FULL SYSTEM CALIBRATION IN AERIAL PHOTOGRAMMETRY RESULTS AND PROSPECTS

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INTRODUCTION

The aims of full calibration of a photogrammetric system can be manyfold. Some of them are typical:

- Test of metric reliability
- Test of correspondance with laboratory calibration
- Deduction of a refined functional and/or stochastical model of photogrammetry

As the former goals are without real consequence to data handling, the latter leads to more or less altered results of the whole photogrammetric process. This alteration is most pronounced in analytical photogrammetry, where an estimation of calibration parameters may be part of the procedure. As is common use in routine work unsignificant parameters may be cancelled.

Full system calibration should resemble to the utmost possible extent to real working conditions. For aerial photography this requires verticality of optical axis in calibration etc.

The accuracy of certain parameters from inflight calibration may be less than that of laboratory calibration. They may be highly correlated with other parameters, especially those of exterior orientation. Besides that the geometric properties of a whole photogrammetric system are not stationary, as the system consists of a multitude of components, which are subject to changes resulting in altered calibration parameters.

Experts of geometric optics as well as of laboratory calibration may very soon come to the conclusion that this procedure is no calibration at all. Full system calibration however is by necessity field calibration under real working conditions if it can be applied in practice and if it will be of any consequence for increasing accuracy of results under economic aspects.

PRACTICAL RESULTS

The practicability of full system calibration is undoubted and has been exercised e.g. by Merchant 1972. Proper formulae were given by e.g. D.C. Brown 1976.

For certain types of terrain a simulation has been performed (G.Kupfer et al.1982), which led to the prediction of fairly acceptable results for alpine regions as well as for Rhenanian brown coal opencast in the Federal Republic of Germany.

Unfortunately up to now no optimal calibration flight could be performed as had been suggested. There exist however photo flights performed over well targeted parts of an open-cast. where the bulk of points was part of precise classical survey net in planimetry (Reichenbach 198o).

Fig.1 shows the extension of the test range with spot heights of targeted points or natural details in metres above/below sea level. Flight lines 11 - 32 were flown with a nominal scale of 1 : 7ooo, lines 41 - 52 with a scale of 1 : 58oo. One flight was performed on 1.11.198o, the other one on 6.11.1982. The latter comparised only strips 41 - 52 with a somewhat smaller test range, but all points targeted. Both flights were performed with(different)Zeiss RMK A 15/23.

Measurements were performed for both flights on original photonegatives, for the first flight on a Zeiss PK 1, for the second on a Jenoptik Comess 3o3o.

Distribution of control and check points is shown in Fig.2. There exist for both flights two control versions (cf.also Tab. 1). The one shown gives the minor type withholding elevations for check purpose. All these elevations are in a second version considered as control. In this case only planimetry is checked against ground survey coordinates.

Although not quite correct, all control coordinates were considered errorfree for the flight of 198o. There exist however computations with standard deviations a priori of ± 2 cm for planimetric coordinates and ± 5 cm for elevations. This was done, as ground surveys were carried out with high accuracy only for planimetry, not for elevations. For the 1982 flight all terrestrial coordinates were given equal standard deviations a priori, i.e. ± 1 cm.

Bundle adjustments were for each control version performed firstly without full calibration of the system to get comparable results. A version with full calibration was added carrying two parameters for radial and asymmetric distortion each. There exist also versions with application of the system calibration, adding additional parameters of a third order polynominal type. The bundle program at hand does not allow for simultaneous calibration and other additional parameters.

Some results of the series of computations are given as follows. Tab.1 shows calibration parameters and/or their standard deviations, whereas Tab.2 comparises standard deviations of point resections (check and tie points) as well as differences against ground survey coordinates. Maximum standard errors and differences are also given where possible.

Fig.3 and 4 show radial distortion from laboratory calibration and as achieved from system calibration for the 198o flight and sparse control case.

Whereas almost all parameters in Tab.1 are in good agreement with laboratory calibration, there is a significant alteration of calibrated focal length of the 198o flight under dense vertical control. Plots of discrepancies between photogrammetric and terrestrial elevations reveal a pronounced systematical deformation close to the upper edge of the open cast, on the neighboring plain. It is not quite sure, whether this stems from photogrammetry, as there is no possibility of a check of ground survey and/or photogrammetry. It should be mentioned again, that only planimetry was given high accuracy in ground survey.

Vertical control was not established for calibration purposes. This is however at least a hint, that sparse control in field calibration may lead to mistakable results.

Correlations between flying height and calibrated focal length are very high, as the slope of the open cast is comparatively small considering flying height and image scale. Hence the insertion of a calibration range with proper scaling of photos as advocated at the Helsinki Symposium is highly recommended.

The 198o flight comparises 45 photos. Therefore the standard errors given in Tab.1 are very favourable as compared with results of the simulation (Kupfer et al.1982). The 1982 flight consisted of 16 photos only. Thus standard errors are higher, this in spite of a smaller σ_o.

As check points are not distributed regulary over the whole test range, the figures of tab.2 are not very typical. For correctness sake however points were excluded, from computation, which lay outside the control frame.

A last stress shall be laid in the discrepancies of the photo coordinates a posteriori. They are comparatively high at the edge of photos, which is quite well known. There are at least two possibilities of dealing with this phenomenon. The more conservative one (among photogrammetrists) advises cancellation of points near the edge of photos, e.g. within a margin of, say 1 cm. The other possibility, proper or at least adequate weighting of photo coordinates seems to be the only reasonable one, when dealing with calibration. One should not reject rays from resection which have the best geometrical properties for computation of calibrated focal length. An extension of the stochastic model is therefore highly recommended. For the time being, this was not yet possible.

SOME FURTHER SIMULATIONS

The Watzmann area of the Bavarian Alps was in another simulation of system calibration taken under closer inspection. This included judgement of the trigonometric network as well as a local reconnaissance of targeting possibility of these points and additional resection points for evaluation of distortion parameters. In various computer simulations taking into account proper situation of trigonometric points and - deducted from aerial photography at hand - of additional resection points, different control distributions were assumed.

The following assumptions were e.g. made:

c = 153 mm (wide angle camera)
Double cross flight with center over the peak of Watzmann Mittelspitze
8o % longitudinal lap
Flying height ~ 68oo m above sea level; 9 trigonometric points with heights between 271o m (center) and 6o4 m (border).
A priori standard deviations $\pm$ 5 cm (all coordinates), levelled elevations $\pm$ 1 cm.
32 well distributed additional targets.
$\sigma_o = \pm 3$ µm a priori

This leads to very promising results: The standard error of focal length amounts to $m_c = \pm 6.5$ μm. All other standard errors (principal point location, parameters of distortion) are by far within practical results given above.

The simulation was also carried out with fewer trigonometric points, which gave a slight decrease of accuracy for focal length only. Additional distance measurements did not give much better results. Correlation of flying weight and focal length is o.98 for the worst photo.

The choice of the Watzmann itself and also this simulation have however some weak points:

The assumed accuracy of the trigonometric net must be verified.

The influence of deflection of the vertical must be taken into account. The same applies for possible anomalous refraction.

The flying height is not commonly used. Lower levels are investigated. With a flying height of 55oo m above sea level and $\sigma_o = \pm 3 / \pm 5$ μm (other parameters unchanged), one has a standard error of calibrated focal length of $\pm$ 4,3 μm/$\pm$ 7,1 μm, which is still excellent.

Under fair weather conditions for photo flights in this region the Watzmann peak is likely to be crowded by mountaineers who may tend to picknick on the targets.

In a discussion of this project with Prof.Dr.Ebner, Chair of Photogrammetry, and Prof.Dr. Schnädelbach, Chair of Surveying, Technical University of Munich, the latter hinted at an exsisting three dimensional test net with average point errors better than $\pm$ 1 mm, situated around the Brecherspitze some 5o Km south of Munich air-port Schnädelbach 1981 . With height differences up to more than 8oo m in its vicinity, there exists a very good possibility for construction of an outstanding calibration range even for large photo scales, which could range as a maximum between 1 : 35oo and 1 : 9ooo on the peak and lower parts of the range. Flying and targeting requirements would be much simpler than in the vicinity of the Watzmann. The authors feel that both projects would complement one another for large and small photo scales.

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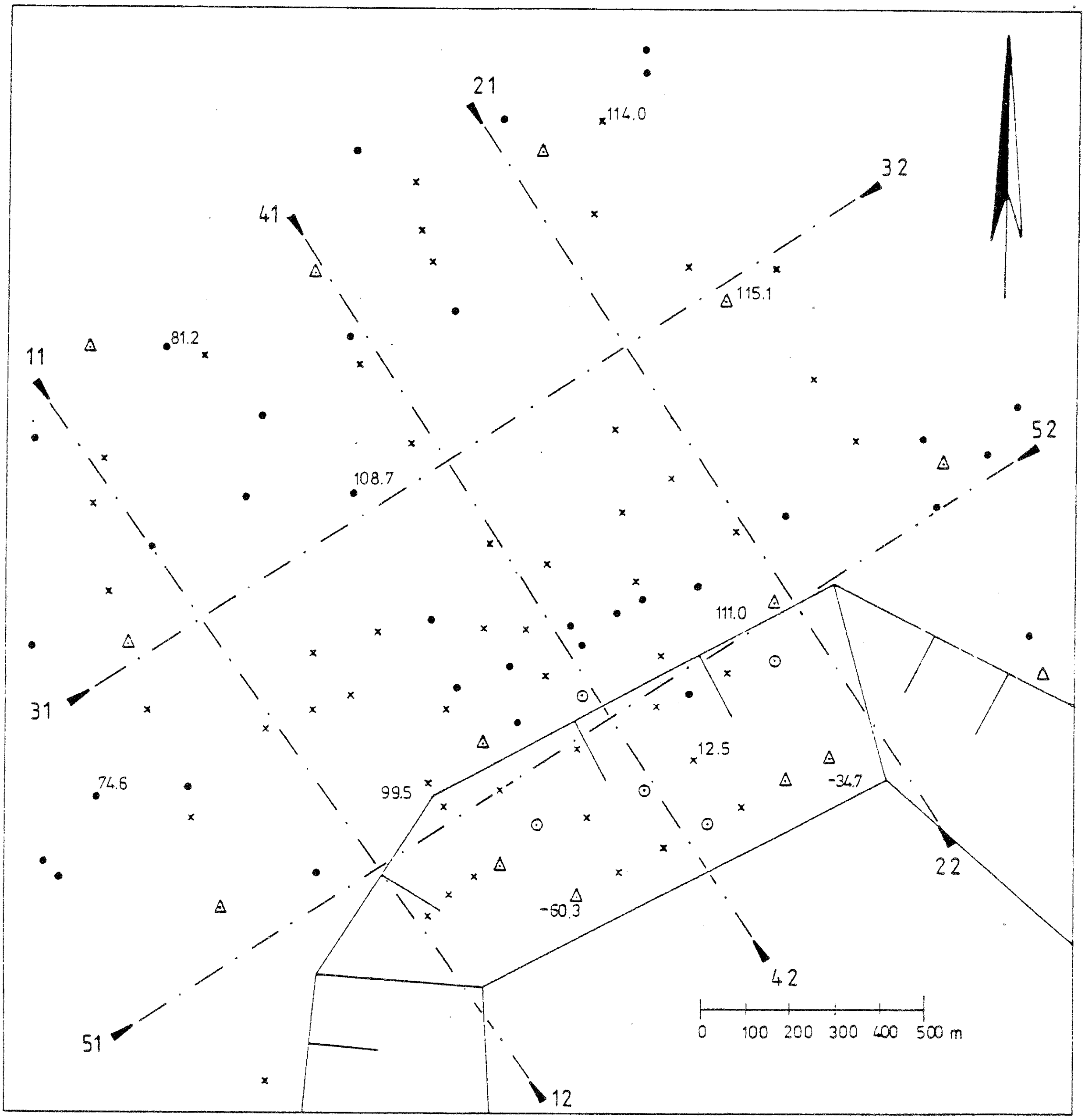
Calibrations from real flights were part of master theses of Mr.Dapper and Mrs.Trenkmann, simulations of the Watzmann project part of that of Mr. Schumann.



△ Full Control

⊙ Vertical Control

• Tie Point

x Check Point

Fig.1 Test range on the border of a Rhenaian brown coal open cast.

Spot heights in meters above/below sea level.

Flight lines 11 - 32 : photo scale 1 : 7ooo,
Flight lines 41 - 52 : photo scale 1 : 58oo,
as related to the upper edge of the slope

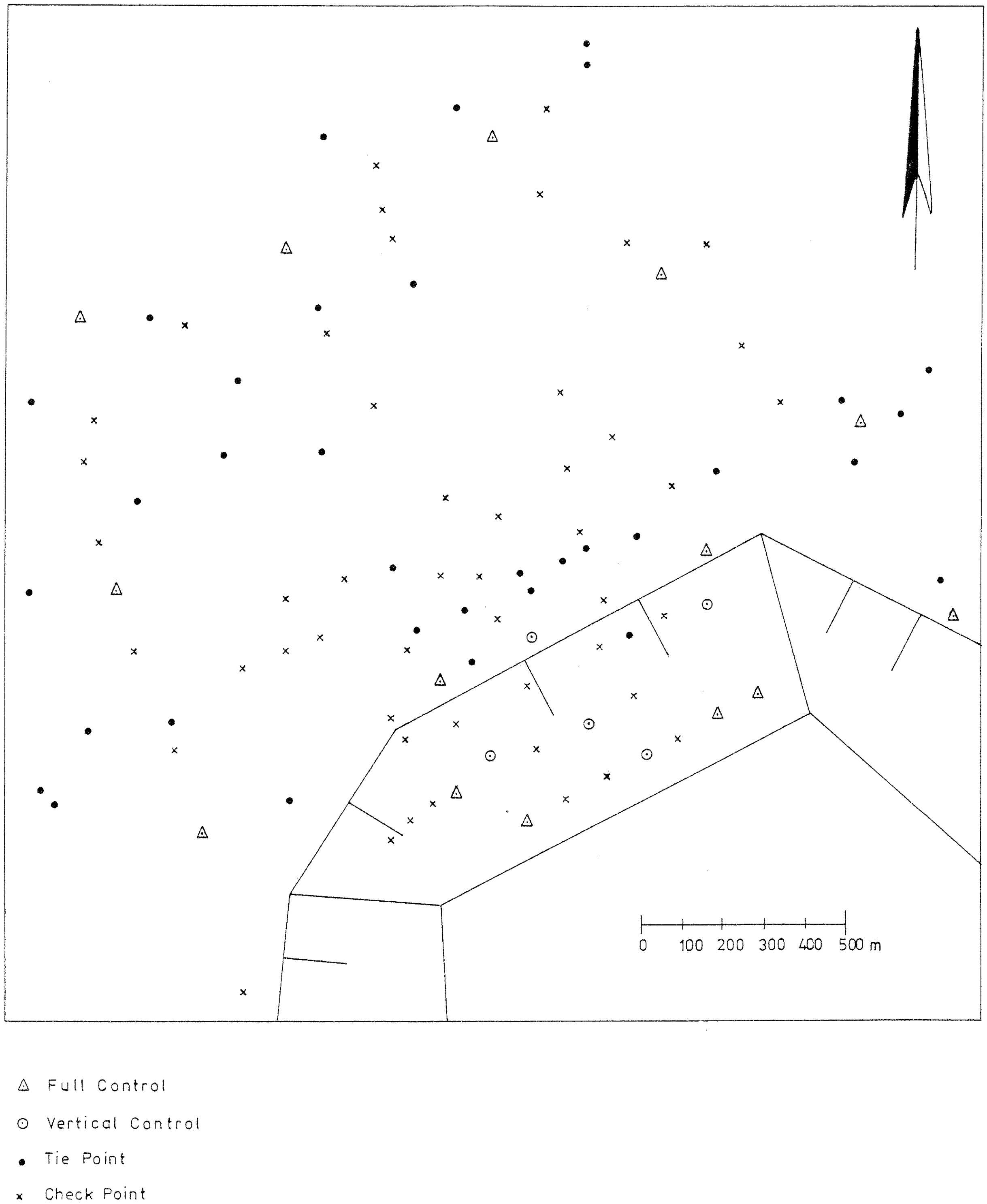


Fig.2 Control distribution, check points and tie points in 198o. In a second control version, all elevations of check points are taken as control.

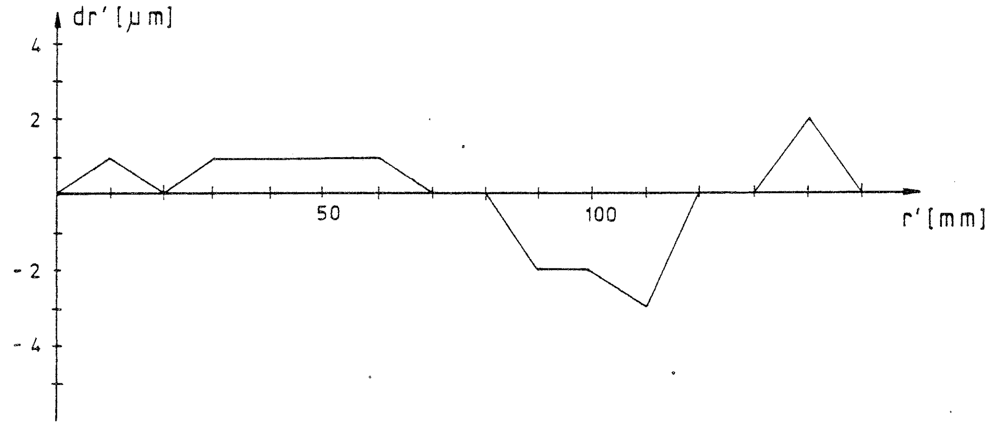


Fig.3 Radial symmetric distortion, according to laboratory calibration. Flight 1.11.198o

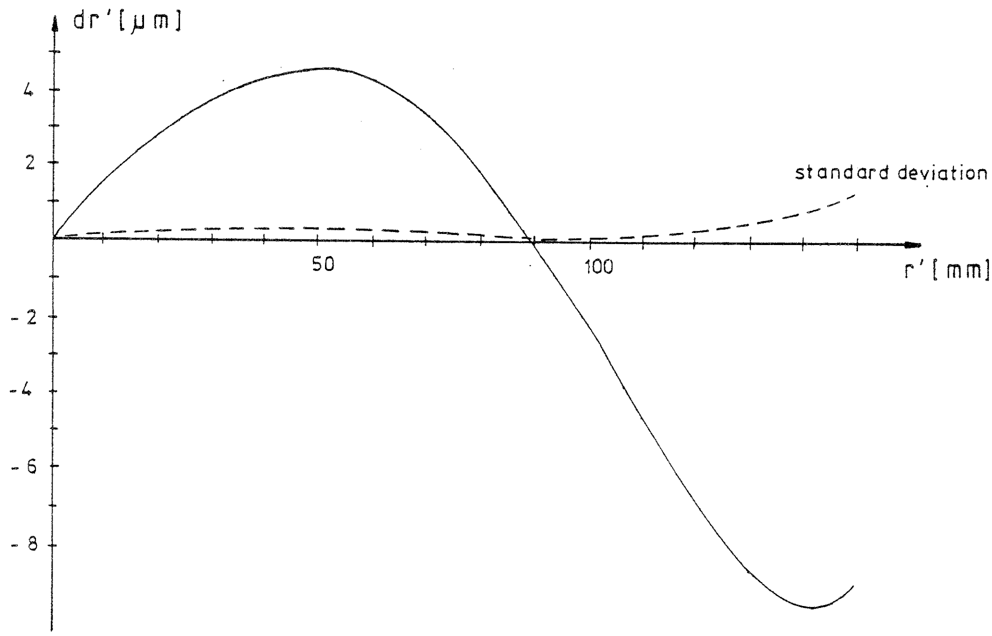


Fig.4 Radial sysmmetric distortion from system calibration, flight 1.11.198o, minor control version.

Flight	Simulation	1. 11. 1980					6. 11. 1982		
Control	19 + 0 + 0	14 + 0 + 5			13 + 1 + 51		14+0+6	46 + 2 + 0	
Calibration	Full	Lab	Full	Add	Lab	Full	Full	Lab	Full
σ_o [μm]	5	4.7	4.2	3.4	5.0	4.7	4.1	4.0	3.9
c [mm]	150.0	152.799	.794	.794	152.799	.866	.712	152.707	.742
m_c [μm]	17	-	12.1	-	-	10.6	24.5	-	16.9
X_{pp} [μm]	-	+7	-15	-15	+7	-14	+1	-2	±0
m_{xpp} [μm]	<5	-	3.9	-	-	4.3	5.0	-	4.8
Y_{pp} [μm]	-	-13	-17	-17	-13	-18	±0	+3	-1
m_{ypp} [μm]	<5	-	3.7	-	-	4.1	5.5	-	5.2
$m_{A1} \cdot 10^{-8}$	<.30	-	.14	-	-	.15	.31	-	.28
$m_{A2} \cdot 10^{-12}$	<.12	-	.058	-	-	.063	.15	-	.14
$m_{B1} \cdot 10^{-7}$	<.60	-	.33	-	-	.36	.69	-	.65
$m_{B2} \cdot 10^{-7}$	<.55	-	.33	-	-	.36	.66	-	.63

Tab.1 Results of different calibration procedures.
Control distribution is given as the sum of full + planimetric + vertical control.

Flight	1. 11. 1980					6. 11. 1982		
Control	14 + 0 + 5			13 + 1 + 51		14+0+6	45 + 2 + 0	
Calibration	Lab	Full	Add	Lab	Full	Full	Lab	Full
σ_0 [µm]	4.7	4.2	3.4	5.0	4.7	4.1	4.0	3.9
m_{xy} [mm]	9.4	8.5	7.9	9.9	9.3	10.0	8.5	8.3
m_z [mm]	19.2	18.7	14.6	21.2	20.0	21.4	20.9	20.8
max m_{xy} [mm]	21.7	19.7	15.8	22.4	21.0	20.0	17.3	16.9
max m_z [mm]	42.2	38.6	30.6	40.0	37.8	46.9	45.6	44.8
e_{xy} [mm]	17	13	13	20	18	6	-	-
e_z [mm]	56	65	76	-	-	21	-	-
max e_{xy} [mm]	67	61	55	57	50	21	-	-
max e_z [mm]	171	220	210	-	-	65	-	-

Tab.2 Standard deviations and quadratic means of differences against ground survey coordinates.

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