LIMITS OF KDGPS-SUPPORTED AERIAL
TRIANGULATION FOR HIGH PRECISION POINT DETERMINATION

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Abstract
It is presently expected that the stringent need for ground control for the adjustment of aerial triangulation blocks may be substantially alleviated by continous provision of in-flight gathered GPS data processed off-line in kinematic-differential mode (KDGPS). Although true in principle, this combined method cannot be considered operational as yet on the sub-decimeter accuracy level for large scale aerial photography. The paper attempts to demonstrate some of the pitfalls presently still to be expected. The investigation is based on highly redundant aerial photograpy of 1:4500 scale obtained with a modern Zeiss RMK-TOP 15/23 camera interfaced to an Ashtech LD-XII GPS-receiver. Controlled by a centimeter precision test field, the block exhibits an exceptionally high degree of interconnectedness. By comparing the antenna positions between GPS and photogrammetry, problems arising from unreliable time recording and indefinite ambiguity determination were detected. Although a novel time-relaxed combined block adjustment and systematc ground control reductions confirmed the general expectation, certain limits have become obvious.

1. Introduction

The following elaboration is based on a particular project that was performed in close cooperation with Rhein-Braun of Köln and the Institute for Physical and Astronomical Geodesy of our university. Similar to previous experiments (Dorrer and Schwiertz, 1990) an aerial survey of a highly precise test field owned by Rhein-Braun was carried out in conjunction with kinematic GPS positioning. The project parameters are given in Tab. 1. Contrary to our former work new technology was used, viz. a Zeiss RMK-TOP 15/23 aerial camera and two Ashtech LD-XII GPS-receivers. The airborne receiver was equipped with a socalled photogrammetric option, i.e. with electronics capable of recording the exact time of exposure onto the GPS time scale.

Region: Hambach-Sophienhöhe	
Purpose:	Monitoring of terrain slope movements in opencast mine
Size of area:	4.1 Km x 1.8 Km
Terrain elevation :	-70 ... 290 m
Time of flight:	July 20 and 23, 1990
Aircraft:	Cessna
Altitude:	950 m above sea level
Camera:	Zeiss RMK-TOP 15/23
Photo scale:	1:6600 ... 1:4200
Area coverage:	Cross flights 90% overlap (60% used) 17 strips with 97 photographs
Triangulation points:	198
Control points:	- 6 full - 25 vertical standard deviation 1 cm
GPS-recveivers:	2 Ashtech LD-XII
GPS-antenna:	Ashtech L1-L2 antenna

Table 1. Project parameters

Objectives of the experiment were both a feasibility and accuracy study of GPS-supported aerial photogrammetry for open cast mine surveys. Fig. 3 shows a terrain model of part of the mine. Notice the elevation difference of several hundred meters. Fig. 1 exhibits the entire flight route in the vicinity of the test area. The total block consists of 5 longitudinal and 6 lateral strips with an unsually high degree of overlap of 80 %. As may be seen from Fig. 2, this entails an extremely stable conventional photogrammetric block.

For the bundle block adjustment all data were referred to a local cartesian coordinate system; neither atmospheric refraction nor local geoidal anomalies were considered.

2. Comparison GPS - Photogrammetry

By virtue of the special conditions of the testfield (high stability and large photo scale; see Table 1) the antenna positions determined by kinematic DGPS can directly be controlled by an ordinary bundle adjustment of the photogrammetric block extended to consider antenna offset (Dorrer and Schwiertz, 1990). Referring to Fig. 4 all GPS-antenna positions given in WGS84 were transformed by means of a Helmert transformation to the local photogrammetric system utilizing the photogrammetric positions as reference. The corresponding coordinate differences are illustrated in Fig. 5 and 6. Remarkable is the astonishingly low error level for altimetry (Fig. 6) with an RMS value of 0.036 m. This indicates high inner precision both of the GPS and the photogrammetric altitudes.

However, the vector diagram for planimetry (Fig. 5) reveals large systematic disturbances mainly in the directions of flight. This effect will be enhanced by a second Helmert transformation with four ground control points only (Fig. 7). Fig. 8 exhibits the planimetric coordinate differences of the antenna positions resulting from a modified Helmert transformation with unconstrained exposure times (Dorrer and Schwiertz, 1990). The standard deviations of the photo-

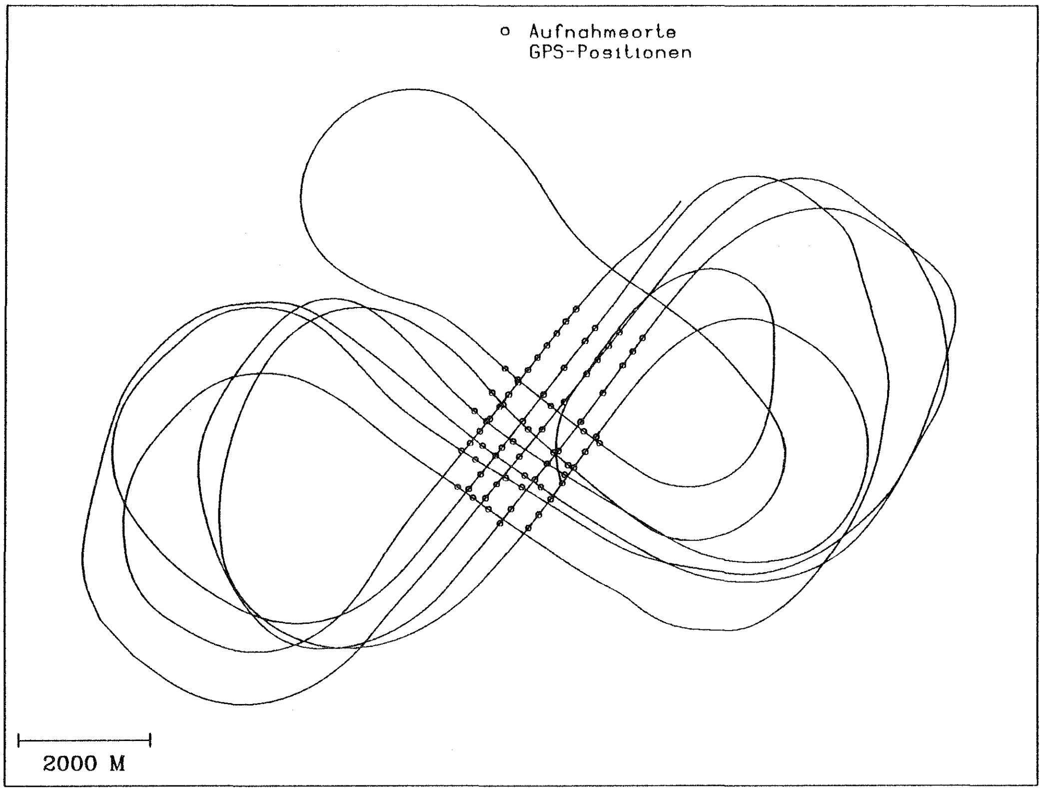

Figure 1. Block flight route

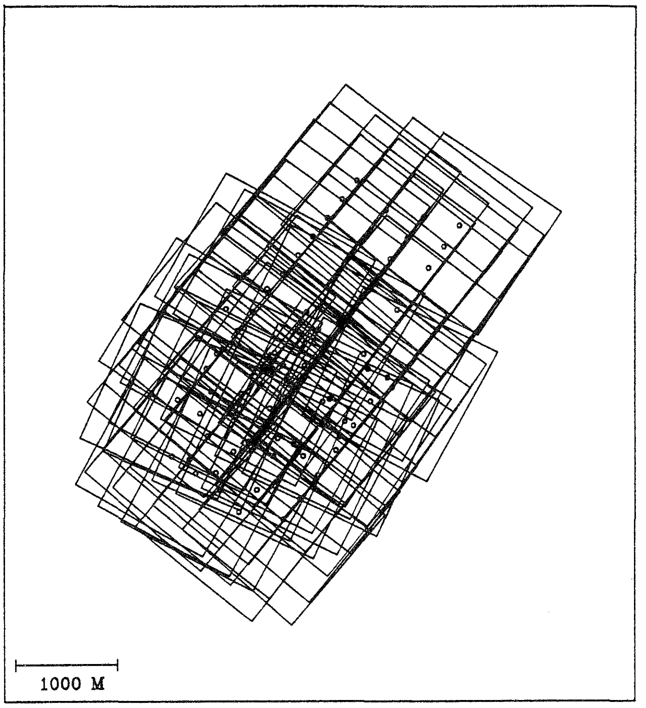

Figure 2. Photo coverage of test block

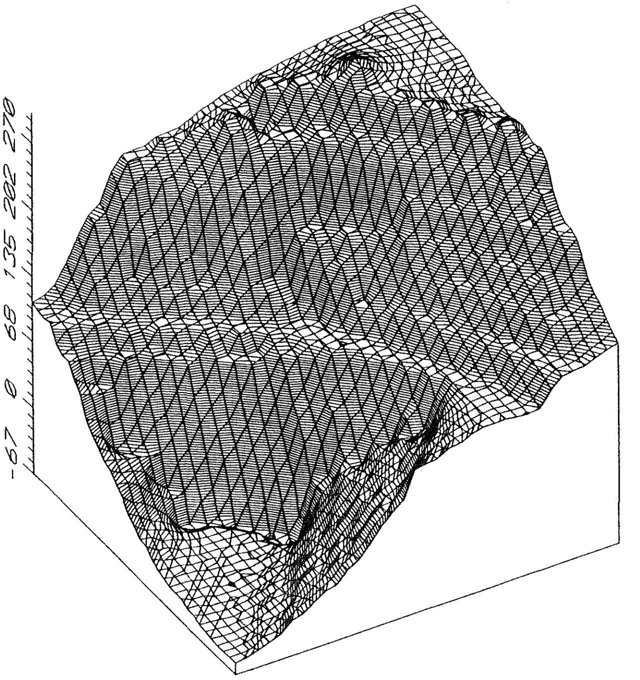

Figure 3. Surface representation of test block

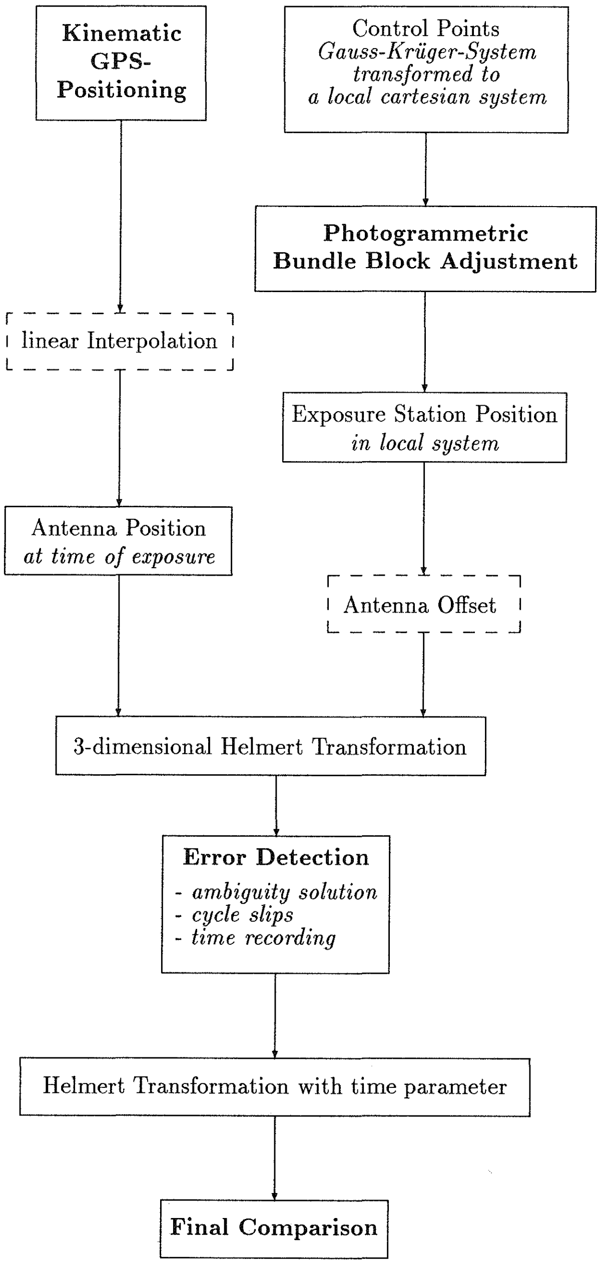

Figure 4. Schematic procedure of the comparison

standard deviation of photogrammetric antenna position			
	X	Y	Z
σ (m)	0.047	0.051	0.070
max. (m)	0.123	0.160	0.126
min. (m)	0.023	0.023	0.055
residuals (m)			
RMS (m)	0.056	0.047	0.035
max. (m)	0.208	0.123	0.088
min. (m)	-0.177	-0.167	-0.096

Table 2. Standard deviations and residual differences

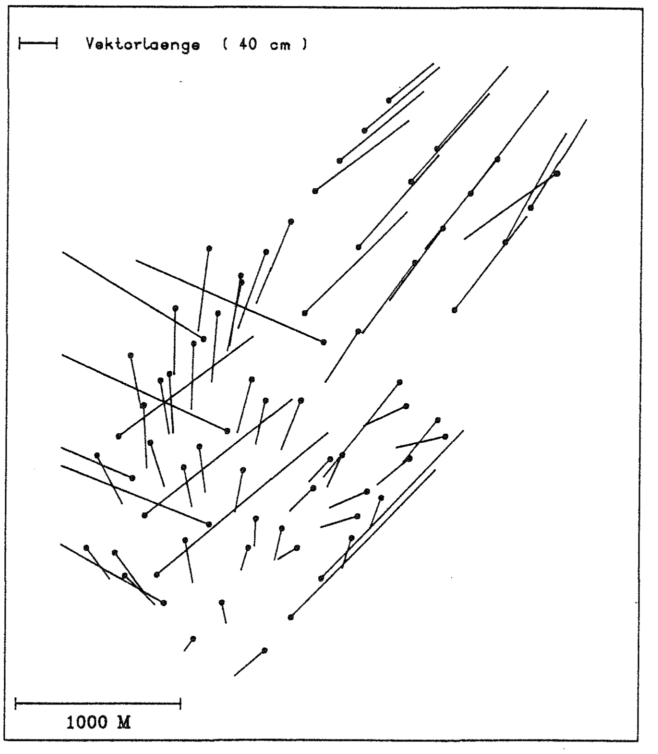

Figure 5. Planimetric coordinate differences after Helmert transformation

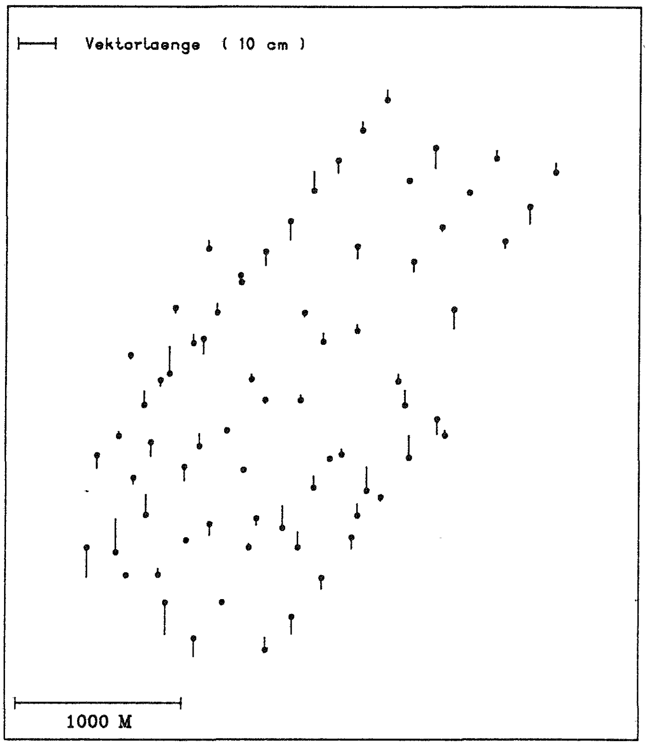

Figure 6. Altitude differences after Helmert transformation

grammetric antenna positions as well as the residual coordinate differences corresponding to the time-relaxed transformation are listed in Table 2. The two sets of error values agree rather well with each other. The gross planimetric error vectors in Fig. 5 are obviously caused by time recording errors.

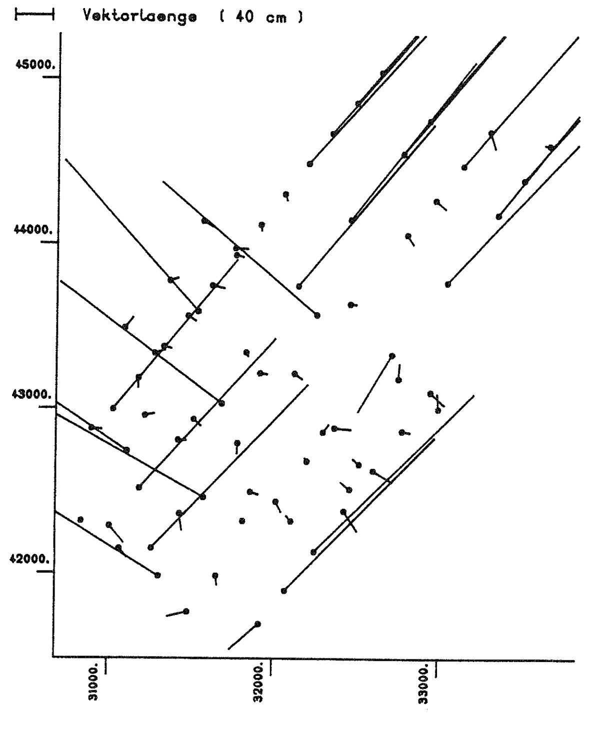

Figure 7. Planimetric coordinate differences after Helmert transformation using 4 GCP´s only

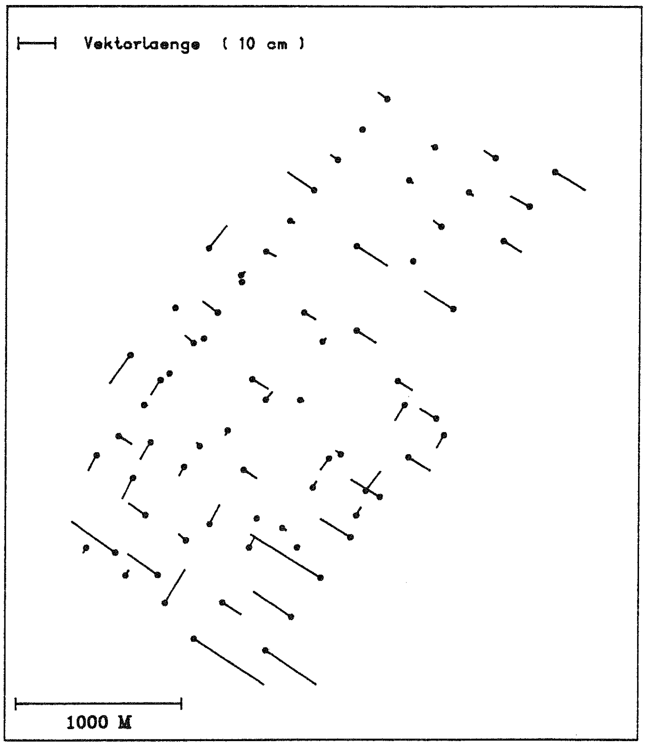

Figure 8. Planimetric coordinate differences after modified Helmert transformation with unconstrained times.

3. Bundle Adjustment Combined with GPS

In order to detect the influence of the GPS-determined airborne antenna positions upon the photogrammetric approach, several versions of a combined block adjustment were investigated. The available program package MMOR, a modification of MOR (Wester-Ebbinghaus, 1985) allows antenna offsets, inner orientation and other parameters to be considered. Within the study, however, nether lens distortion (maximum 3 µm) nor additional parameters were taken into account.

All versions 0 to 5 encompass the photographs of flight one only (Fig.2), and are compared to a conventional reference block adjustment using the entire set of photographs taken during two days (flights one and two).

Version	$\hat{\sigma}_0$ (μ)	σ_X	σ_Y (cm)	σ_Z	RX	RY (cm)	RZ
ref.	3.9	1.21	1.22	1.75	-	-	-
V0	3.9	1.32	1.32	1.87	0.85	0.75	1.96
V1	3.8	1.26	1.24	2.22	1.06	0.83	3.27
V2	3.8	1.27	1.24	2.69	0.88	0.80	3.41
V3	3.9	1.30	1.28	2.61	1.51	1.08	3.09
V4	3.8	1.75	1.75	2.84	1.85	1.41	2.91
V5	3.8	2.17	2.09	7.84	2.51	1.57	7.39

Table 3. Accuracy of combined block adjustment for different versions

Version 0 represents a contentional photogrammetric bundle adjustment with 6 full and 25 height control points. Its results may be considered as reference for the following versions. Fig. 9a/b exhibit the planimetric (a) and altimetric (b) coordinate residuals with respect to the reference block. A few rather large height residuals at the upper end of the block are typical for the investigated data and will appear throughout the other versions, too.

Tab. 3 lists the standard errors and RMS-values of the residuals for all versions. The versions 1 to 5 are defined as bundle adjustment combined with GPS, viz.

Version 1 8 ground control points (2 vertical only)
Version 2 6 ground control points
Version 3 4 ground control points
Version 4 1 ground control point
Version 5 without ground control.

As an example, Fig. 10a/b exhibit the residuals for version 2, Fig. 11a/b for version 4. Evidently, systematic perturbations as yet not understood result in a deteriorating influence. Finally, Tab. 4 gives an indication of the resulting values for the inner orientation parameters depending on the individual versions. When compared to the original calibration values, systematic shifts can clearly be recognized.

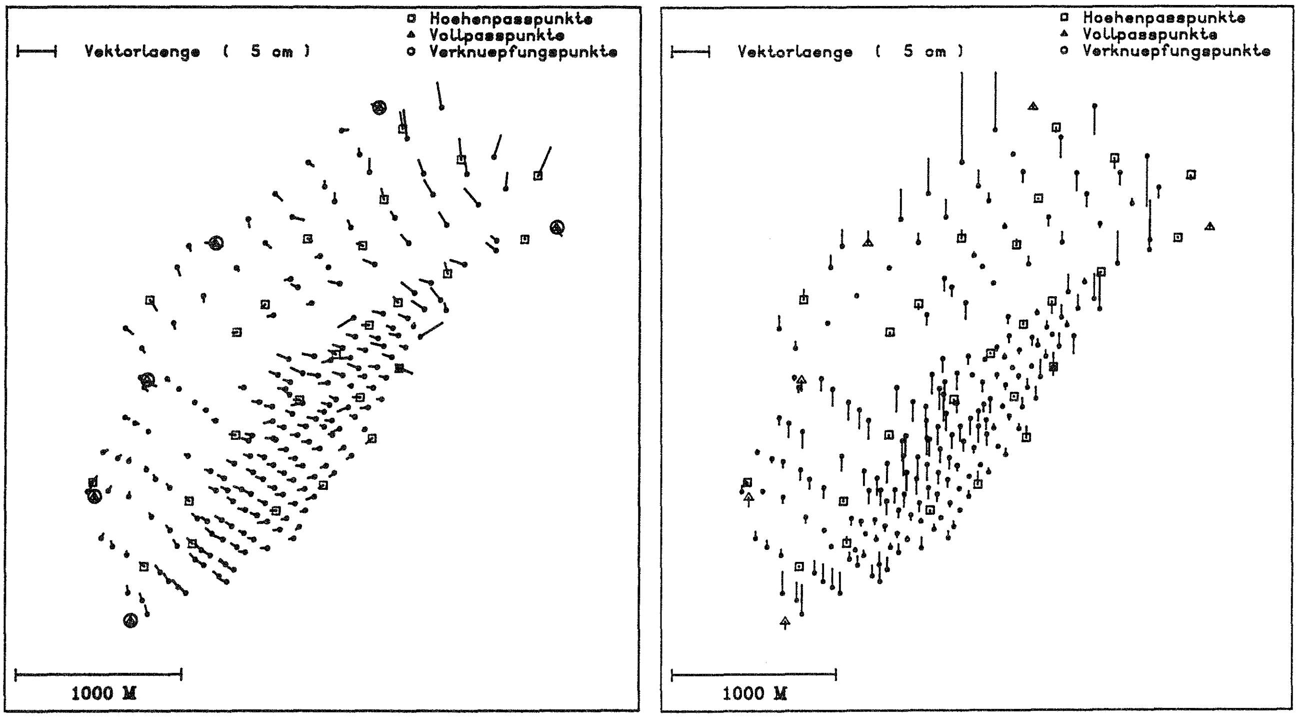

Figure 9a, b. Conventional photogrammetric bundle block adjustment as reference (version 0)

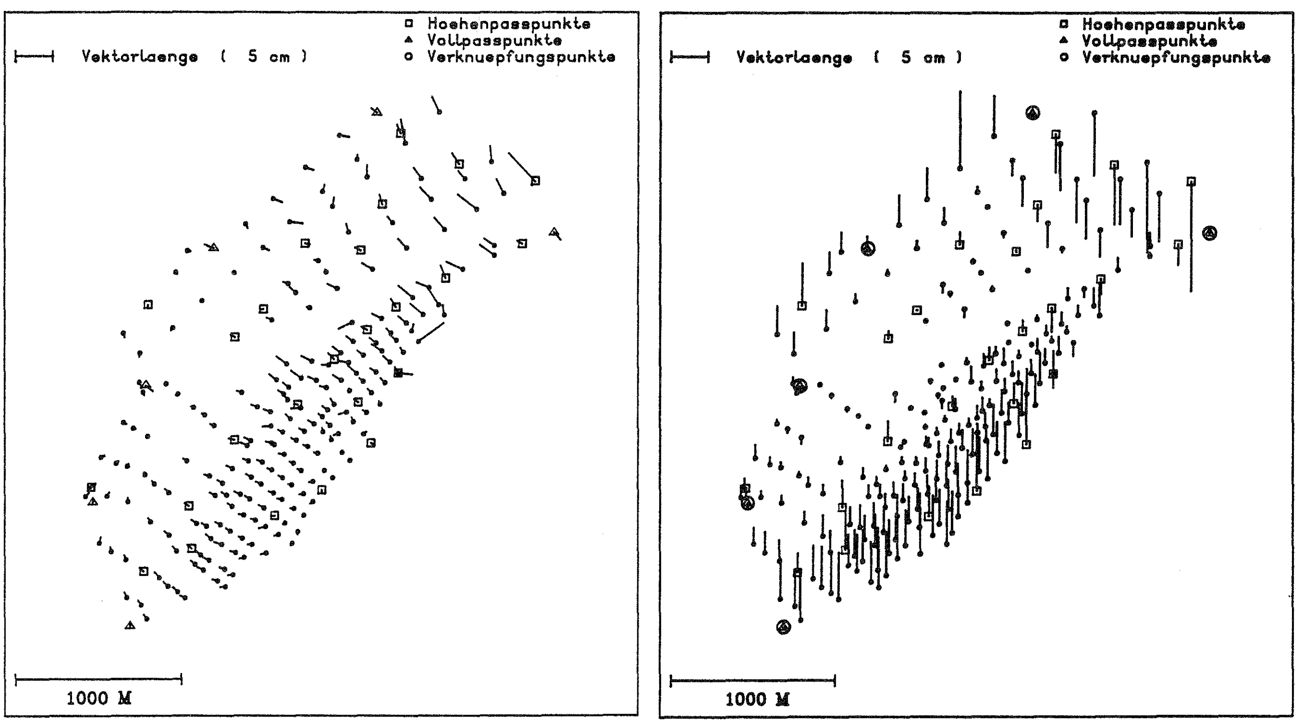

Figure 10a, b. Residuals of combined block adjustment with 6 GCP´s (Version 2)

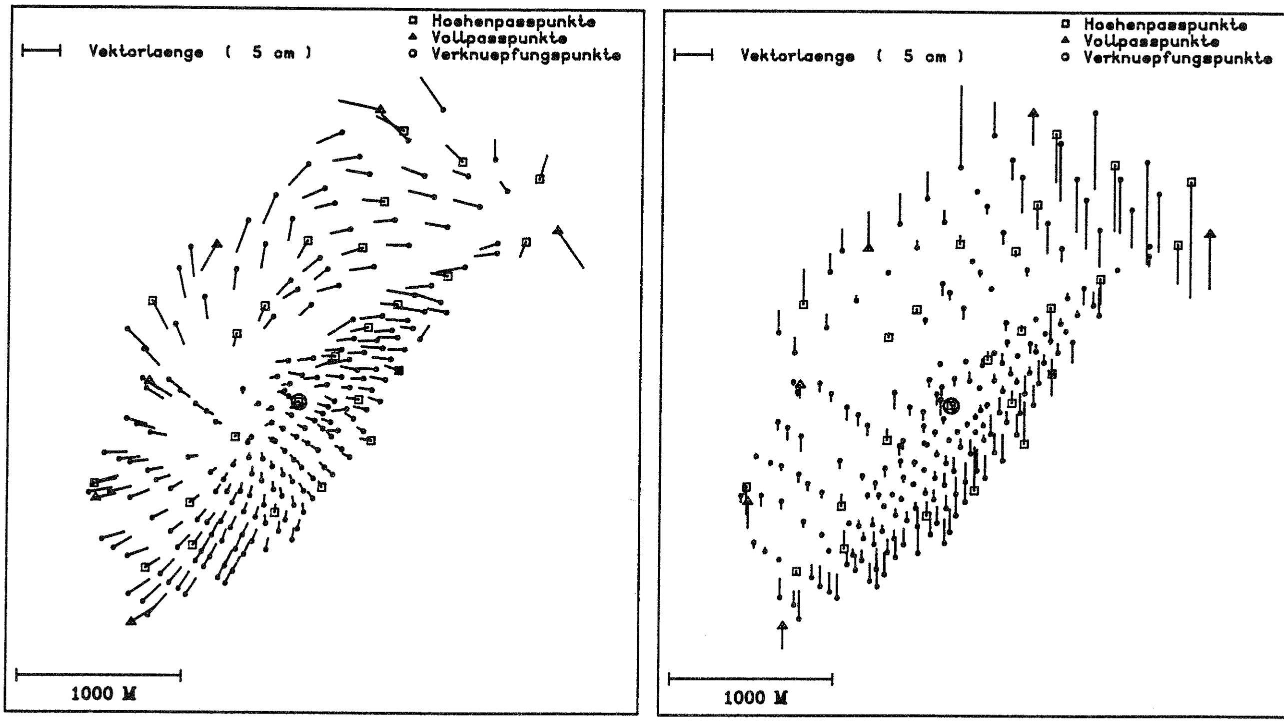

Figure 11a, b. Residuals of combined block adjustment with one central GCP (Version 4)

4. Discussion and conclusions

Focus has been placed only on the results of this investigation, which is characteristic for large-scale photography. Thus, any conclusions transferred to other configurations must be taken with care.

(1) During the fligth seemingly uncontrolled time recording errors in the order of up to 40 ms may occur. This amount corresponds to a positional error of several meters, and may not be neglected. Currently, detection and elimination is possible only by means of a separate investigation of the antenna positions. Obviously acquisition of time still poses certain problems (see also Jacobsen, 1991). An operational solution would necessitate special detection ("snooping") techniques.

(2) The benefits of kinematic GPS-support are less pronounced if the photogrammetric block exhibits already high absolute accuracy. Therefore, image scale plays a dominant role.

(3) Self calibration of the inner orientation requires at least one ground control point complementary to the aerial GPS points.

(4) The reference station needed for differential GPS should preferably coincide with a ground control point.

(5) The influence of systematic image errors upon a GPS-combined photogrammetric bundle adjustment must still be investigated further.

(6) Systematic perturbations of the model can only be separated from model noise if several ground control points are available.

Version	c (mm)	x_H (mm)	y_H (mm)
cal. [a]	153.641	-0.001	-0.006
ref.	153.659 ± 0.011	0.016± 0.002	-0.008± 0.002
V0	153.664 ± 0.012	0.013± 0.002	-0.009± 0.002
V1	153.654 ± 0.013	0.013± 0.002	-0.009± 0.002
V2	153.660 ± 0.005	0.013± 0.002	-0.009± 0.002
V3	153.655 ± 0.005	0.014± 0.002	-0.008± 0.002
V4	153.660 ± 0.006	0.014± 0.002	-0.009± 0.002
V5	153.651 ± 0.012	0.013± 0.002	-0.009± 0.002

[a] cal. = calibration

Table 4. Adjusted inner orientation parameters for different versions

Literature

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