WORKING WITH GPS/INS

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ABSTRACT:

One of the basic problems of photogrammetry is the reconstruction of the elements of the exterior orientation. Over the last 40 years, triangulation techniques have been developed and improved, in order to determine these elements of the exterior orientation by computation.
A different approach is taken by the method of direct geo-referencing.
This technique allows to transfer sensor or object data immediately into a local or global co-ordinate system, which makes their further processing possible. Such a system exists of receivers of the global positioning system (GPS) on board and on the ground (reference stations) and an inertial system combined with a sensor, which determines angles and accelerations of the sensor with high precision.
Since the year 2000 Hansa Luftbild German Air Surveys is operating the modular system AEROcontrol™ (IGI, Kreuztal; Germany) in the combination with several sensors. In total more than 40 projects have been finished till 2003 with analogue and digital cameras. (besides the LiDAR projects which will be far more than 100).
Over time, pros and cons of the system have been witnessed, experiences in terms of reliability have been made. The technical procedure for flight preparation, flight mission and post-processing has been improved.
Quality checks in ortho photo projects have shown the precision of the exterior orientation parameter. Using the GPS/INS data as additional information in triangulation for areas of very low contrast (desert, e.g.) has been very helpful.
The technique of GPS/INS is clearly in a production stage for several applications, but also limitations have been found.

KURZFASSUNG:

Eines der grundlegenden Probleme der Photogrammetrie ist die Wiederherstellung der Aufnahmegeometrie durch die Elemente der äußeren Orientierung. In den letzten 40 Jahren, wurden Techniken zur Triangulation entwickelt und verfeinert, um diese Elemente der äußeren Orientierung berechnen zu können.
Ein deutlich anderer Ansatz wird bei der Methode der direkten Georeferenzierung genutzt.
Diese Technik erlaubt es, die gemessenen Orientierungswerte direkt in ein globales oder lokale Koordinatensystem zu übertragen für die direkte Weiterverarbeitung. Ein solches System besteht aus GPS Empfängern an Bord er Flugzeuges und am Boden sowie einem Sensor, der mit einem Inertialsystem kombiniert wird. Das Inertialsystem bestimmt Winkel und Beschleunigung der Sensors mit hoher Genauigkeit.
Seit dem Jahr 2000 setzt Hansa Luftbild das modulare System AEROcontrol™ der Firma IGI, Kreuztal ein in Kombination mit verschiedenen Sensoren. Insgesamt wurden bis zum Jahr 2003 mehr als 40 Projekt mit analogen und digitalen Kameras durchgeführt (zusammen mit Laserscanning-Flügen sind es weit über 100 Projekte).
In dieser Zeit hat man die Vor- und Nachteile des Systems kennengelernt und es wurden Erfahrungen mit der Zuverlässigkeit gemacht. Der technische Ablauf von Bildflugplanung über Bildflug bis zur Auswertung der Daten wurde diesen Erfahrungen angepaßt. Qualitätskontrollen in Orthophotos als Endprodukt haben den Beweis für die erreichte Genauigkeit erbracht. Auch als zusätzlich Beobachtungen in Triangulationen über schwierigem Gelände (z.B. Wüste) ist GPS/INS erfolgreich eingesetzt worden.
Die Technik des GPS/INS ist sicherlich Produktionsreif, allerdings sind auch einige wenige Einschränkungen gefunden worden.

1. INTRODUCTION

In the field of photogrammetry and remote sensing airborne sensors are more and more applicable. Hansa Luftbild German Air Surveys operates about 2000 hours per year of survey flights. The users are more and more requiring very fast, inexpensive and actual information.
The most common airborne sensors are still the optical systems (passive) like film cameras or in a growing number digital cameras. Additionally active sensors like the airborne laser systems (LiDAR = Light Detection And Ranging) or InSAR (Interferometric Synthetic Aperture Radar) are more and more important.
Users of all these sensors facing the same problem: it is necessary to know their 3-dimensional orientation during the time of detection of the information. This is known in photogrammetry as the determination of the exterior orientation parameters and is a standard procedure called aerial triangulation in the photogrammetric workflow.
In order to avoid ground control as much as possible, differential GPS were introduced to measur1e some of the elements of the sensor orientation in a direct way. Only in the last few years the direct measurement of all parameters of the exterior orientation (so called direct geo-referencing) by a combination of GPS and INertial System (INS) or Inertial Measurement Unit (IMU) was successful and could be offered at a reasonable price to the users.
In the following some of the projects and findings for an GPS/INS system in practical use should be introduced. The experiences out of the projects from the point of view of a service company will be described.

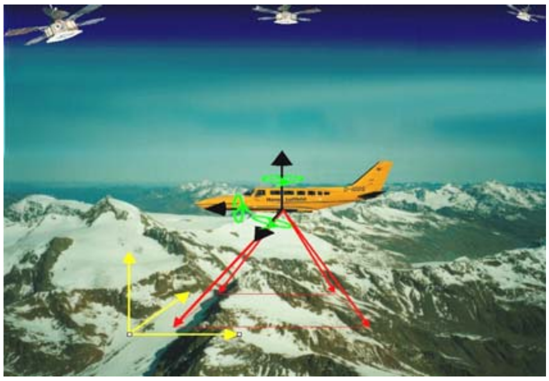

Fig. 1. Principle of direct geo referencing, Positioning (X,Y,Z) and rotations (ω, φ, κ) will be captured during the survey flight

Fig. 2. GPS/INS system AEROcontrol™ by IGI, Kreuztal, Germany

2. DIRECT GEO-REFERENCING

The method of direct geo-referencing allows to transfer sensor or object data immediately into a local or global co-ordinate system, which makes their further processing possible (see figure 1). Such a system exists of receivers of the global positioning system (GPS) on board and on the ground (reference stations) and an inertial system combined with a sensor, which determines angles and accelerations of the sensor with high precision.
Offsets between sensor and inertial system are determined by a calibration done by the user (boresight alignment). During post-processing, the GPS position is computed and the calibration results are taken into account. Finally the transformation from the global co-ordinate system (usually UTM /WGS84) to the requested local system has to be done.

The components of the complete system AEROcontrol™ are (see figure.2):

- Inertial system (INS)
- 12 channel L1/L2 GPS receiver
- AEROcontrol™ computer
- Flight management system CCNS 4
- GPS reference station

For post processing, the specific software AEROoffice™ by IGI is of course also needed.
Hansa Luftbild German Air Surveys operates successfully since the year 2000 two GPS/INS systems AEROcontrol™ by IGI, Kreuztal, Germany. The IMU unit is on demand attached to the camera, taken from the company own pool of five Zeiss RMK TOP and several Zeiss RMK A with different focal length.

2.1 Typical Work flow

Typically, at Hansa Luftbild German Air Surveys, GPS/INS data are used in ortho photo projects or LiDAR. This paper is restricted to camera projects only.
Following the sequence of a GPS/INS project in a commercial company, the typical work flow runs as follows:

- Acquisition of the project
- flight planing
- survey flight
- establishment of ground control
- computation of the projection centers
- triangulation of the calibration field
- computation of exterior orientation
- (triangulation of all images)
- production of final products

For each of these steps, attention has to be paid to specific needs of the GPS/INS project.

2.1.1 Acquisition Phase: During the acquisition of a project, it has to be checked carefully, whether or not GPS/INS technically and economically is suitable.
The project has to have a certain size – a calibration field of twelve images does not save much money when the complete project covers only 20 to 30 images. An exception to this could be very special conditions in the area in question.
For example:

- a triangulation block covering small and scattered islands,
- very homogenous areas with no details (ice, sand, e.g.)
- inaccessible areas (open pit mining, post war areas with land mines, e.g.)

Some of this cases might even make it necessary, to have a calibration field outside the project area, although the project is so small.

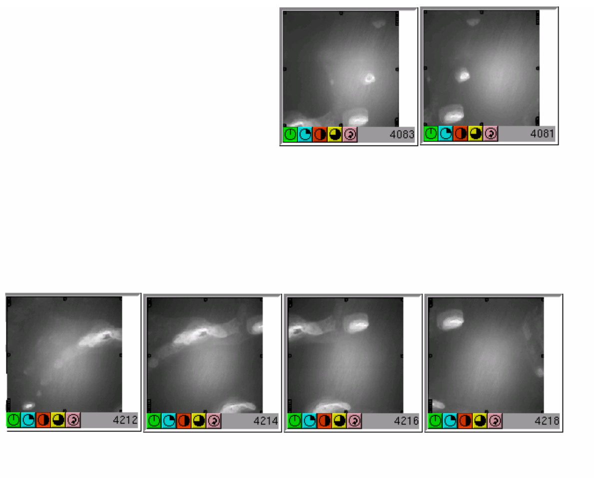

Fig. 3. Islands in the Red Sea

The accuracy is not needed to a extreme high level.
Using the calibrated orientation parameters directly without an overall triangulation, the accuracy on the ground, which can be reached, depends mainly on the flying height. The angular measurements of the IMU are published by IGI with 0.005 grades for ω and φ (roll and pitch) and for κ 0.01 grades. (heading) (AEROcontrol, technical information sheet).
Assuming a flying height of 1000 m, for ω and φ 0,07 m each on the ground and for κ 0.15 m, gives a total of about 0,1 m for angular measurements only. The expected accuracy of the projection centers has to taken into account as well as the quality of the DTM data used.

The score of the project are ortho photos, no measurements are involved, e.g. a DTM.
Using the calibrated orientation parameters directly without an overall triangulation, might or might not be sufficient for stereo restitution.

Can the project be done using other techniques?
The question might sound strange, but sometime GPS/INS is the only possible technique to fulfil customers requests considering the time planed for the project or the terrain involved , e.g..
A triangulation of about 1770 images along a planned pipeline with some sixty flight lines covering about 770 km can be done in six weeks including the establishment of ground control. But that was the time, we had from offer to delivering finished ortho photo mosaics.

Fig. 4. Flight layout for a pipeline planing, Germany

The customer accepts the technique.
Even if all parameters are perfectly set up for a flight based on GPS/INS, the customer sometimes cannot be convinced to use this rather new technique.

2.1.2 Flight planing is the next step in the procedure.
Of course, these flights have to be based on kinematic GPS, where the distance to the GPS station should exceed 50 km.
Within Germany, a dense network of permanent public GPS base station can be accessed easily. For international missions, the base stations have to be mostly organised in a sufficient number and quality.
The layout of the flight has to consider the fact, that turns have to be made with less than 20 grades roll, in order not to loose the GPS signal. Flight restrictions along national borders , e.g. can therefore become a even larger problem.
Transport of the high-tech equipment can also become a problem due to restrictions in export of these technical products to certain countries.

The calibration field used to be a small area covered by two strips with six to eight images each, where side and forward overlap were set to 60 percent. This requirement was relaxed by IGI to 60 percent forward and 30 percent side lap with the latest software solution, so any part of a usual survey flight can be used.
The time spend on a flight line should not exceed 20 min. in order to restrict the drift for heading to the specified accuracy of 0.01 grades. If an integrated sensor orientation is planed, this restriction does not apply, because the heading is of less influence.

2.1.3 The survey flight has to start with an initialising phase of some minutes for the system while still grounded which is needed for the real time solution during flight rather than the post processing.
Shortly before arrival at the project area, a s-turn had to be flown to activate the inertial system. This requirement was also relaxed by IGI lately with the latest software solution.
At the end of the strips, left hand side and right hand side turns should alternate.. This is to avoid possible cumulating of errors.

2.1.4 Ground control has to be established within the calibration field. Usually natural points are chosen (man holes, corner of building, e.g.) and co-ordinates provided by local survey. In some cases, co-ordinates are taken from cadastral information or even a map. The accuracy needed depends of course on the image scale.

2.1.5 Computation of the projection centers can be done using Aerobic™, where the GrafNav DGPS software package of Waypoint Consulting Inc. is delivered with. Other packages can be used as well.

2.1.6 The triangulation of the calibration field are done at Hansa Luftbild German Air Surveys digitally, utilising the GPS positions as additional observations. The RMS of the projection centers is set to 0.01 m, in order to keep them nearly fixed.

2.1.7 Exterior orientation values for all images are computed finally. The difference between the exterior orientation values for ω, φ and κ determined by GPS/INS and the triangulation for the images of the calibration field serve as calibration values. This is applied to all other angular measurements of the project.

3. Examples

3.1 Project Hessen

The federal state of Germany Hessen (21115 qkm) had to be covered with CIR-images scale 1: 24.000 within a short period of time in early summer 2003. About 2800 images (60 % forward overlap) have been taken with 12 flights within 8 days, using 3 planes, and three cameras (two at the time), equipped with GPS/INS. The IMU´s had to be changed between different cameras.
In order full fill the very tight time schedule to produce ortho photos, it was decided to scan only every second image and use the results of calibrated GPS/INS directly without overall triangulation. Distributed over the area, three calibration fields have been established.

day	**camera**	**plane**	**IMU**	**Roll=ω**	**Pitch= φ**	**Heading= κ**	**Roll RMS**	**Pitch RMS**	**Heading RMS**
14.07.	141297	IBGF	2	0.2833	-0.0511	0.1477	0.0049	0.0029	0.0098
15.07.	141297	IBGF	2	0.2818	-0.0433	0.1551	0.0017	0.0040	0.0050
15.07.	141297	IBGF	2	0.2697	-0.0487	0.1467	0.0037	0.0031	0.0044
16.07.	141297	IBGF	2	0.2783	-0.0477	0.1498	0.0028	0.0035	0.0056
16.06.	141308	IDOS	1	0.2600	-0.0375	0.0010	0.0032	0.0028	0.0097
17.06.	141308	IDOS	1	0.2634	0.0348	-0.0267	0.0034	0.0015	0.0074
13.07.	141308	IHLB	1	0.2916	-0.0439	-0.0288	0.0039	0.0031	0.0182
14.07.	141308	IHLB	1	0.2792	-0.0485	-0.0100	0.0024	0.0021	0.0162
16.07.	141308	IHLB	1	0.2353	-0.0524	-0.0329	0.0043	0.0026	0.0157
20.07.	141308	IBGF	1	0.2296	-0.0523	-0.0419	0.0043	0.0027	0.0135
16.06.	141829	IBGF	2	0.0970	-0.0725	0.0579	0.0025	0.0041	0.0084
17.06.	142829	IBGF	2	0.0963	-0.0715	0.0628	0.0028	0.0026	0.0095
26.06.	142829	IBGF	2	0.0870	-0.0135	0.0949	0.0031	0.0045	0.0100

Table 1: results of GPS/INS for project Hessen

From the results in table 1, one can conclude mainly two things:

1. The accuracy achieved after post-processing is within the expectations, given by IGI.
2. If the data should be used for direct geo-referencing without integrated sensor orientation, calibration of the system is needed for each and every flight. Even if the IMU has not been detached (flight 15.07., morning and afternoon, e.g.), the results differ considerably.

The project has been finished successfully.

3.2 Project Pipeline

For pipeline planning in Germany, ortho photos had to be produced. The total distance was about 770 km, including several variations in certain areas (see figure 4). As already mentioned, the time table was tight (six weeks) and the budget of course not very high.
Using an image scale of 1: 6.000, 1770 images covered the complete project, flown in five consecutive days. Four calibrations fields have been established distributed over the area to minimise additional flying to reach the nearest one.
Also this project was flown with 60% forward over lap, out of which only every second image was scanned. Also here, no overall triangulation took place, which reduced the number of ground control points from app. 250 to 24.
The DTM could be bought from the local survey authorities.
This way, about 500 ortho photos mosaics have been produced (nearly) in time.

4. Conclusions

For the first projects, Hansa Luftbild German Air Surveys had an signalised general calibration field in the vicinity of the home airport Münster Osnabrück. Laid out for an image scale of 1: 6.000, 22 ground control points have been permanently signalised. The idea was, to have a reliable calibration field for permanent using, which could easily be flown just after starting or before landing or even both. From the economic point of view, it was planed to be a mid term investment, which would reduce cost overtime for GPS/INS projects.

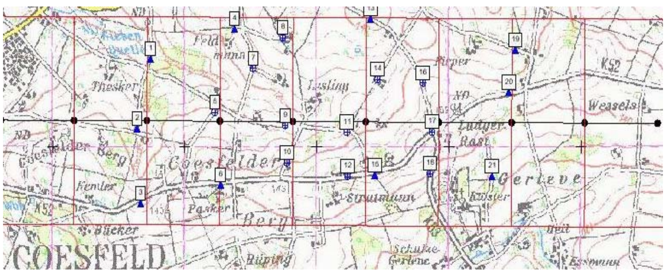

Fig. 5. Layout of the general calibration field

It was never the case, that due to clouds over the calibration field, this could not be used before or after a GPS/INS flight.

But very soon it was found out, that different conditions in terms of image scale and therefore flying height caused so different meteorological conditions (temperature, pressure, e.g.) that this caused problems. For projects close by and similar project parameters concerning image scale, etc. the results have been within the expectations. But this was not the case for projects with image scales of factor 3 or more, (6.000 to 18.000, e.g.) or locations several hundred kilometres off. During quality checks for these ortho photo products, large discrepancies between neighbouring stripes have been found, which could not be explained by simple reasons. By computing a triangulation, it was shown, that the exterior orientation was the source.
The calibration for these projects had to be repeated with data taken from the actual project area, which drastically improved the result. Consequently, the calibration field in the vicinity of the airport was abandoned and since then, the boresight alignment is done under the same conditions in the actual project area successfully.
This shows that the process of calibration does not only serve the task to determine the offset between projection center and center of the IMU. Also influences of transformation to the local system, variations in the focal length due to influence of pressure and temperature during flight, e.g. are modelled in the triangulation process an therefore included in the calibration values.

Direct geo-referencing for ortho photos can be used quite successfully – technically and economic – by using the calibrated results directly. The possible loss of accuracy compared to a triangulation has to be balanced against the gain in speed and higher economic performance.

From the point of reliability of the GPS/INS system , there was absolute no problem – no loss of data or any other complication so far.

Using direct geo-referencing for stereo restitution was tried only once in a very small project at Hansa Luftbild German Air Surveys. It was successful, but due to the structure of most of our contracts, usually the achievable accuracy does not meet the requirements of the stereo restitution projects.

Using the GPS/INS data as additional observations in a digital triangulation process make sense in certain described cases, but in general, the matching process runs with the kinematic GPS data already quite well.

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