INTEGRATED SENSOR ORIENTATION – TEST RESULTS OF PHASE I

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1. TEST OBJECTIVES AND EXPECTED RESULTS

The European Organisation for Experimental Photogrammetric Research (OEEPE) has embarked on a multi-site test investigating integrated sensor orientation using GPS and IMU in comparison and in combination with aerial triangulation. The Institute for Photogrammetry and GeoInformation (IPI), University of Hannover acts as pilot centre. Data acquisition and pre-processing including the organisation of test flights and the necessary fieldwork was carried out by the Department of Mapping Sciences (IKF), Agricultural University of Norway in Ås.
The focus of the test is on the obtainable accuracy for large scale topographic mapping using photogrammetric film cameras. The accuracy of the results is assessed with the help of independent check points on the ground in the following scenarios:

- conventional aerial triangulation,
- GPS/IMU observation for the projection centres only (direct georeferencing),
- combination of aerial triangulation with GPS/IMU (integrated sensor orientation).

The test is expected to demonstrate to which extent direct georeferencing and integrated sensor orientation are accurate and efficient methods for the determination of the exterior orientation parameters for large scale topographic mapping.
Another test goal is to transfer the technology recently developed within the research arena to potential users. This goal is in line with the mission of OEEPE, and it is the main reason for choosing a multi-site test approach. As a consequence, the duration of the test is somewhat lengthy when compared to a single site investigation. This disadvantage, however, is taken into account, because we believe that in the long run the technology transfer issue is more important.

2. TEST SET UP

The test consists of two phases. The first phase comprises the determination of so-called system calibration parameters, i. e. the determination the boresight misalignment (the angular difference between the IMU and the image coordinate systems), and possibly additional parameters modelling GPS shifts, the interior orientation of the camera, GPS antenna offsets, time synchronisation errors etc. The second phase deals with the integration of the GPS/IMU data into the bundle block adjustment, i. e. the integrated sensor orientation itself.

2.1. Data acquisition and GPS/IMU pre-processing

Two companies producing suitable GPS/IMU equipment agreed to participate in the test, namely Applanix of Toronto, Canada, using their system POS/AV 510-DG[1] and IGI mbH of Kreuztal (formerly of Hilchenbach), Germany, with the system AEROcontrol Iib[1]. The test imagery was acquired in October 1999 by the Norwegian companies Fotonor AS and Fjellanger Widerøe (FW) Aviation AS using photogrammetric cameras equipped with a wide angle lens. For each GPS/IMU

[1] It should be noted that the equipment used for the test represents the state-of-the-art technology of 1999, and is a little out of date at the time of writing (July 2001). For instance, while in the AEROcontrol IIb from IGI dry-tuned gyros were used, they have been replaced by fibre optics gyros in the current system AEROcontrol IId. Similar developments have taken place at Applanix.

system calibration flights in two different scales (1:5.000 and 1:10.000) followed by the actual test flight in 1:5.000 were carried out. All six flights (three per company) were flown over the Fredrikstad test field in Southern Norway maintained by IKF.
From the raw GPS and IMU measurements flight trajectories for the camera projection centres and roll, pitch and yaw values describing a three-dimensional rotation from local level coordinate system to the body frame of the aircraft were computed by Applanix and IGI, respectively.

2.2. Phase I: System calibration and direct georeferencing

The first test phase deals with the determination of the system calibration parameters from the information of the calibration flights. Phase I also comprises the direct sensor orientation of the actual test flight based on the GPS/IMU data and the results of system calibration and – as part of the analysis of the results - the derivation of object space coordinates. Thus, all elements of direct georeferencing are contained in phase I.
34 potential test participants asked for the data, 13 participants returned their results in time to be included into this report (July 2001). Besides the two companies having provided the GPS/IMU sensor systems, three software developers (GIP, inpho, LH Systems), one National Mapping Agency (ICC Barcelona), one commercial user (ADR) and four university institutes (Milano, Stuttgart, Vienna, Hannover) have taken part in the test. Nearly all participants used existing bundle block adjustment programmes, partly augmented by additional software development. In this way, besides demonstrating the state-of-the-art in integrated sensor orientation, the distributed data also served as test data for refinements of the existing software, which is well within the goal of technology transfer.

2.3. Phase II: Integrated sensor orientation

The second phase deals with the integration of the GPS/IMU data into the bundle block adjustment in order to obtain an optimum, i. e. the most accurate solution. After having returned the results of phase I the participants have received image coordinates of tie points and GCP of the test flight images. Together with the system calibration parameters determined in phase I they have then performed an integrated sensor orientation, refining the exterior orientation (and partly also the system calibration parameters), and estimating the object space coordinates of the tie points and the GCP. These values have subsequently been returned to the pilot centre together with a detailed report describing the adopted model for the integration. Analysis of the phase II results is currently under way.

3. ANALYSIS OF PHASE I RESULTS

The results delivered back to the pilot centre have been analysed and are presented in this chapter. As was to be expected the different participants have used different approaches for computing the results. The two most noticeable distinction were (a) The number of system calibration parameters estimated in the adjustment: Many participants used the six standard parameters (3 GPS shifts, 3 misalignment angles), which can be computed from only one calibration flight. Some participants also corrected for the parameters of interior orientation and the additional parameters known from camera self-calibration, one participant also improved the time synchronisation between the attitude values and the exposure time; and (b) The choice of the object space coordinate system used for the computations. Seven participants worked in the UTM system, three of them in the mathematically more rigorous local tangential system, and one participant in both systems.
While it is obvious that in object space a comparison between the computed coordinates and those of independent check points can serve to judge the results, it is not clear a priori how to assess the

derived orientation parameters themselves. Rather than trying to analyse the GPS/IMU measurements and to quantify their accuracy we have taken a users´ perspective for this test and have looked at remaining y-parallaxes in the resulting stereo models. The reason for this approach was that the most sensitive application for the image orientations in terms of accuracy is that of stereo plotting, which relies on parallax-free models. Thus, if the determined exterior orientation is accurate enough for this task, it is also good enough for other tasks.
In order to analyse the participants´ results we have measured a dense set of conjugate points incl. all visible GCP in the test flight images using the analytical plotter Planicomp P1. In a second step, we transformed the image coordinates of the GCP into object space via a least-squares forward intersection with the exterior orientation of the participants being introduced as constant values. The resulting object space coordinates were then compared to the known values of the GCP yielding RMS differences, and the residuals in image space were interpreted as remaining y-parallaxes in stereo models formed using the participants´ exterior orientation.

The main results of phase I of the test can be summarised as follows:

- The accuracy potential of direct georeferencing lies at approximately 5-10 cm in planimetry and 10 – 15 cm in height when expressed as RMS values at independent check points, and at 15 - 20 µm when expressed as remaining y-parallaxes in image space.
- These values are larger by a factor of 2 - 3 when compared to standard photogrammetric results.
- For the IGI data the results do not depend on the chosen object space coordinate system, the situation is different, however, for the Applanix data. Here, the RMS values for planimetry and in particular for the height are significantly better in the more rigorous local tangential system than in the UTM system.
- Whereas in the IGI data a dependency on the chosen calibration model was not found, the Applanix results significantly depend of the number of parameters estimated during system calibration. Allowing for a change in the calibrated focal length and the position of the principal point improves the results approximately by a factor 2, a further refinement using self calibration parameters does not lead to significantly better results.
- Excellent results were obtained by explicitly introducing a possible time synchronisation error.

The most important finding is the fact that based on the obtained results direct georeferencing has proven to be a serious alternative to conventional bundle adjustment and currently allows for the generation of orthophotos and other applications with less stringent accuracy requirements. However, stereo plotting is not possible due to the relatively large remaining y-parallaxes, and the reliability of the results remains uncertain due to a lack of redundancy in absolute orientation Systematic errors in the GPS/IMU measurements cannot be detected without the introduction of GCP coordinates.
Based on the obtained results it is recommended to include the interior orientation parameters into the system calibration whenever possible. Also, an explicit consideration of possible time synchronisation effects also seems worthwhile. If it is not feasible to use two different calibration flights, the calibration should be carried out in the same scale as the actual project. In this case, some of the potential errors are highly correlated, and therefore their effect does not have to be modelled separately and explicitly.
As for the object space coordinate system, preference should be given to a local tangential system, because in this case the approach is mathematically more rigorous. If for whatever reason a project has to be carried out in a non-cartesian mapping system, however, also the calibration needs to be performed in this system.
It should also be noted that the test results have been obtained immediately after calibration. Within the test, no statement can be made concerning the stability of the system calibration parameters over time. Currently, it is generally recommended to carry out the system calibration before and possibly

also after each block. Since the actual physical reasons for the GPS shift and the possible changes in the interior orientation of the camera are unknown, this recommendation should be followed, at lest for high accuracy work.
In summary, it can be stated and comes as no surprise that the system calibration itself is more complex than one might think at first. This statement is not only motivated by the fact that direct georeferencing is equivalent to an extrapolation and therefore comes with all associated difficulties, but also by the fact that not all test participants have given full details of the actual procedure used for investigating the test data. While it is of course understandable that some crucial information is kept secret, in particular in the commercial arena, this lack of information renders a conclusive interpretation of the results more difficult. Nevertheless, we feel that we could reach the goals set out for phase I of the test.
Future developments in the areas of GPS and IMU sensors and data processing will probably also reduce this problem. The best results in terms of accuracy and in particular in terms of reliability are expected from an integration of GPS/IMU data into the bundle adjustment A point, which needs to be addressed in this regard, is the choice of a proper stochastic model for the GPS/IMU data. Integrated solutions are investigated in phase II of the OEEPE test; results will be available shortly.

WEB SITES ABOUT THE TEST:

http://www.nlh.no/ikf/projects/gpsins/
http://www.ipi.uni-hannover.de/htm-deutsch/forschung/laufend/oeepe-gps-imu/index.html