USE AND BENEFITS OF X, Y, ΔZ AUXILIARY DATA FOR AERIAL TRIANGULATION - RESULTS OF THE TEST MISSION "BODENSEE" 1982

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1. INTRODUCTION

The developers of computer controlled navigation systems have, up to now, concentrated entirely on the flight navigation aspects of the systems and on the subsequent benefits derived from regular photo coverage.

There is a second aspect, however, which seems not to have been pursued so far. It refers to the fact that air survey navigation data are, or can be converted to, camera orientation data which could be used in the subsequent data processing in-conjunction with photogrammetric image evaluation procedures.

There are two cases to be distinguished:

a) Direct use of camera orientation data for the absolute orientation of photographs. This is, of course, an ideal ultimate aim. It would simplify all photogrammetric orientation procedures tremendously. It has been suggested very often and also tried to some extent.

   Unfortunately, the presently obtainable navigation data do not meet the accuracy requirements of direct absolute orientation of photographs for most of the photogrammetric processes. The accuracy requirements would be about 5 cm - 1 m in position (depending on photoscale) and 0.4 mgon - 1 mgon in angular attitude.

b) In the second case camera orientation data are only used as additional observations to be processed together with photogrammetric data in a combined adjustment procedure. This way of using navigation data is particularly important for aerial triangulation, i.e. the simultaneous computation of the orientation of all photographs of a block, together with the determination of the ground coordinates of an arbitrary number of terrain points, This method is known in photogrammetry as aerial triangulation (block adjustment) with auxiliary (orientation) data.

The expectation is, that auxiliary orientation data are highly efficient, they stabilize a block considerably, and allow a great reduction in the necessary number of ground control points, even when the auxiliary data are not precise enough for direct use as orientation data.

The success of the method is based on the fact that a block is formed conventionally, by well known aerial triangulation methods. It's particular property is high relative precision. On the other hand the auxiliary data, by virtue of their different error properties, control the long range errors of a block very well. For instance, the datum errors of the auxiliary data are compensated by the block, in conjunction with some ground control points. Thus the combined result will be extremely favourable, making best use of the different error properties of either class of data.

The following presentation refers only to this case, i.e. to the use of navigation data as auxiliary orientation data in the joint adjustment of photogrammetric blocks.

2. SOME SIMULATIONS AND PRE-STUDIES

In order to assess the potential of navigation data in combination with block adjustment a number of preliminary studies and simulations were carried out at the Photogrammetric Institute of Stuttgart University (in conjunction with the Ph.D. thesis of P. Suharto). The simulations concentrated on positional data (x, y) of the camera stations.

The ultimate aim is, to develop a blockadjustment computer program which could handle data from navigation systems such as INS (inertial navigation) and the Thomson CPNS system (computer controlled navigation system , based on the Trident system of continuous positioning). Later, an extension to GPS (global positioning system) satellite data is planned.

The theoretical approach implies combined adjustment of navigation data and of photogrammetric aerial triangulation measurements, either set of data being appropriately weighted. A decisive feature of the system is that the drift of the navigation system, the datum errors and other systematic errors are taken into account by additional unknown parameters which would sufficiently model the error effects which would be determined by the adjustment. The important result of this approach is that no absolute values of navigational positioning data are required. It is only their relative positioning capability which becomes effective. The intention is to reduce ground control requirements to perhaps 4 horizontal ground control points only, located in the 4 corners of a block.

Whether it will be possible to use the combined system without any ground control at all remains to be seen.

The simulation studies will not be laid out in detail here. Although they refer to somewhat idealized assumptions the overall result permits very optimistic expectations. Accordingly, the use of navigation data as auxiliary data will be most favourable. The studies confirmed that such data will stabilize a block very much and allow considerable reduction of horizontal ground control, even when the accuracy of the auxiliary data is rather poor. All preliminary results suggested that at least for medium and small scale mapping the system would be highly effective and economical.

With regard to the third dimension no pre-studies were made, as sufficient experience is available from block adjustment with statoscope data. Vertical auxiliary data have already been proven to be most effective and permit drastical reduction of vertical ground control.

The extended computer program for block adjustment with auxiliary data has not yet been developed. The available program PAT-M, however, is directly capable of handling CPNS positional data and statoscope data as well. The reason is that CPNS data should not have any substantial drift errors. The perspective centres can therefore be used directly as additional control points with appropriate weights. The PAT-M program can handle this case directly.

3. EXPERIMENTAL RESULTS FROM THE CPNS FLIGHT "BODENSEE" 1982

In 1982 a test flight in the Bodensee area (Lake of Constance) was organized by Grimm/Heimes. It's main purpose was to test the performance of the CPNS system for flight navigation which is based on the Thomson CSF Trident Positioning System [1]. In this case 4 beacons (transponder antennae) were installed outside the flight area [2].

The positional data of this CPNS test flight were submitted to the Institute of Photogrammetry of Stuttgart University, and we investigated them with regard to their utilization as auxiliary camera position data in joint blockadjustment. As the data referred only to horizontal positioning (x, y) the following results are limited to horizontal block adjustment.

From the total flight area a subblock of 3 strips with altogether 53 photo pairs (models) was selected for the investigation, as it had sufficient ground control points. The photographs were measured with a Zeiss Planicomp C 100 , in the stereocomparator mode. The image measurements were processed to independent models.

For the subsequent block adjustments the program PAT-M-43 (block adjustment with independent models with plan/height iterations) was applied.

The main features of the block can be briefly summarized as follows (see tables 1 and 2):

Photo scale 1 : 16 000, wide angle photography, flying height above ground 2450 m; 3 strips with 15, 22, 19 pairs, respectively; 34 signalized horizontal ground control points, 380 natural vertical ground control points; about 10 signalized tie points per model.

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1) *see Beumelburg, Grimm, Heimes: CPNS-Computer-Controlled Photo Navigation System, Presented Paper, ISPRS Symposium, Comm. I , Canberra (Australia), 1982*

2) *see IGI (Ingenieur-Gesellschaft für Interfaces mbH) : CPNS, Intermediate report about a test mission based on Thomson-CSF-Trident positioning, 1983*

The investigation is clearly separated in 2 phases:

(A) Accuracy analysis of navigational data
(B) Utilization of navigational data in the block adjustment

The 2 phases will be treated separately:

A. Accuracy Analysis of the navigational data

In order to check and analyze the navigational data conventional block adjustment was applied, making use of all available ground control points. In this way quasi-true xy coordinates of the camera stations are obtained which then are compared with the horizontal position data as derived from the CPNS data.

The block adjustment gave the following standard errors of unit weight, referring to model coordinates:

$\sigma_{o_{plan}}$ = 0.11 m = 7 μm in photo scale
$\sigma_{o_{vert}}$ = 0.20 m = 0.07 $^o/oo$ h = 12 μm in photo scale

These figures prove that the block has a good level of precision, according to expectation.

The r.m.s. values of the internal residuals at the (photogrammetric) coordinates of the perspective centres (camera stations) were:

$\overline{v}_x = 0.22$ m , $\overline{v}_y = 0.26$ m , $\overline{v}_z = 0.09$ m

Also these figures are according to expectation. They imply an estimated absolute accuracy of the photogrammetric horizontal camera station positions of about 0.4 m to 0.5 m . The camera stations as obtained from the conventional block adjustment were to be compared with the camera station coordinates as derived from the CPNS systems. For that purpose the photogrammetric xy-coordinates were treated as (quasi-) true values.

We obtained the coordinates of the camera stations as derived from the CPNS data from Grimm/Heimes without having had any influence nor deeper information about the computation. It was known, however, that the majority of stations were computed in a joint trilateration adjustment, comprising 3 - 4 distances for each station (group a). The joint trilateration adjustment gave an accuracy level of $\sigma_o = 1.0$ m. The remaining stations were computed individually by intersection of 2 - 4 distances per station (group b), as not all stations could receive signals from all transponder beacons. Their accuracy is not known but could be expected to be poorer than with group a. This has been confirmed in the course of the investigations.

The comparison of the photogrammetric camera station coordinates (which can be considered here as "true" values) with the coordinates derived from CPNS data is displayed in tables 3 and 4.

The average position errors of the CPNS derived stations (groups a and b together) amounted to about 18 m. The vector diagram (table 3) shows clearly that there is in first instance a large constant shift error, and in addition a systematic error going with the flight direction. These errors may have attributed, most likely, to errors in the coordinates of the transponder stations which serve as reference for the CPNS data. (The coordinates of the transponder stations were only obtained graphically from topographic maps). The errors which change sign with the flight direction will have to be determined, in future, by a system calibration. (For instance, the antenna at the airplane is several meters away from the camera; there may also be additional constant errors in the electronic system).

As the large constant and systematic errors were to some extent explained, and as they can potentially be assessed by system calibration it seemed legitimate to remove them and to continue the investigation by looking at the remaining random errors.

After similarity transformation of the CPNS-coordinates of each strip (only the shift parameters were significant) the remaining average positioning errors amounted to 3.6 m and 3.1 m (see table 3 and 4). In the latter case point no. 1120 was omitted, as it obviously was poorly determined. For the well determined camera stations (group a) the average magnitude of the CPNS position errors is 2.6 m.

This empirical result can be interpreted as the horizontal precision of the camera stations, valid under the conditions of the test, after removing the constant errors. As no background information was available to us, it was not possible to push the analysis of the data any further.

B. Utilization of the positional navigation data as auxiliary data in a joint blockadjustment

The investigation A had given an assessment of the (internal) accuracy of camera stations as derived from CPNS data. With this information it was possible to assign appropriate weights to the horizontal coordinates of camera stations and to test the result of joint block adjustment into which these data would be introduced as auxiliary data, i.e. as additional control points.

The use of navigational auxiliary data is supposed to allow a reduction in ground control points. Investigation B was intended to confirm this empirically.

For this purpose the following data were introduced into a joint block adjustment with independent models (PAT-M-43):

- 4 horizontal ground control points
- 53 CPNS coordinates of camera stations, corrected for constant errors (also used as ground control points, appropriately weighted) [1]; point 1120 was omitted.
- all measured tie points (as in standard block adjustment)

The remaining 30 known ground points served as check points only. They were not used as control points in the adjustment but allowed for the independent assessment of the absolute accuracy of the adjusted block.

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[1] *A future program would allow for the compensation of constant or systematic errors in the block adjustment. Thus, the a priori correction of constant errors in this test is representative, anticipating the results of more sophisticated and more general adjustment programs.*

The joint block adjustment resulted in an absolute (average) accuracy of the adjusted block of

$$\mu_x = 0.23 \text{ m}$$
$$\mu_y = 0.34 \text{ m}$$

(determined as the r.m.s. differences of the photogrammetric coordinates of 30 check points against their (true) geodetic coordinates).

This result could, on face value, be interpreted as an effective contribution of the CPNS air stations to the joint block adjustment. If compared, however, with the block adjustment based on the 4 control points only (omitting th CPNS camera station coordinates), resulting in an absolute block adjustment accuracy of

$$\mu_x = 0.25 \text{ m} , \quad \mu_y = 0.42 \text{ m}$$

it is evident, that the contribution of the navigational data to the joint block adjustment was only marginal, in this particular case. Yet this result was to be expected. This block is too small and too precise (photo scale too large) to leave room for effective contribution from the navigational data. In view of the precision ratio they would become really effective only in larger blocks and with smaller photo scales.

Thus, taking circumstances into account, the results of this particular test can be interpreted as confirming the expected effectiveness of taking navigational positioning data of camera stations into the joint block adjustment.

In order to prove the effectiveness of navigational positioning data more directly a final joint block adjustment was done in which all ground control points were deleted. The block adjustment was based only on the 53 CPNS camera stations (corrected for constant errors) and the photogrammetric tie points (as before).

The resulting absolute accuracy of the adjusted block in this case was:

$$\mu_x = 0.36 \text{ m} , \quad \mu_y = 0.53 \text{ m}$$

(r.m.s values as assessed from 34 check points)

This result is highly interesting. It shows the effectiveness of navigational data in the adjustment of otherwise poorly determined or, in this case, indetermined blocks [1]. It also shows possible application in hitherto unforeseen cases.

4. SUMMARY AND CONCLUSION

It must be emphasized that the CPNS test flight "Bodensee 1982" can only be considered a preliminary test. It was not extended enough for a thorough investigation and it suffered from some initial shortcomings. Nevertheless it gave valuable information about the potential use of navigational positioning data as auxiliary data for joint block adjustment.

The analysis (part A of the investigation) showed that the position data of the camera stations had originally errors in the order of 18 m. However, a large percentage of these errors is due to the poor link with the coordinate system and because no system calibration had been carried out. Thus they are not representative for the inherent accuracy of the CPNS system. After removing the constant errors random errors of 3.1 m remained (for well determined air stations 2.6 m). They indicate the internal (and potential absolute) accuracy of the air stations as determined from the CPNS data.

The application of such navigational positioning data was demonstrated in phase B of the investigations. By the joint adjustment of the navigational data and the photogrammetric measurements, and using 4 ground control points only, the resulting block had an average absolute coordinate accuracy (in x and y) of 0.29 m.

This result is only a slight improvement against the conventional photogrammetric adjustment of the block with 4 control points

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[1] *Generalizing this case it should be kept in mind that this adjustment refers in reality to the local coordinate system as determined by the transponder beacon stations. It should also be observed that in such a case any correction for constant errors is impossible. Therefore application is only feasible with a good a priori system's calibration or when any remaining constant errors would be acceptable. Nevertheless, the above results stand for the internal accuracy of the adjusted block.*

only (and not using any navigational data), because in this case the photo scale (1 : 16000) was quite large, and the block rather small. Nevertheless, the results confirm the expected effectiveness of navigational data in the joint block adjustment, even when the accuracy of them is considerably poorer than of the photogrammetric measurements.

This overall result has been confirmed in the final block adjustment in which no horizontal ground control points were used at all. The camera station positions alone, as obtained from the CPNS data, together with the photogrammetric measurements resulted in an absolute coordinate accuracy of the adjusted block of 45 cm.

These results are most encouraging. We therefore intend to continue the investigations with CPNS data and to extend them to inertial navigation systems (and later on to GPS satellite data). The PAT-M-43 block adjustment program will be modified to cope with such data by allowing for the automatic correction of constant and systematic (drift) errors of navigational data. Also the extension to the 3rd dimension is planned.

It can safely be anticipated that the use of auxiliary camera orientation data in joint block adjustment will be highly effective and economic by allowing a substantial reduction of the required ground control points. Applications will be particularly economic in medium and small scale photogrammetric projects.

Table 1

CPNS - TEST "BODENSEE 1982"

flight mission on 8,May,1982

- 5 strips , 223 photos
- photo scale 1:16 000
- flying height : h_{abs} = 2900 m , h_{rel} = 2450 m
- wide angle camera Wild RC 10 A
- forward overlap p ~ 70%
- side overlap q ~ 45%

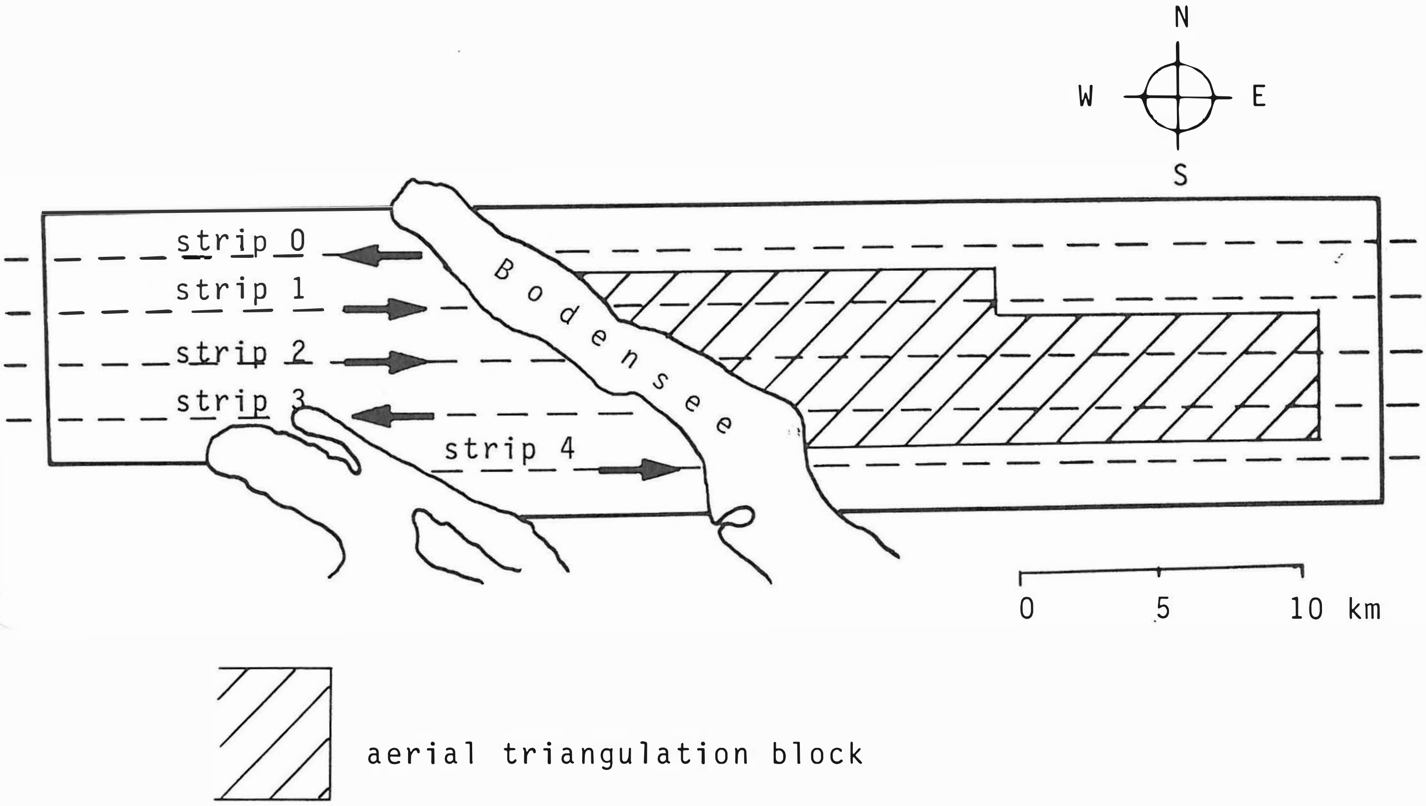
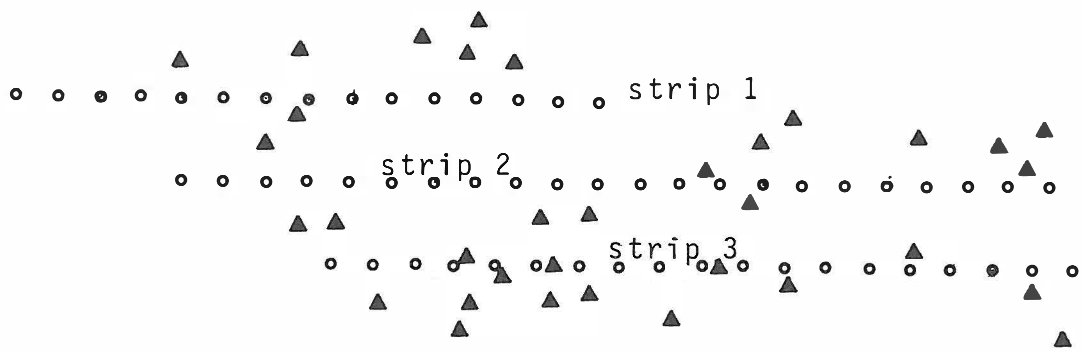


Table 2

CPNS - TEST "BODENSEE 1982"

Aerotriangulation with a subblock of 53 models



▲ horizontal ground control points
° camera stations

strip	no. of photos	flight direction
1	15	W - E
2	22	W - E
3	19	E - W

geometry of the block :

34 horizontal ground control points (signalized)

380 vertical ground control points (natural points)
~ 18 per model

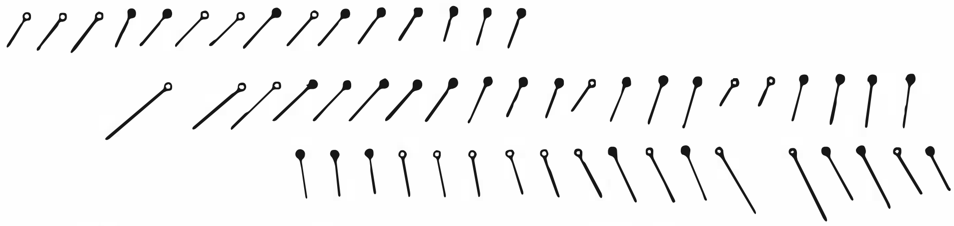
~ 10 tie points per model (signalized)

Table 3

CPNS - TEST "BODENSEE 1982"

Vectors of differences between photogrammetric and CPNS coordinates

1. CPNS - coordinates derived from trilateration adjustment and distance intersections

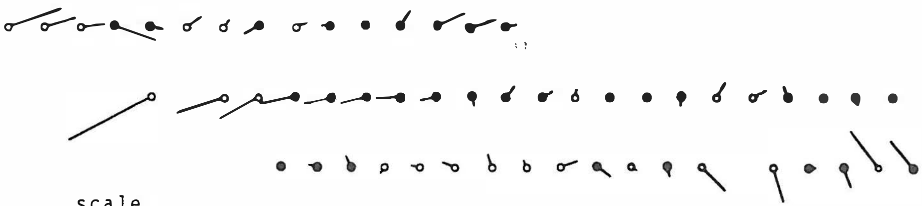


scale of vectors: 0 20 m

group a

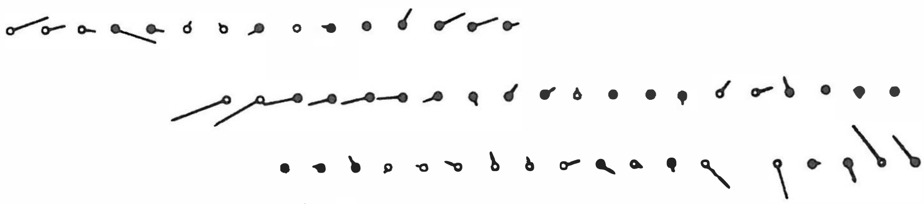
group b

2. CPNS - coordinates, constant errors removed (by 4-parametertransformation)



scale of vectors: 0 10 m

3. CPNS - coordinates, constant errors removed (by 4-parametertransformation), point 1120 omitted



scale of vectors: 0 10 m

Table 4

CPNS - TEST "BODENSEE 1982"

COMPARISON OF HORIZONTAL COORDINATES OF PERSPECTIVE CENTRES, FROM CPNS DATA AGAINST PHOTOGRAMMETRIC VALUES OBTAINED BY BLOCKADJUSTMENT WITH PAT-M 43 PROGRAM

CPNS - coordinates	group	rms. values of the differences in meter μ_x	μ_y	$\mu_s = \sqrt{\mu_x^2 + \mu_y^2}$	number
from trilateration and distance intersections	a	8.14	14.97	17.05	32
	b	10.78	15.81	19.14	22
	a+b	9.31	15.32	17.93	54
constant errors removed by 4-parameter transformation	a	2.27	1.34	2.64	32
	b	3.95	2.51	4.68	22
	a+b	3.07	1.91	3.62	54
const. errors removed by 4-par. transf. point 1120 omitt.	a	2.27	1.34	2.64	32
	b	2.99	2.17	3.69	21
	a+b	2.58	1.72	3.10	53