke et al., 2002)) – this quality is significantly worse, showing the strong impact of non optimal GPS/inertial data integration. Within this test the maximum accuracy performance of GPS/inertial integration was not fully exploited definitely, which in fact is influencing the object point quality of DG but even more the quality of overall system calibration as it was explained before. For sure, this is not a deficiency of this GPS/inertial technology in general but clearly shows the need for careful data analysis and processing before using the data for system calibration and direct georeferencing. Nevertheless, although the results from this specific operational data set are somehow disappointing compared to the results from specially designed performance tests, it has to be re-confirmed whether these experiences are typical for practical projects or not. In general it should be possible to realize higher accuracy even when using long-term calibration parameters in operational applications assuming a proper GPS/inertial data processing.

3. AAT USING GPS/INERTIAL DATA

The results from DG based on long-term calibration parameters in operational environments showed the influences of non optimal system calibration, which in this case is partly due to non optimal processing of GPS/inertial data. The obtained accuracy in object space is in the range of a few to several decimeters. Especially the vertical component is critical and dependent on the aspired

application such errors cannot be accepted. The only chance to overcome such errors (even though the GPS/inertial exterior orientations are non optimal) is to introduce the directly measured exterior orientations in an integrated sensor orientation. This approach allows for the subsequent refinement of systematic errors and will increase the overall accuracy of object point determination.

3.1. Potential of integrated sensor orientation

The potential of integrated sensor orientation is already shown in different applications especially in the context of overall system calibration. Therefore, in this place only one typical example should be given to illustrate the performance. For this example the results from the calibration flight line #6 from the operational calibration flights of the Jeddah project are depicted in Figures 2 and 3. The positive influence of integrated sensor orientation is clearly visible. After direct georeferencing (DG) the presence of remaining systematic errors is obvious from the horizontal and vertical check point differences (Figure 2). The mean RMS is about 18cm, 12cm and 46cm for east, north and vertical components respectively and corresponds to the error bars already shown in Figure 1. After performing integrated sensor orientation based on one single control point located in the middle of the line, and including additional parameters for the refinement of boresight misalignment and position offsets the accuracy of object point determination is increased significantly (Figure 3). The resulting RMS values from analysis of 20 remaining check point differences are about 7cm (east), 9cm (north), 14cm (vertical), which is an obvious quality improvement compared to results from DG. This again underlines the potential of integrated sensor orientation even when one set of long-term calibration parameters is applied only, originally.

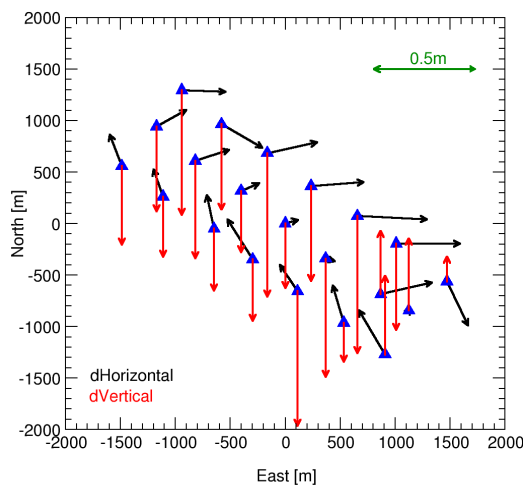


Figure 2: Quality of DG based on long-term boresight calibration (line #6).

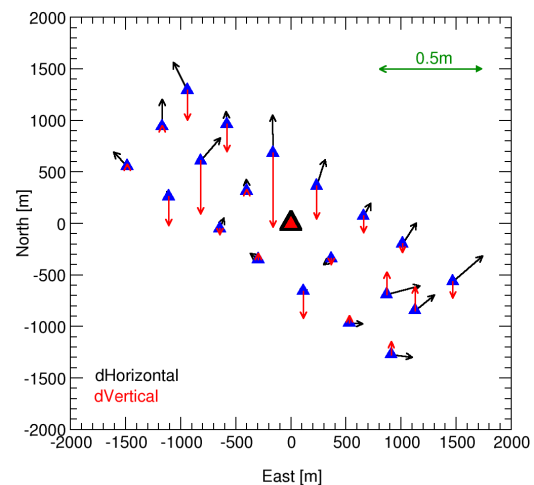


Figure 3: Quality of integrated sensor orientation using 1 GCP (line #6).

3.2. The role of GPS/inertial data in AAT

In the meantime a certain number of academic non-commercial and commercial software developments is realized with sufficient handling of the additional observations from GPS/inertial systems. An overview of appropriate software modules can be found in Heipke et al. (2002). Besides classification into non-commercial and commercial products these programs can be divided into pure, stand alone bundle adjustment software starting from measured image coordinates and automatic AT programs where the automatic image matching procedure itself is a substantial part of

the software. Especially the fully integration of GPS/inertial data into AAT programs seems to be very straightforward since the high-quality direct exterior orientation measurement should simplify the automatic block organization and improve the quality of automatic image matching significantly. Today different AAT software developments are commercially available where only the main systems and their suppliers are mentioned here:

- ORIMA with Socet Set or Leica Photogrammetry Suite – Leica Geosystems (Leica, 2003)
- ISAT – Z/I-Imaging (Dörstel et al., 2001)
- MATCH-AT – inpho (Sigle & Heuchel, 2001)

Within all products the direct support of GPS/inertial positioning and attitude data is realized. Quite similar to the standard approach of GPS-assisted AT the well-known shift and drift parameters are applied for attitude observations also to compensate for the boresight misalignment angles and remaining systematic attitude drifts. Typically the attitude data are introduced as additional observations and the offset and drift parameters are estimated for each single flight line separately. Unfortunately in some of the AAT programs the exclusive estimation of offset parameters is not possible – only the combined introduction of offset and drift is realized, which results in an over-parameterisation, since time dependent drift errors should not be expected for high-quality GPS/inertial observations. Especially for the calibration of boresight angles the exclusive estimation of three attitude offsets is sufficient for the whole block. Even in the GPS/inertial attitude data sets from the before mentioned operational project the significant accuracy increase from integrated sensor orientation is obtained from refinement of attitude offsets only without consideration of additional systematic attitude drift corrections.

3.3. MATCH-AT – a small example with use of GPS/inertial data

In general the additional use of GPS/inertial data should improve the quality of tie point matching and increase the overall stability and reliability of the block. In order to evaluate the influence of GPS/inertial data within AAT, some exemplary investigations were done with real data. These tests were based on image sub-blocks recorded during one of the Vaihingen/Enz test flights. Within this specific case, the data from the test flight June 2000 (Table 1) were chosen, where parallel to standard RMK wide-angle images ($m_b=13000$, image scan resolution $14\mu\text{m}$) GPS/inertial data from the AEROcontrol-IIId system were acquired. Since the high quality of the direct exterior orientations was already proven as one part of the test, these orientation elements were introduced as high-performance direct exterior orientations in the MATCH-AT 3.3.0 program from inpho (Germany) to perform a GPS/inertial assisted AAT process.

Two different data sets should be presented in the following (see Schneider (2002) for more tested configurations). The first one consists of a small block with two parallel flight lines (7 images each) and standard overlap conditions, representing the more or less typical block configuration from standard AT in practice. For the second test series one single flight strip (7 images) was considered only. Within the different tests, the GPS/inertial data were introduced with their estimated accuracy and compared to the results from GPS-assisted AT (with/without GCP) and standard AT based on a sufficient number of ground control points only. The accuracy values are obtained from independent check points. Some exemplarily results for the chosen block configuration with two flight lines are given in Figure 4. It can be seen that for this specific data set the additional use of GPS/inertial data (POS+ATT) for AAT is of almost no influence on the obtained quality of object point determination. The results from GPS/inertial assisted AAT are almost similar to the results where GPS positions (POS) are used only. The introduction of additional 4 ground control points (GCP) in the corners of the block is sufficient to obtain almost highest accuracy. Note the accuracy increase for vertical components when direct observations for exterior orientation elements are introduced compared to the standard approach based on ground control points only.

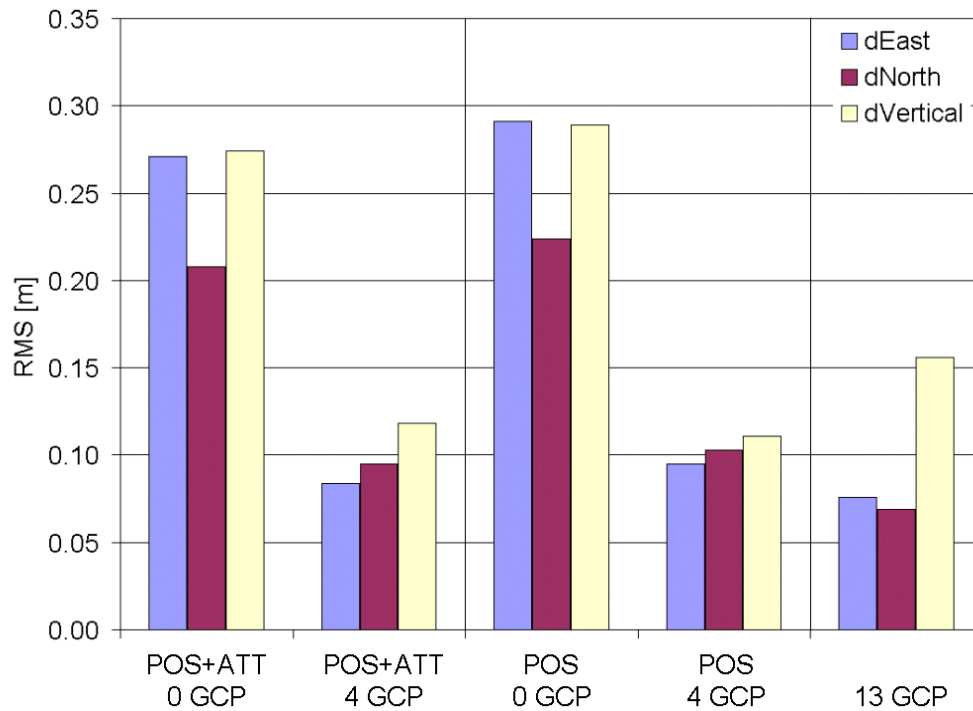


Figure 4: Object point quality (RMS) from AAT based on different input data.

For the second configuration used in this AAT test quite similar results were obtained. Within this version 7 images from a single flight were used for adjustment only. Even though one third of each image information was grayed out (northern part of the East-West strip) – in order to simulate a “worst case scenario” of a coastline survey, where no automatic point transfer is possible in water areas – almost no significant accuracy increase is visible from additional use of GPS/inertial attitude information compared to GPS-assisted AAT. When using 4 GCPs, accuracy (RMS) $\sigma_{\text{East}}=5\text{cm}$, $\sigma_{\text{North}}=7\text{cm}$, $\sigma_{\text{Vertical}}=13\text{cm}$ from GPS/inertial-AAT corresponds to values $\sigma_{\text{East}}=8\text{cm}$, $\sigma_{\text{North}}=7\text{cm}$, $\sigma_{\text{Vertical}}=12\text{cm}$ from GPS-supported AAT. For the sake of completeness it has to be mentioned that GPS/inertial positions and attitude data allow for the adjustment of single flight lines without using any GCP which is impossible even for GPS-supported bundle adjustment.

Although the added value from GPS/inertial data seems to be somehow disappointing at least from the tests presented in this context experiences from operational projects with very large scale images ($m_b=2000$) have already shown the important role of additional attitude observations from GPS/inertial (Braun, 2003). In this specific case numerous images were covered with wood exclusively preventing a sufficient automatic tie point measurement, even in the lower pyramid levels. From Figure 5 this situation is clearly visible. The yellow lines in the upper part and lower right of the block scheme indicate individual photos with no connection to the rest of the block. Without using GPS/inertial attitude data the quality of triangulation is very weak (at least) and in some cases might totally fail. Although a less accurate triangulation might be accepted for orthoimage generation in such areas, significant problems will occur when stereo mapping is performed (e.g. mapping of small forest tracks or clearings as they can be seen from the small flight strip in Figure 5). In such applications only the use of high-quality GPS/inertial attitudes could solve the problem and an acceptable block stability is established.

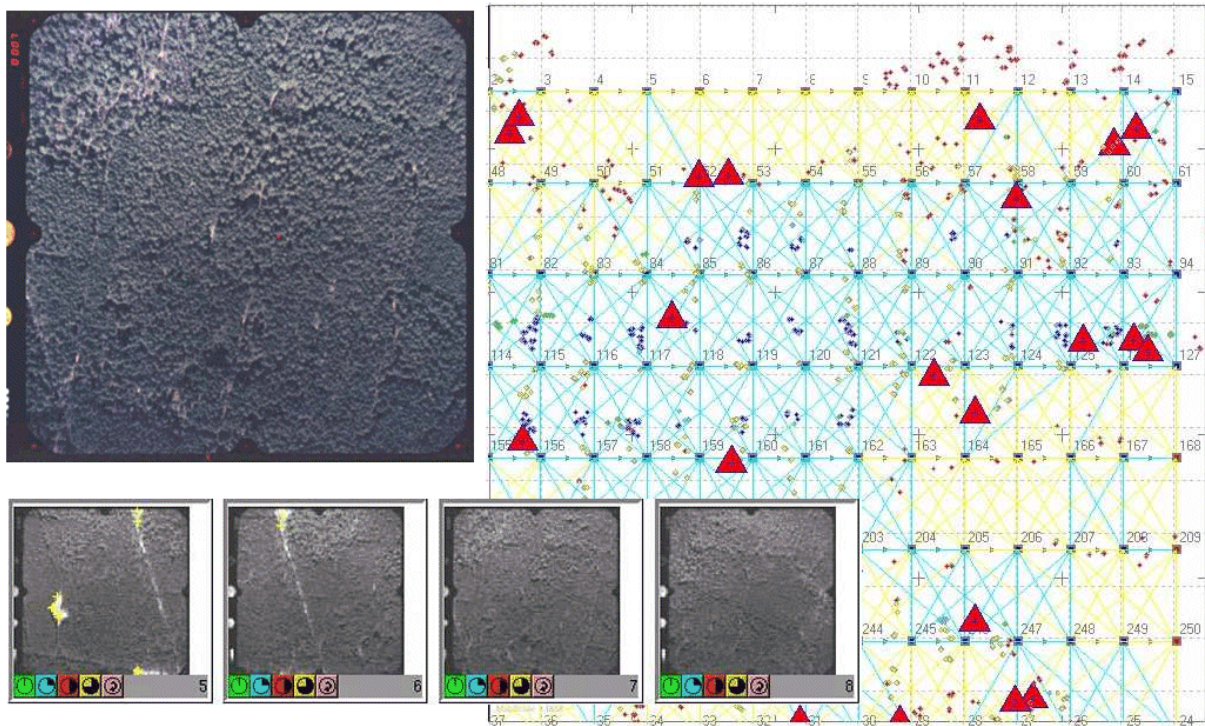


Figure 5: AAT with problematic image data (© inpho 2003).

4. CONCLUSIONS

Within this paper the use of GPS/inertial data in operational environments is highlighted. With GPS/inertial almost “on-line” direct georeferencing of digital sensor data in very short time intervals after data acquisition should be possible in optimal cases. Although the positive influence and potential of integrated GPS/inertial systems especially in combination with new digital sensors is proven and commonly accepted, practical experiences have shown that very special care has to be laid on the processing of GPS/inertial data itself. If the potential from GPS/inertial data integration is not fully exploited, non optimal exterior orientations from GPS/inertial will significantly decrease the quality of system calibration and object point determination. Although operator skills with such data processing will increase pushed by the increased use of this technology in future practice, still some projects will remain where pure direct georeferencing is not able to fulfil the aspired accuracy demands. In that cases, and only in that cases, GPS/inertial data should be used for integrated sensor orientation. Integrated sensor orientation offers the most effective way to calibrate the overall system and to compensate any remaining errors even with very reduced number of ground control. In the ideal case observations from high-quality GPS/inertial systems should be standard for automatic AT software modules. Although for typical block standard block configurations the accuracy increase is not really obvious especially in comparison with the productivity jump from standard AT to GPS-assisted AT, directly measured attitude data are supporting the automatic block organization and automatic image matching, especially in situations where image orientations significantly diverge from the assumed nadir case. For applications where image matching fails for large parts of the block area highly accurate GPS/inertial data are essential to keep a sufficient block geometry. With the broad future use of digital sensors the GPS/inertial technology will become standard tool within the sensor orientation process.

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