FULL GEOMETRICAL SYSTEM CALIBRATION AT THE TEST RANGE BRECHERSPITZE

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INTRODUCTION

Metric cameras are mainly delivered by their makers with an inspection slip, in which the data of interior orientation originate from laboratory calibration. Real working conditions however deviate more or less from a well defined laboratory environment. Thus a calibration of the whole system involved during a survey flight is advisable. This includes camera carrier, among others.

Several tasks in everyday photogrammetry may be tackled without such a procedure. For applications which ask for high precision in terrain with larger elevation differences system calibration however should be considered as meaningful, both in view of accuracy requirements and cost efficiency.

Some typical tasks of this type are

* Establishment or densification of precise survey net works, also for cadastral purposes;
* Industrial applications, e.g. supervision of opencasts;
* Engineering applications, e.g. dam constructions or deformation control.

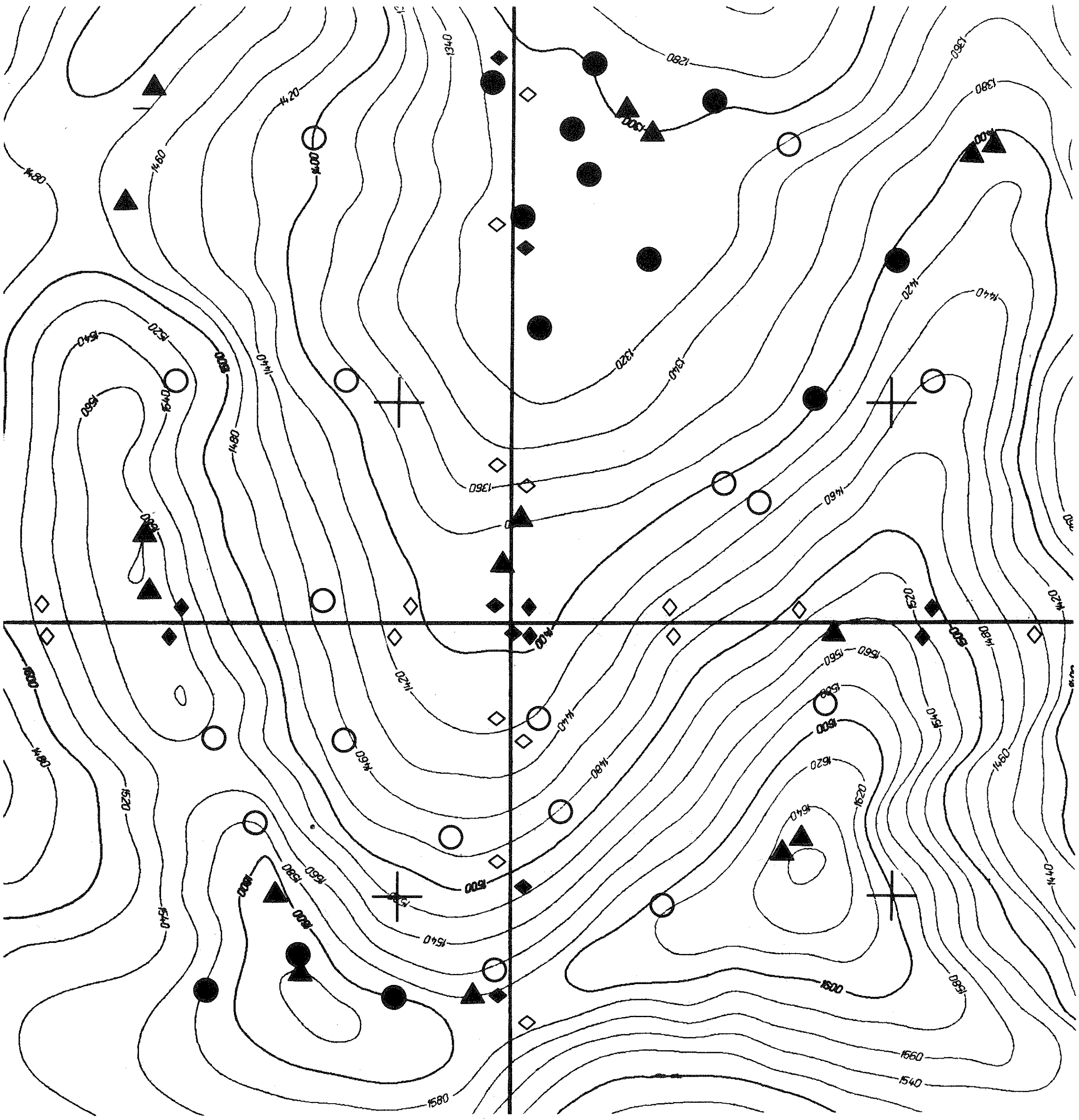
This paper aims last but not least at the establishment of internationally recognized and agreed at standard procedures for a full geometrical system calibration.

An survey of history and state of the art of camera calibration under real working conditions was given in KUPFER 1986. That paper also includes a proposal on establishment of the Test Range Brecherspitze in the Bavarian Alps and some results of simulated calibrations, which demonstrated the feasability of the proposed configuration. Anticipated overhead for terrestrial monumentation, targeting and measurements seemed to be reasonable compared with obtainable accuracy of calibrations. Thus the test range has been implemented in 1987, and shortly before snowfall first calibration flights could be performed.

Geometrical properties of the range, its configuration and first results from calibrations are outlined. Furthermore a blueprint of proposed activities and cooperations is given.

THE TEST RANGE

Its origin dates from a trigonometrical test net of highest accuracy established by the Geodetic Institute of the Technical University of Munich (SCHNÄDELBACH 1981). Its six points showed standard errors smaller than ± 1 mm from original measurements in a free net adjustment. A resurvey after 8 years did not show significant alterations of coordinates.



▲ Full Control

● Elevation Control

○ Point Targeted for Ray Intersection

◆
◇ Taking Positions Considered in Different Computations

Scale is appr. 1:6,700

Fig.1. Test Range Brecherspitze. Net and Flight Configuration

All points of the test net have been monumented by stainless steel rods mostly concreted in stable rock. They carry circular wooden targets in forced centering, coated with white plastic. The location of the points has been chosen after a great lot of simulated calibrations with different point distribution for optimisation of cost-benefit relations.

Ground survey for the second order calibration net was accomplished in connection with the first order net of SCHNÄDELBACH by measuring slant ranges, horizontal and vertical directions, and levelling with good precision. The resulting point coordinates for full control are expected with an accuracy of appr. $\pm$ 5 mm. Besides these there exist points with elevation control only, or targeted points which only serve for ray intersection. Cf. Fig.1.

ALGORITHMS FOR SYSTEM CALIBRATION

Calibration parameters of a camera shall be computed within a bundle adjustment as the standard procedure in analytical photogrammetry. ZIEMANN 1986 gave some hints concerning a mathematical model. We aim at a solution in just one step. This opens the possibility of best supervision of the whole system. To show just one benefit: Algebraical highly correlated system parameters are easily identified, which is not detectable in a stepwise procedure.

In advance of bundle triangulation a computation of point coordinates from ground survey data has to be performed. There should however also exist a possibility to compute system calibrations from hybrid observations, i.e. performing an adjustment of a free net including parameters of interior orientation of the camera using observations of ground survey and photo measurements simultanously. This calls for proper weighting of observations of different type, which in a rigorous adjustment should be performed by estimation of variance components.

Through partial or total inversion of the normal equation system an insight into correlations and algebraic stability properties of the whole system of observations involved shall be possible. Last but not least the set of estimated parameters should be expandable by well established sets of additional parameters to describe image deformations. Those given by D.C.Brown (BROWN 1976) may be considered as convenient, as they contain the sought for parameters of interior orientation.

The bundle adjustment program MOR-S (WESTER-EBBINGHAUS 1985 and HINSKEN 1985) provided a good starting point for a global solution. This program was generally written for application to close range photogrammetry. Adaptation to the new tasks is under way and shall be delt with elsewhere.

CALIBRATION FLIGHTS 1987

Due to bad weather conditions the test range was only in service in October 1987. Despite this three cameras could be flown for calibration purposes on four strips in a crosswise manner with each strip flown in both directions. A typical configuration of real camera positions with appr. 90 % longitudinal lap is shown in Fig.1. Image scales vary for a WA camera from appr. 1:3,500 and 1:6,000 and for a NA camera from appr. 1:4,000 and 1:5,300, according to a maximum elevation difference in the range of some 480 m and flying heights above sea level of 2,200 m and 2,900 m respectively.

Due to being very late in the year sun elevation was very low which resulted in low illumination and long shadows.

MENSURATION OF PHOTOS

The last mentioned problems prevented almost errorless measurements of image coordinates at a high precision monocomparator. Instead of this they were performed at a ZEISS Planicomp C 100 in four different positions for each photo for the following reason. The photo coordinates of all points were known a priori with good approximation, thus enabling automatic prepositioning of the points and avoiding blunders. Despite this precaution standard deviations of image coordinates remained high.

FIRST CALIBRATION RESULTS

The requirements for a first overview were best met by a calibration flight, dated 1.10.87, of Rheinische Braunkohlenwerke AG of Cologne with a ZEISS RMK A 15/23 equipped with a Pleogon A2 of very low distortion. Low flying height at a cruise speed of 110 kn asked for an exposure time of 1/450 sec. Local time was appr. 10.30 hrs. Thus the shadowy parts of steep northern slopes showed almost no contrast on the original photos. This led to pointing errors of appr. ± 3 micrometers for the mean of four pointings, including however also errors of the Planicomp. Its comparator coordinates were reduced to photo coordinates by affine transformation.

Tab.1 gives a selection of some interesting results from quite a lot of different calibration computations. Unvariably the following applies: Standard errors a priori for photo coordinates are set at ± 3 micrometers. Only points at the outer margin (10 mm) of photos are given twice this amount, close to the border however ± 10 micrometers as well. Fig.1 shows among others the taking position of the photos involved in different adjustments.

The presented variations differ in the following characteristics (cf. Fig.1):

1) Ground coordinates of 17 points are given in a Cartesian system for x,y,z and for another 11 points for z only from

an approximative adjustment. Standard errors a priori for these coordinates vary between 2 mm and 5 mm, according to measuring accuracy. 12 photos are used (3 photos/strip with appr. 60% longitudinal overlap; black diamonds in Fig.1).

2) 22 "bundles" from terrestrial observations of horizontal and vertical directions are included in the adjustment. Considering pointing errors for shorter distances (< 100 m), standard errors a priori are variable. Typical standard errors are assigned to slant and horizontal ranges as well as to levelled elevation differences. The calibration range is tied to the first order net, which is considered errorless, thus avoiding rank deficiency.

   Number of photos corresponds to 1).

3) All terrestrial observations are part of the adjustment, corresponding to 2).

   Number of photos is 28, positions marked by black and white diamonds in Fig.1.

Tab.1 contains estimates of the parameters of interior orientation and their standard deviations a posteriori. Distortion parameters lead to differences of photo coordinates

$$dx = x(R_1r^2 + R_2r^4) + B_1(y^2 + 3x^2) + 2B_2xy$$

$$dy = y(R_1r^2 + R_2r^4) + 2B_1xy + B_2(x^2 + 3y^2)$$

The full parameter set by BROWN 1976 may be completed, which shall be done in near future.

Results may be commented as follows:

1) Sigma naught is relatively large in all cases, which may be due to adverse circumstances (see above). Under fair conditions (better illumination), sigma naught should at least drop to appr. $\pm$ 3 micrometers, cutting all other standard deviations to 75 % or less. This would favourably correspond to simulated calibration results (KUPFER 1986).

2) Parameters from variations 1) through 3) are almost invariant. This shows that redundancy from measurements on 12 photos is large enough to get proper results.

3) Estimated calibrated focal length corresponds very well to that of laboratory calibration in this case. Decentering distortion includes in all variations image deformation from film etc. This is correlated to the amounts of coordinates of the point of best symmetry (PPS). Despite this their variations from one adjustment to the other are very small.

4) Algebraic correlation of parameters corresponds to expectations, e.g. for calibrated focal length and flying height >0.9.

Table 1. Results of System Calibration at Brecherspitze Range
ZEISS RMK 2A 15/23 with Pleogon A2, 01.10.87

The first line of each variation shows parameters,
the second one their standard deviations,
number of unknowns u and redundancy r

Number of Photos u/r	Terrestr. Obs.incl. yes/no	Calibrated Focal Length mm	Point of B.Symm. x μm	y	Radial Distortion R_1 10^{-8}	R_2 10^{-12}	Decenter. Distortion P_1 10^{-6}	P_2
Lab.Cal.		153.481	0	-1				
12	no	.485	+9	-29	-.13	-.08	+.16	-.46
273/665	3.7	9.3	4.0	4.4	.23	.10	.05	.06
12	yes	.485	+9	-30	-.11	-.10	+.15	-.47
405/853	4.1	8.4	4.3	4.8	.25	.11	.06	.07
28	yes	.485	+10	-26	-.47	+.07	+.16	-.43
501/1835	3.7	5.9	2.9	3.2	.15	.06	.04	.05

Photos from a NA camera flight suffered still more from adverse illumination than those mentioned above. This and some navigation problems led to even larger pointing errors and a weak geometry of the triangulation block. Referring to a standard error of unit weight of ± 3 μm would also in this case lead to results as obtained in simulated computations.

Summarizing results at hand it may be said that system calibration at the Brecherspitze range came up to expectation. Parameters of interior orientation may be calibrated under real working conditions with very good accuracy at reasonable expenses. For a WA camera calibrated focal length will be estimated with an accuracy of appr. ± 5 μm and coordinates of PPS with appr. ± 2 μm, provided a fourfold block of photos with 3 photos each. Lens distortion parameters are well estimable, as well as image distortion parameters, if added.

PROPOSED ACTIVITIES

A proposal for system calibration has been presented to OEEPE last fall, which is now being discussed by its Commission F. It is hoped that activities on an international scale will commence during this years flying season.

There seem to be several tasks in this context, which ask for a solution. Inflight GPS seems to be a very useful tool in analytical photogrammetry (ACKERMANN 1986). A joint calibration procedure for camera system and GPS seems to be advisable.

With the establishment of digital cameras it is worth while to calibrate these systems under real working conditions, especially for dynamic systems like MOMS etc.

PROPOSED COOPERATIONS

Although the calibration range Brecherspitze shall be used on an international basis, this is only possible under economical aspects for experimenters from adjacent countries due to economical reasons. Thus cooperations should be extended by exchange of data from similar activities, as has already be done with experimenters from Drivdalen range in Norway, courtesy Prof. HÅDEM and his colleagues. On request photogrammetric offices from Australia also gave comments on their activities, which are however restricted to partial field calibration (estimation of distortion parameters).

An exchange with other experimenters would be welcome. This should all aim at an internationally agreed at procedure for system calibration under real working conditions within the scope of Commission I, ISPRS.

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