ON THE USE OF MODERN GPS RECEIVER AND SOFTWARE TECHNOLOGY FOR PHOTOGRAMMETRIC APPLICATIONS

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ABSTRACT:

In the last years, photogrammetric equipment in an aircraft can not be restricted to an aerial camera alone. The use of the Global Positioning System (GPS) for photo flight navigation and automatic control of aerial cameras is already widely spread. Also, the concept of GPS based aerial triangulation by using post processed GPS raw data in combination with photogrammetric image data can be considered as operational. The cost benefits for the user, by the reduction of flying time and ground control have lead to a fast acceptance of this new technology. It is the aim of this paper to give an overview of the performance of „state of the art" GPS hard- and software and to discuss requirements and solutions posed by photogrammetric applications. Two points which have caused uncertainty amongst photogrammetrists will be specifically addressed: the performance of new GPS receivers and the question if dual frequency receivers are needed in photogrammetric applications.

KURZFASSUNG:

In den letzten Jahren wurde zunehmend deutlich, daß man die photogrammetrische Ausrüstung in einem Flugzeug nicht allein auf die Luftbildkamera beschränken kann. Mittlerweile, wird GPS für die Flugnavigation und das automatische Auslösen der Kamera an vordefinierten Positionen bereits häufig in der Praxis eingesetzt. Auch die GPS gestützte Aerotriangulation kann heute als operationell betrachtet werden. Die Kostenreduktion durch die kürzeren Flugzeiten und die deutliche Reduzierung der erforderlichen Paßpunkte haben zu einer schnellen Akzeptanz dieses Verfahrens geführt. Es ist das Ziel dieses Aufsatzes die Qualität und Leistung der aktuellen Hard- und Software aufzuzeigen und darüber hinaus die Anforderungen und Lösungsansätze für photogrammetrische Anwendungen aufzuzeigen. Speziell werden zwei Punkte vertieft diskutiert, die in der nahen Vergangenheit einige Unsicherheiten bei Photogrammetrie Anwendern hervorgerufen haben: die Güte der neuen Empfängergenerationen und die Frage ob Zweifrequenzempfänger in photogrammetrischen Anwendungen notwendig sind.

1. INTRODUCTION

GPS for photogrammetric applications has become extremely popular in the last decade, due to the advantages of accuracy, speed, versatility and economy. Generally, there are three major areas where GPS plays a key role in photogrammetry:

- high precision photo flight navigation for a reduction of flying time
- automatic camera release at predefined positions, for a perfect image overlap and less camera operator stress
- combined block adjustment of GPS and image data, for a significant reduction of ground control points

Flight navigation and automatic camera release is already standard for technologically advanced aerial camera users. Also, the financial benefits of the combined block adjustment (CBA) has been accepted widely. Products, such as the LEICA ASCOT system (Merminond [1994]), already provide a continuous and comfortable data flow from the flight planning to the block adjustment. However, the rapid changes in GPS receiver technology and processing algorithms, require a constant evaluation of the currently available methods and products. It is the aim of this paper to give an overview on the current GPS technology (hard- and software) and to discuss the impact of this new technology on the specific photogrammetric applications.

2. ACCURACY REQUIREMENTS

The required accuracy for the photogrammetric GPS application can be grouped in two main areas: navigation + automatic camera release and as a second area GPS post processing for combined block adjustment. Depending on the application area and the desired image scale the required positioning accuracy may vary significantly. The Figures 1 and 2 summarize the respective required accuracies for the two application areas.

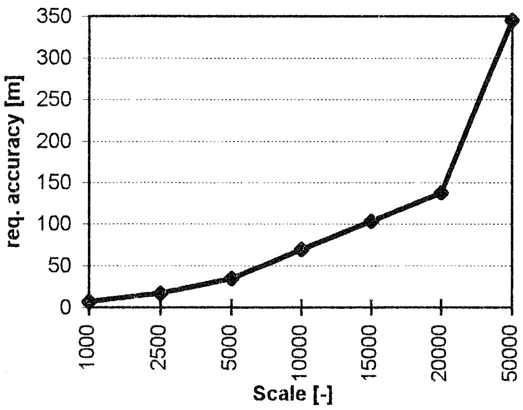

Figure 1 Required Accuracy for Navigation and Automatic Camera Control

The above figure is based on the assumption that 3% overlap error is tolerated in a conventional survey flight. Similarly, a „rule of thumb" can be used for the estimation of the required accuracy for the combined block adjustment.

$$A_{REQ} = \sigma_0 * m_B * 1.5$$

Typically the measurements of a block adjustment can be carried out with a σ_0 of roughly 10 μm. The corresponding required accuracy (A_{REQ}) of the camera perspective centers is related to this value via the scale. Due to the intersection geometry and the averaging effects in a block adjustment a detoriation factor of 1.5 to 3 may be applied (see also Ackermann [1992])

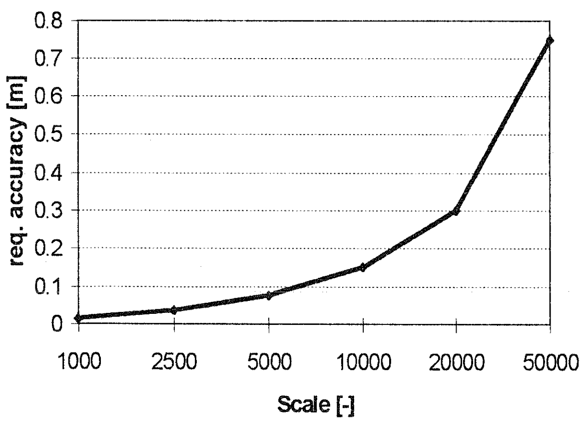

Figure 2 Required Position Accuracy for the Camera Perspective Centers in a Combined Block Adjustment

As it can be seen from the above figures the accuracy requirements may vary between a few centimeters to hundreds of meters depending on the required scale and application. It is obvious that the techniques and the hardware requirements to achieve the quoted positioning accuracies are also extremely different. Similar to the difference in required accuracy, also the operational circumstances for the two major photogrammetric applications are different. While absolute, real-time positioning with medium accuracy is required for navigation and camera control, highly accurate post-processed positions are required for the GPS based aerial triangulation. Table 1 summarizes the operational circumstances and the solutions which are provided by GPS for the specific application areas.

Operational Circumstances	**navigation + automatic camera control**	**GPS based aerial triangulation**
Required Accuracy	10-300 m	0.01 - 1 m
Movement	highly dynamic	highly dynamic
Time of position	Real Time	Post-Processing
Differential positioning	only limited, with radio link	yes
Baseline-Length	10-500 km	10-500 km
Receiver Update Rate	min. 1 Hz	min. 1 Hz
Ambiguity Resolution	not required	required in large scale applications
Observation Type	Code only, Carrier smoothed code	Phase only, Carrier smoothed code

Table 1 Operational Circumstances for the major photogrammetric application areas

After giving this short introduction to the specific needs of photogrammetric GPS applications, the remainder of this paper will concentrate on GPS-hardware and algorithmic aspects, which are of special importance for photogrammetry.

3. HARDWARE AND SOFTWARE ASPECTS

Today many GPS receivers are already built for specific applications, like GIS data collection, precise static (or static like) geodetic surveying, high dynamic or low dynamic navigation, or even leisure time applications, but there is no receiver on the market which has been specifically designed for photogrammetric applications. From the photogrammetrists point of view, to choose a receiver and the corresponding processing software is rather difficult. Especially the highly dynamic environment and the stringent accuracy requirements over extremely long baselines are not standard capabilities which can easily be solved with today's GPS technology. To find the appropriate receivers and software, which can provide such high precision results even under these stringent conditions is rather difficult, as also the terms in the data sheets and the quoted performance parameters are often misunderstood or misleading. (A good overview over today's receiver technology can be found for example in van Dierendonck [1994]).

Today, normally two types of receivers are used for photogrammetric applications:

- dual frequency geodetic receivers
- single frequency navigation receivers

As it can be seen from Table 2 each of the two receiver types have certain advantages and disadvantages. The major difference in the receivers and also in the price, is the inherent positioning accuracy, and their ruggedness in an airborne environment. In principle the geodetic receivers can provide more accurate positioning results, both in real-time and post-processing, as the ionospheric error effects can be eliminated using a linear combination of L1 and L2 observations. Also, the dual frequency observations are the key to resolving ambiguities on the fly. However, it is necessary to discuss the necessity of this feature in connection with photogrammetric applications more specifically (see Chapter 6).

	Geodetic Dual Frequency Receiver	Single Frequency Navigation Receiver
Observation Types	L1: carrier, C/A-Code, P-Code L2: carrier, P-Code	L1: carrier, C/A-Code
Accuracy	low noise, by narrow correlator or P-Code tracking	low to medium noise with narrow correlator tracking
Ionosphere	Ionospheric free linear combination	can only be modeled
Tracking bandwidth	usually very narrow	medium
Measurm. Frequency	usually 1Hz	at least 1 Hz
Ambiguity Resolution On the Fly	Possible under optimal conditions	most likely not possible with GPS data alone
Channels	typically 12 continuous („all in view")	typically 6-12 continuous
Electromagnetic Impact	sensitive	usually not very sensitive
Price range	high	low to medium

Table 2 Performance characteristics of GPS receivers used in photogrammetry

4. DESCRIPTION OF THE TEST DATA

To assess the performance potential of modern GPS receivers under photogrammetric conditions a series of tests has been carried out with two receivers which are used in photogrammetry today. The SR 399 is a full dual frequency receiver, which has been mainly designed for high precision geodetic applications. It provides C/A-Code observations on the L1 frequency with a noise reduction using the narrow correlator technique. P-Code observations are available even under Selective Availability as a proprietary, patented P-Code technique is used. Phase observations are availbale on both frequencies (Jackson et al. [1995]). On the other hand the 9212-Aero is a receiver mainly designed for navigation in a rugged dynamic environment. It is a continuous 12 channel single frequency receiver, giving L1 carrier phase and C/A-Code observations.

The data which was used in this analysis is from two testflights which have been carried out over the photogrammetric test fields in:

- BUCHS, close to the Leica Factory in Switzerland
- OHIO, a photogrammetric testfield in the vicinity of Columbus, Ohio, USA

The most important parameters for these testflights are summarized in Table 3.

	Test Ohio	Test Buchs
Image Scale	1:8000	1:4000
# of Lines	3	3
# of Images	14	20
Forward Lap	80 %	60 %
Side Lap	30 %	30 %
Camera	Leica RC 30	Leica RC 30
# of control points	42	57
GPS receiver	Leica SR 399	Leica 9212-Aero
Anti-Spoofing	On	On
Distance from Reference Station	< 20 km	< 80 km

Table 3 Blockparameters for Testflights Ohio and Buchs

The coordinates of the camera perspective centers which are taken as reference for the accuracy analysis are derived from a conventional aerial triangulation. In the 1:4000 block Buchs the estimated σ_0 for the perspective center coordinates is 2.3 cm and for the Ohio block the σ_0 is 4.9 cm.

5. ACCURACY OF REAL TIME POSITIONING FOR NAVIGATION AND CAMERA CONTROL

As it has been mentioned above, photo flight navigation and automatic camera release requires real-time positioning. Today, the real-time position computations are usually based on code observations from the airborne receiver alone. Normally, no radio links are used to increase the positioning accuracy using real-time differential GPS. However, the situation may change, as wide area augmented GPS networks and additional satellite systems are currently beeing built up (McLellan et al. [1994], Till et al. [1994]), to provide GPS correction signals with standardized communication protocols, allowing for real-time differential code positioning. It will take another few years until real-time differential phase positioning becomes feasible for airborne applications. The limiting factor is the high transmission rate, which is required to transmit all the phase observations within the measurement update rate.

For the tests which have been carried out in the scope of this paper no radio link was used. The coordinates which have been derived from the real-time code solutions of the airborne receiver were compared with the results from the aerial triangulation. The differences between these solutions are shown in figures 3a and b for the two receiver types.

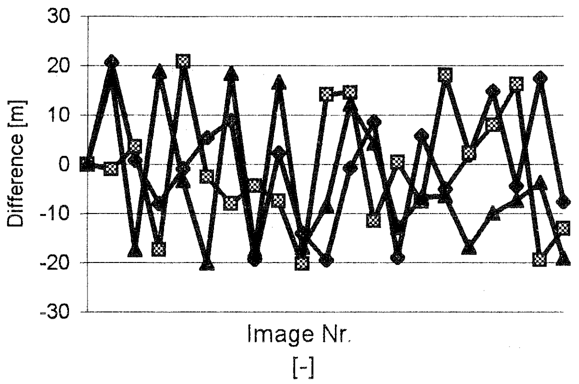

Figure 3a Differences (x,y,z) between Aerial Triangulation and Real-Time Computed Positions (Leica 9212 Aero)

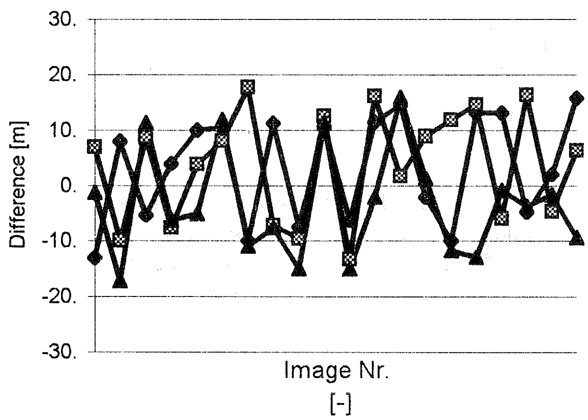

Figure 3b Differences (x,y,z) between Aerial Triangulation and Real-Time Computed Positions (Leica SR 399)

For the Leica 9212-Aero a root mean square value of 16.24 m has been achieved over all 3 coordinate components (x,y,z). As expected the performance of the SR 399 is slightly better (r.m.s. = 14.25), because the receiver is capable of reducing the effect of the ionosphere using the observations on both frequencies. Also, it is expected, that the signal to noise ratio of the SR 399 is superior to the one of the 9212-Aero receiver, as special techniques allow P-code aided tracking on both frequencies. Similar accuracies could have been achieved in further tests under varying conditions. Apart from the above mentioned features the dual frequency receiver does not have apparent advantages over the cheaper single frequency navigation receiver. When comparing the achieved results with the demands for photoflight navigation and automatic camera release, it can be seen, that using the tested hardware the given accuracy requirements can be met even for large scale applications.

6. ACCURACY OF POST-PROCESSED DGPS CAMERA COORDINATES FOR REDUCTION OF GROUND CONTROL

Besides navigation and camera control, GPS is used more frequently for the determination of the camera perspective centers. The economic benefits, due to a significant reduction of ground control points have convinced photogrammetrists to use post-processed GPS observations in the block adjustment. Although, the majority of the GPS error sources can be eliminated by differential positioning, the code observations of modern receivers still can not provide the required centimeter accuracy for large scale applications. To achieve this accuracy it is necessary to use the GPS carrier phase observations. However, the problems with the phase observations is, that it is necessary to determine the correct set of cycle ambiguities in order to exploit the inherent accuracy of a few millimeters. Several methods have been proposed to fix the cycle ambiguities in an airborne environment. These methods will be briefly reviewed here:

1. As long as no loss of lock or cycle slips occur, the ambiguities remain constant integer values. In principle, they can be estimated and fixed in a static initialization at the beginning of a continuous trajectory, but due to banking angles in flight turns and the highly kinematic environment losses of phase lock and cycle slips are frequent in photogrammetric applications.
2. Ambiguity resolution on the fly (AROF), tries to resolve the carrier phase ambiguities from the GPS data alone. Sophisticated statistical tests are used to distinguish between the correct and incorrect ambiguity sets.
3. The third method is the combined adjustment of GPS and photogrammetric image data (CBA). The ambiguity resolution is done in a two step procedure. In a first step the ambiguities are fixed only roughly in a GPS post-processing step and the final determination of the camera perspective center coordinates is done in the block adjustment using the image coordinate measurements and the post-processed GPS positions (Frieß [1990], Ackermann/Schade [1993]).

It is obvious, that the first method has lost importance, due to the doubtful reliability and the unfavorable economic aspects as flat turns increase the flying time considerably.

Today, photogrammetrists are usually choosing between the methods 2 and 3. Under geodetic conditions ambiguity resolution on the fly has already reached an operational status (see e.g. Frei/Beutler [1990], Hatch [1990]). The statistical tests which are used in AROF are based on the assumption, that the carrier phase observations are unbiased, therefore several side conditions have to be observed when trying to do AROF:

- The distance between the reference station and the roving receiver may not exceed 10-20 km so that all common systematic error effects are canceled out when differencing the observations from the reference station and the rover.
- At least 5-10 minutes of continuous data is required for a successful ambiguity resolution, because a certain number of observations are required to achieve a maximum significance level in the statistical tests.
- No, larger biases may be on the phase observations (e.g. from multipath or larger tropospheric differences) because otherwise the statistical tests produce incorrect results.
- Dual frequency receivers are required, to allow for widelaning observations

Until today, these prerequisites have prevented a successful and economical use of AROF in airborne photogrammetric applications. (see e.g. Schade [1992]). The reasons speaking against AROF in an airborne environment are:

- the critical logistics: it is often difficult to have a reference station within a radius 10-20 km. Especially, under varying weather conditions the flying crews often do decide in a short time which project will be flown during the day. Further the photogrammetric projects often cover larger areas, so that multiple reference stations are necessary.
- the tropospheric errors which are still inherent in airborne GPS data even if observation differencing is used. Differencing can not eliminate the error effects, because the tropospheric conditions (temperature, pressure) in the aircraft and on the ground reference station are usually clearly different.
- using AROF also flat turns have to be flown, because longer continuous stretches of data are required for a successful ambiguity resolution.

The major advantage of using AROF is, that in principle no ground control points would be required if the correct ambiguities could have been estimated. However, doing a block adjustment entirely without ground control brings up some other problems which need to be addressed:

- The datum transformation between the WGS 84 and the mapping system needs to be known with cm accuracy
- The geoid in the block area needs to be known with cm accuracy, as the GPS heights are not orthometric
- estimation of self calibration parameters in the block adjustment is not possible without any ground control points
- Quality control is very difficult (How can one find an error in the camera focal length?)

The combined block adjustment (CBA) of GPS and image coordinates is based on the idea, that GPS and aerial triangulation can both determine the camera perspective center coordinates. The concept is that the GPS ambiguity resolution is done in the blockadjustment, and although more unknowns have to be estimated, the number of ground control points can be reduced significantly. The GPS observations strengthen the block so much, that normally a minimum of 4 ground control points in the block corners are sufficient for the adjustment. As the ambiguity resolution is ususally done stripwise, losses of phase lock may occur during the turns, hence no restrictions apply to the normal flying behavior. Especially, steep turns may be flown without paying attention to loosing the GPS signals. GPS biases, like troposphere, ionosphere or clock errors can also be modeled in the block adjustment, so that the distance between the reference station and the rover can be as much as 500 km. Also, with the CBA there is no need for dual frequecy obsevations, as the ambiguity resolution is supported wit the image coordinate observations. The above mentioned operational advantages have lead to the conclusion that the combined block adjustment is still the better choice for the use of GPS in photogrammetric post-processing.

For the performance analysis of the GPS receivers, the cycle ambiguities have been determined with the combined block adjustment method. Figures 4a and 4b show the differences between the conventional block adjustment and the GPS positions which have been determined with the cycle ambiguities in the combined block adjustment.

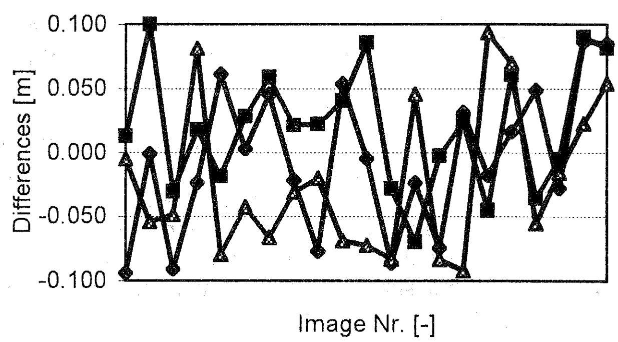

Figure 4a Differences (x,y,z) between Aerial Triangulation and GPS Post-Processing Positions (Leica SR 399)

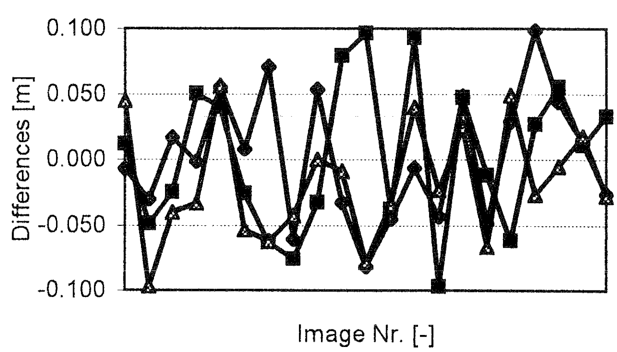

Figure 4b Differences (x,y,z) between Aerial Triangulation and GPS Post-Processing Positions (Leica 9212-Aero)

For both cases the estimated root mean square values over all 3 coordinate components are very similar (4.2 cm for SR 399 and 4.4 cm for Leica 9212 Aero). This demonstrates, that the combined block adjustment compensates sufficiently for all systematic GPS errors, and that the ambiguity resolution has been successful in the combined block adjustment. This example also demonstrates, that an L1/L2 receiver does not bring any significant gain in accuracy as compared to the L1 receiver.

7. SUMMARY AND CONCLUSIONS

This paper has analyzed the performance of new generation GPS receivers under the specific and stringent conditions of a photogrammetric survey flight. Special attention has been given to the needs for navigation, automatic camera control and precise positioning of the camera perspective centers to reduce ground control points. The performance analysis has been done with a high quality dual frequency geodetic receiver and a single frequency navigation receiver. Both receivers did not show any major accuracy differences in the photogrammetric application areas. This result leads to the conclusion that there is still no need to switch to the more expensive dual frequency receivers for photogrammetric applications.

Further, the ambiguity resolution on the fly has been compared to the combined block adjustment (CBA) of photogrammetric and GPS data, setting a special focus on the new GPS receiver technology. Although, using the new receiver technology, ambiguity resolution on the fly becomes feasible even in an airborne environment, the side conditions which are required today to make the ambiguity resolution reliable are so stringent, that this procedure can not be fully recommended for practical use. Due to the simplicity of use, the robustness, the simple logistics and the favorable economic aspects the combined block adjustment is still the best choice for photogrammetric GPS post-processing applications. However, one should be aware that this situation may change if new receivers with improved code accuracy, or improved algorithmics make the ambiguity resolution reliable even over large distances and with short data sets.

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