XIV CONGRESS OF THE INTERNATIONAL SOCIETY FOR PHOTOGRAMMETRY HAMBURG 1980

Commission III Presented Paper

W. Förstner, Stuttgart University

THE THEORETICAL RELIABILITY OF PHOTOGRAMMETRIC COORDINATES

Summary

The theoretical reliability of photogrammetric coordinates is investigated. This concerns the possibility to detect gross errors (internal reliability) and the influence of non detectable gross errors on the result (external reliability). The paper shows how reliability depends on different block parameters e. g. blocksize, overlap, control point and tie point distribution.

1. Introduction

Aerial triangulation has become a powerful tool for point determination. One important reason is the homogeneous precision, which can be predicted, if the measuring equipment, the calculation method and some parameters of the block geometry are given. Several studies on the theoretical precision of photogrammetric blocks (e. g. Ackermann, 1966; Ebner, 1973, 1977) have been confirmed by various controlled tests (Oberschwaben, Appenweier, Jämijärvi etc.) and by normal application.

The quite satisfying quality suggests the conclusion, that one can generally rely on points determined photogrammetrically. However, usually an enormous effort, e. g. double coverage, is necessary to reach high reliability or the conditions do not allow a real check of the data and the geometry. For e. g. the local redundancy is too low or the computer programs do not contain appropriate statistical test. As a consequence either the economy or the reliability of the method sometimes is doubted. The reason is simply the problem of gross error detection, as the problem of systematic errors is, though not solved, but practically rendered safe by the technique of selfcalibration.

The paper is supposed to show how the reliability of photogrammetric blocks depends on the different block parameters and thus completes the theoretical knowledge about the quality of photogrammetric coordinates, which can form a basis for the planning of aerial triangulation projects.

Reliability in this context is understood as the ability to detect gross errors, i. e. the controllability of the observations, which is also designated as internal reliability, and the effect of non detectable gross errors on the result of the block adjustment, which is also called the external reliability.

The theory was developped by Baarda (1967,1968,1976) for the use in geodetic networks. It contains the well known "data-snooping" test. Though this test in the original form is not always quite suitable for error detection in photogrammetric blocks (cf. Förstner, 1980), the investigation is based on the original theory. The neglections are tolerable, as the aim of this study is not to obtain substitute reliability values, but to show the trends in the form of reliability models. They will confirm practical experience and also give some guidelines how to increase the reliability by using more points per unit or by additional coverage. A comparison of independent model blocks with bundle blocks will show under which conditions the one or the other method can be advised. The investigations already existing (Förstner, 1978, 1979; Grün, 1979) are therefore above all supplemented by the analysis of the external reliability.

2. Concept of investigation

First we want to describe the criteria for controllability and reliability, the calculation method and the designation of the blocks investigated.

2.1 Criteria for internal and external reliability

Internal reliability is the ability to control the observations with the aid of a statistical test. The controllability is described by the lower bounds $\nabla_o l_i$ for gross errors, which can just be detected with a given probability β_o, if the test has a significance level of $1-\alpha_o$. If the "data-snooping" test with the standardized residual $w_i = v_i/\sigma_{v_i}$ is used, this lower bound is given by

$$\nabla_o l_i = \sigma_{l_i} \delta'_{o,i} ; \qquad \delta'_{o,i} = \delta_o / \sqrt{r_i} . \tag{1}$$

The lower bounds depend on the precision σ_{l_i}, the redundancy number r_i of the observations l_i and the statistical parameter δ_o.

The statistical parameter itself depends on α_o and β_o. We will use $\delta_o = 4$ throughout the paper. This value corresponds to a significance level of 99.9 % and a preset lower bound for the probability of error detection β_o= 80 % approximately.

The redundancy numbers are defined by

$$r_i = (Q_{vv} P_{ll})_{ii} \tag{2}$$

Q_{vv} weightcoefficient matrix of the residuals v

P_{ll} weight matrix of observations l.

r_i is the contribution of the observation l_i to the total redundancy r, as $\text{trace}(Q_{vv} P_{ll}) = r$. It also connects a gross error ∇l_i in l_i with the resultant error ∇v_i in the corresponding residual via

$$\nabla v_i = - r_i \nabla l_i . \tag{3}$$

Thus r_i shows how far an error is revealed in the residual. $r_i = 0$ means, that there is no control at all, consequently the lower bound for detectable errors is infinite in this case.

The precision of all observations, including the coordinates of the control points, is assumed to be equal, with one exception: the x- and y-coordinates of the projection centres in independant model blocks are assumed to have double the standard deviation. For simplicity we will, however, always refer to the <u>controllability values</u> $\delta'_{o,i}=\nabla_o l_i/\sigma_{l_i}$.

External reliability, i. e. the reliability of the coordinates, is described by the influence of non detectable errors $\nabla l_i \le \nabla_o l_i$ on the coordinates. It is assumed that the "data-snooping" has been applied and all standardized residuals $w_i = v_i/\sigma_{v_i}$ remain under the critical value k, which depends on the significance level (in our case k = 3.29). The maximum influence $\nabla_{o,i} f$ of a non detectable error $\leq \nabla_o l_i$ on the coordinates or on a function f of the coordinates is bounded:

$$\nabla_{o,i} f \leq \sigma_f \, \overline{\delta}_{o,i}; \quad \overline{\delta}_{o,i} = \delta_o \sqrt{u_{k_i}/r_i}. \qquad (4)$$

It depends on the precision σ_f of the coordinates or of the function f and on the reliability value $\overline{\delta}_{o,i}$.

The reliability value itself depends on the statistical parameter δ_o and on the geometry. In addition to the redundancy number r_i, the contribution u_{k_i} of the observation to the determination of the unknown coordinates is taken into account. The smaller u_{k_i} the smaller the influence of observational errors on the result.

The precision σ_f of the function f causes problems in evaluating the external reliability, as we have no exact information about the precision of the coordinates, since the covariance matrix of the coordinates is not available. Therefore slight differences in the reliability values have to be interpreted with care, because the variation of σ_f might be large. However, the variation of $\overline{\delta}_{o,i}$ in most cases is large enough that the local disturbancies of the precision can be neglected.

2.2 Method of calculation

As the inverse of the normal equation matrix is not available, the redundancy numbers are obtained by computer simulation via eq.(2): $r_i = -\nabla v_i / \nabla l_i$, i. e. as the (negative) ratio of the change ∇v_i of the residual to the causing error ∇l_i.

The computation of the values u_{k_i} uses the relation

$$u_{k_i} = 1 - r_i - u_{t_i} \qquad (5)$$

with the contribution u_{t_i} of the observation l_i to the determination of the unknown transformation parameters. It can directly be computed by

$$u_{t_i} = (B\,(B'\,P_{ll}\,B)^{-1}\,B'\,P_{ll})_{ii}. \qquad (6)$$

B is the part of the error equation matrix referring to the transformation parameters.

2.3 Investigated blocks

We investigate square shaped blocks only, single blocks (20 % sidelap) and double blocks, which are designated by S or D resp.. The blocks with independent models use 4 and 6 single or twin points per model. The double blocks are assumed to consist of two single blocks flewn crosswise. The bundle blocks have 9 single or twin points and 25 single points per image. The double blocks here are assumed to have 60 % sidelap. The number of points per unit is added to the S or D to describe the block concerned.

The horizontal control points are situated at the perimeter of the blocks (cf. figure 1, see next page). The vertical control varies for single and double blocks. The height of single blocks is stabilized by chains, the vertical control points in double blocks are situated in a regular grid. The control point intervall i varies from 2 to 20 baselengths b.

2.4 Example

Before we investigate the influence of the different block parameters on the reliability we have a look at a representative example. Figure 2 shows the controllability values $\delta'_{o,i}$ for a vertical block with independant

Figure 1 Control point patterns

20 % sidelap 60 % sidelap

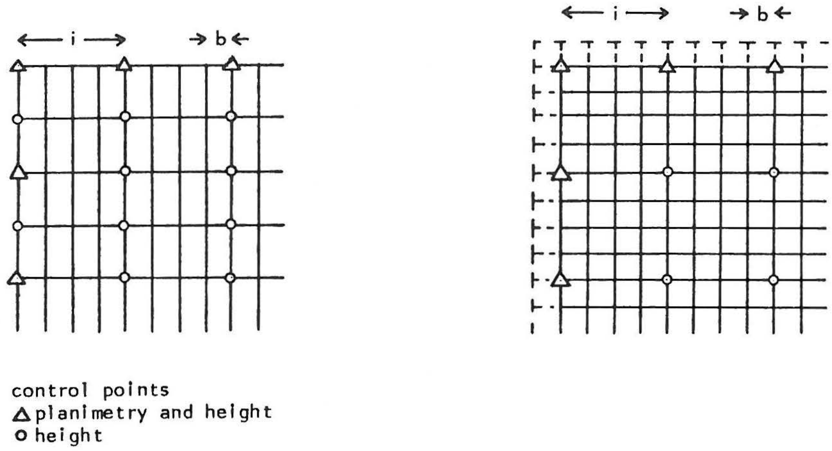
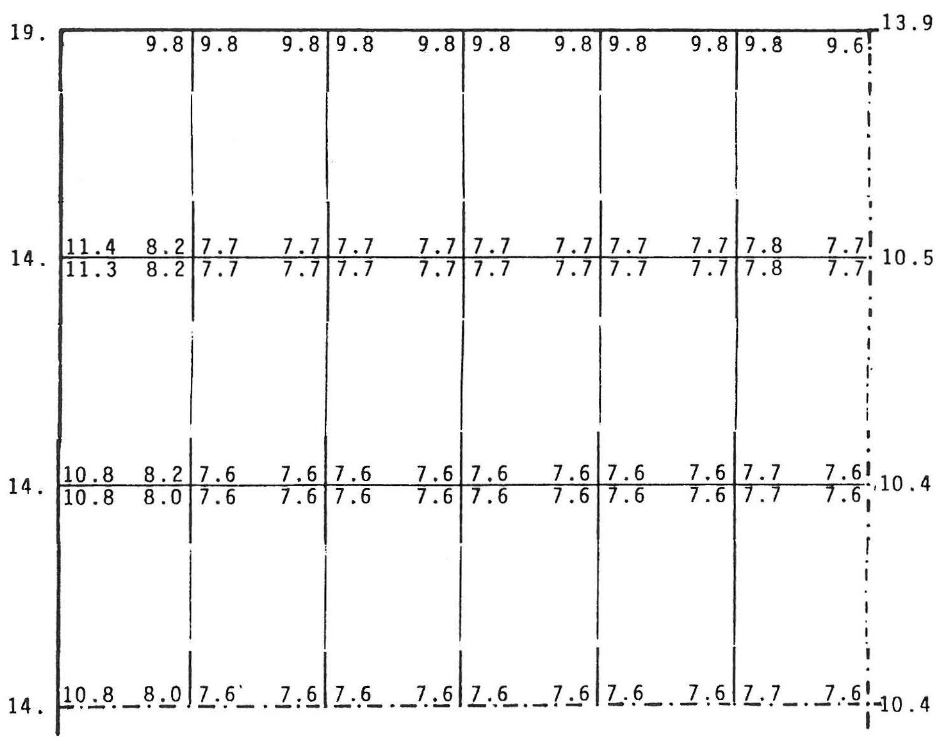


Figure 2 Internal reliability of a vertical block with independent models, $\delta'_{o,i}$ (S4, i = 6, projection centres not shown)



models (Schmitt, 1979). Each model contains 4 tie points and 2 perspective centres (S4). The block consists of 6 strips with 12 models each. The 3 chains of vertical control points thus have a distance of 6 baselengths (i/b = 6). For symmetry reasons only a quarter of the block is shown. The values allow some preliminary conclusions:

1. The controllability is very homogeneous in the interior of the block.
2. The border parts are worse controllable and differ only slightly.
3. The controllability of the control points is worst and depends on the location in the block.
4. The control points have only little influence on the controllability of the tie points.

We therefore analyse photogrammetric and control points separately and distinguish three zones: corner, border and interior of the blocks.

3. Reliability of photogrammetric points

3.1 Average values

The high homogenity of the reliability in the interior of the blocks justifies to look at the average values of $\delta'_{o,i}$ and $\bar{\delta}_{o,i}$ first. They can be obtained by using the average values $\bar{r}_i = r/n$ and $\bar{u}_{k_i} = u_k/n$ instead of r_i and u_{k_i} resp., i. e. by referring to the global redundancy and the total number of unknown coordinates. Tables 1 and 2 contain the average reliability values for the different block types. The values refer to very large

Table 1 Average values for reliability of independent model blocks

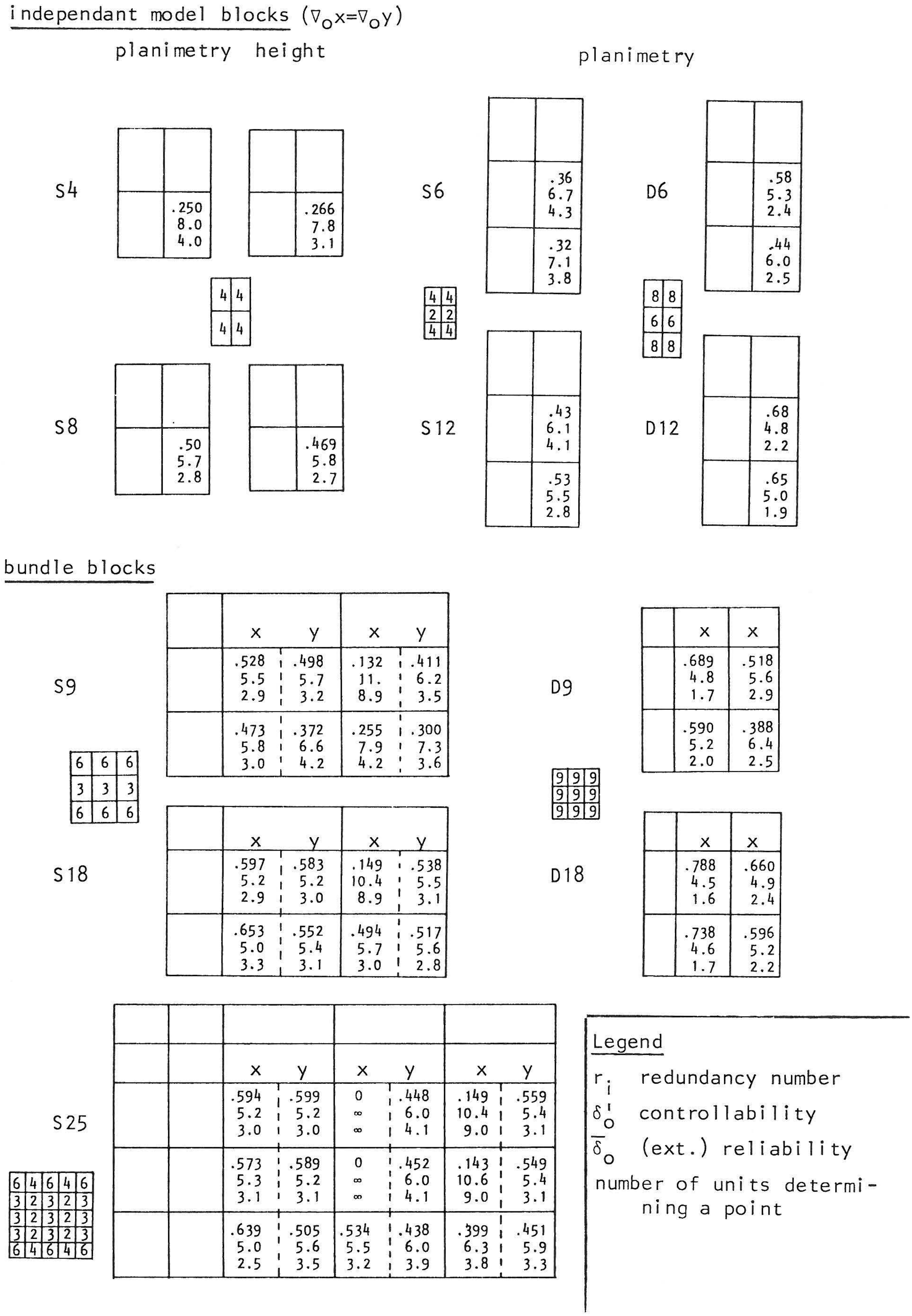
	20 % sidelap				60 % sidelap		
	Planimetry		Height			Planimetry	
Block	δ'_o	$\bar{\delta}_o$	δ'_o	$\bar{\delta}_o$	Block	δ'_o	$\bar{\delta}_o$
S 4	8.0	4.0	7.5	2.5	-	-	-
S 6	6.9	4.0	6.9	2.9	D 6	5.7	2.3
S 8	5.7	2.8	6.2	2.4	-	-	-
S 12	5.7	3.3	6.0	2.9	D 12	4.9	2.0

Table 2 Average values for reliability of bundle blocks

20 % sidelap			60 % sidelap		
Block	δ'_o	$\bar{\delta}_o$	Block	δ'_o	$\bar{\delta}_o$
S 9	6.9	4.0	D 9	5.7	2.3
S 18	5.7	3.3	D 18	4.9	2.0
S 25	6.3	4.4	D 25	5.0	2.45

blocks with poor control and thus give the mean values for the interior of the blocks. It is obvious, that the controllability and the reliability are acceptable. Though rather large errors (up to 8 σ) can stay undetected, the influence on the coordinates keeps below 4 times their standard deviation. Of course the double blocks are much more reliable with reliability values $\bar{\delta}_{o,i}$ below 2.5. In order to understand the seeming discrepancies,

Figure 3 Local redundancy and reliability of units in the middle of large blocks



e.g. the block with 12 points per model on an average being worse than the block with 8 points per model, we have to look at the variation of the values within the units.

3.2 Reliability of the interior of the blocks

The reliability of the units in the middle of the blocks are shown in figure 3 (see prev. page). Also the redundancy numbers and the degree of the connections are given.[1]) The comparison reveals several properties:

1. Measuring of points in the middle of the strips in single blocks (S4-S6, S8-S12) does not increase the reliability very much. Nevertheless it is worth using these points in order to be able to hold a connection if an observation has to be eliminated.

2. Measuring of double points (S4-S8, S6-S12, S9-S18) is better, as also the reliability increases. Points with 2 or 3 rays in bundle blocks form an exception. Their controllability is not influenced by an increase of the number of points in the image at all (S9, S18, S25). This is a real disadvantage of bundle blocks with 20 % sidelap.

3. The variation of the reliability within the units is considerable, especially within the images. The values δ_o' and $\bar{\delta}_o$ on an average increase with the distance of the points from the centre of the units. Even if one takes into account the different number of rays the lower bounds vary up to 100 % for points with 3 rays and up to 36 % for points with more than 3 rays. The variation is even greater, if one compares the values of different block types. This holds for the points in double blocks (S9-S18), where all points are determined by 9 rays! The reliability of the coordinates is fully acceptable, as $\bar{\delta}_o \leq 4.5$, again with the exception of the points with 2 or 3 rays. Though their variation is greater than the variation of the lower bounds, we will not analyse them in detail.

The values are independent on the blocksize. They will therefore be compared with the reliability at the border parts of the blocks.

3.3 Reliability of the border parts of the blocks

Owing to the variation of the values we analyse the maximum values of the different block types, which are given in tables 3 and 4 for the corner and the border parts separately. All these observations, which are not controllable at all, are not taken into consideration, especially single points and the x-coordinate of image points with 2 rays.

Table 3 Extreme values for reliability of independent model blocks (corner, border)

	20 % sidelap								60 % sidelap				
	planimetry				height					planimetry			
	corner		border		corner		border			corner		border	
Block	δ_o'	$\bar{\delta}_o$	δ_o'	$\bar{\delta}_o$	δ_o'	$\bar{\delta}_o$	δ_o'	$\bar{\delta}_o$	Block	δ_o'	$\bar{\delta}_o$	δ_o'	$\bar{\delta}_o$
S 4	21.	15.	18.	13.	12.	5.6	12.	5.4	-	-	-	-	-
S 6	12.	8.0	11.	7.7	-	-	-	-	D 6	7.6	4.3	6.9	3.5
S 8	7.8	5.5	7.8	5.5	7.3	4.5	7.3	4.5	-	-	-	-	-
S 12	7.3	5.2	7.2	5.1	-	-	-	-	D 12	6.4	4.1	5.7	3.1

1) For symmetry reasons only a part of the values are given

Table 4 Extreme values for reliability of bundle blocks (corner, border)

	20 % sidelap					60 % sidelap			
	corner		border			corner		border	
Block	δ'_o	$\bar{\delta}_o$	δ'_o	$\bar{\delta}_o$	Block	δ'_o	$\bar{\delta}_o$	δ'_o	$\bar{\delta}_o$
S 9	15.	10.	15.	10.	D 9	10.	5.7	9.7	4.0
S 18	12.	9.3	12.	9.3	D 18	7.0	3.0	6.3	3.0
S 25	12.	9.8	12.	9.8	-	-	-	-	-

The controllability of the tie points in model blocks highly depends on the number of points per model, particularly in the corner and the border of planimetric blocks. The lower bounds for detectable errors in the tie points of bundle blocks on the contrary are nearly independent of the number of points per image. For there are points with 3 rays in all images of single blocks.

Though double blocks are much more reliable, here again the image coordinates are less controllable than model coordinates. The external reliability of the coordinates of double blocks with independent models is fully acceptable, while the corner of double blocks with bundles is only well controllable if pairs of points are measured.

The fact, that bundle adjustments are more sensitive against gross errors is not really astonishing. For the number of orientation parameters differs (6 against 7). In blocks with independent models they absorb a greater part of the gross errors, this is especially true for the heights (cf. ch. 3.4). Moreover, there generally are more (hidden) observations per point in model blocks than in bundle blocks. A tie point in the middle of a strip needs 8 measurements (4 x 2 coordinates in the original images) for the 2 x 3 coordinates in the adjacent models. This cannot be seen in the number of observations in the blockadjustment but in the fact, that no gliding intersections uccur in independant model blocks.

3.4 Reliability of the projection centres

The ability of the transformation parameters of absorbing great parts of the gross errors is particularly revealed if we look at the reliability of the projection centres, which are treated as nuisance parameters in this context(cf. table 5).

Table 5 Extreme values for reliability of projektion centres (independent models, 20 % sidelap, i=12b)

Block	Coord.	Corner δ'	Corner $\bar{\delta}$	Border δ'	Border $\bar{\delta}$	interior δ'	interior $\bar{\delta}$	precision σ_{l_i}/σ
S 4	x	10.o	4.6	9.5	4.0	8.1	2.7	2
	y	6.4	2.2	6.4	2.2	6.4	2.2	2
	z	6.9	0.37	6.9	0.54	6.9	0.42	1
S 8	x	9.0	4.0	8.3	3.6	7.4	2.5	2
	y	6.0	1.6	6.0	1.6	6.0	1.6	2
	z	6.3	0.2Q	6.3	0.30	6.3	0.23	1

Though gross errors in the y-coordinates stay undetected already if they are smaller than 12 or 13 σ (the lower precision has to be taken into account), the influence of non detectable errors on the adjusted heights is very small, an extreme case are the z-coordinates, where errors have nearly no influence on the result.

The values are almost independent on the control point intervall. The adjacent models have the dominant effect on the controllability. Therefore the influence of x-ccordinate errors on the heights depends clearly, though not considerably on the location ot the projection centre in the block. Alltogether the values are acceptable.

4. Reliability of the control points

The analysis of the control points needs only consider the controolability, as the influence of control point errors on the result can easily be obtained by $\bar{\delta}_{o,i} = \delta_o \sqrt{(1-r_i)/r_i} = \sqrt{\delta'^2_{o,i} - \delta_o^2}$. We also consider single blocks only, as double blocks will usually be applied in special cases, in which high precision is demanded and the reliability of the control points will be guaranteed by geodetic means.

Table 6 Controllability of horizontal control points

Block	Location	$(\delta'_{o,i}/\delta_o)^2$	$\delta'_{o,i}/\delta_o$
S 4	corner border	4. + 0.5 $(i/b)^2$ 3.5 + 0.12 $(i/b)^2$	0.7 i/b 0.35 i/b
S 8	corner border	4 + 0.25 $(i/b)^2$ 2.5 + 0.075 $(i/b)^2$	0.5 i/b 0.27 i/b
S 9	corner border	2.6 + 0.8 $(i/b)^2$ 1.9 + 0.23 $(i/b)^2$	0.9 i/b 0.5 i/b
S 18	corner border	3.0 + 0.43 $(i/b)^2$ 1.9 + 0.13 $(i/b)^2$	0.65 i/b 0.35 i/b

Table 7 Controllability of vertical control points

Block	Location	$(\delta'_{o,i}/\delta_o)^2$	$\delta'_{o,i}/\delta_o$
S 4	corner border interior	3.1 + 3.2 i/b 2.3 + 1.7 i/b 1.2 + 0.9 i/b	1.8 $\sqrt{i/b}$ 1.3 $\sqrt{i/b}$ 1.0 $\sqrt{i/b}$
S 8	corner border interior	3.6 + 1.9 i/b 2.4 + 1.0 i/b 1.5 + 0.6 i/b	1.4 $\sqrt{i/b}$ 1.0 $\sqrt{i/b}$ 0.8 $\sqrt{i/b}$
S 9	corner border interior	0 + 5.0 i/b 0 + 2.6 i/b 0 + 1.3 i/b	2.2 $\sqrt{i/b}$ 1.6 $\sqrt{i/b}$ 1.1 $\sqrt{i/b}$
S 18	corner border interior	2.6 + 2.6 i/b 1.4 + 1.4 i/b 0.7 + 0.7 i/b	1.6 $\sqrt{i/b}$ 1.2 $\sqrt{i/b}$ 0.9 $\sqrt{i/b}$

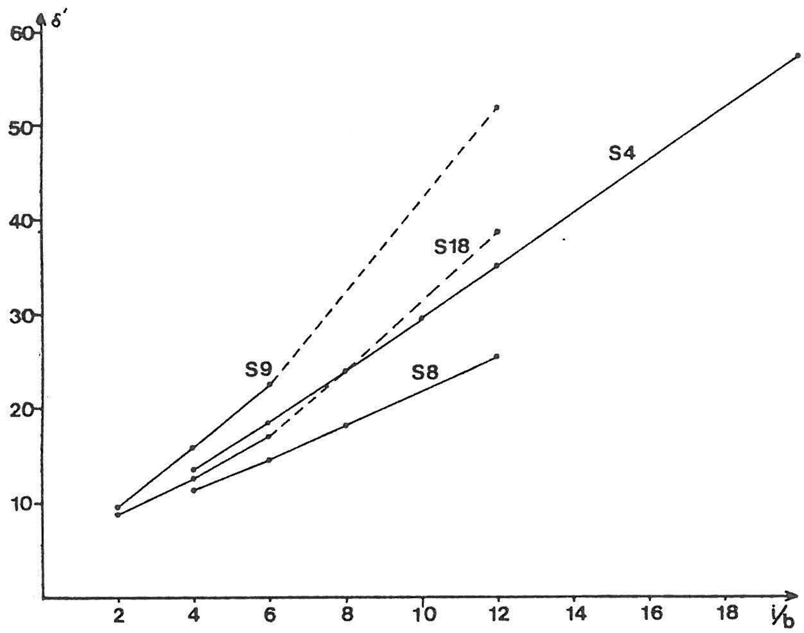


Figure 4 Controllability of horizontal control points, single blocks, corner

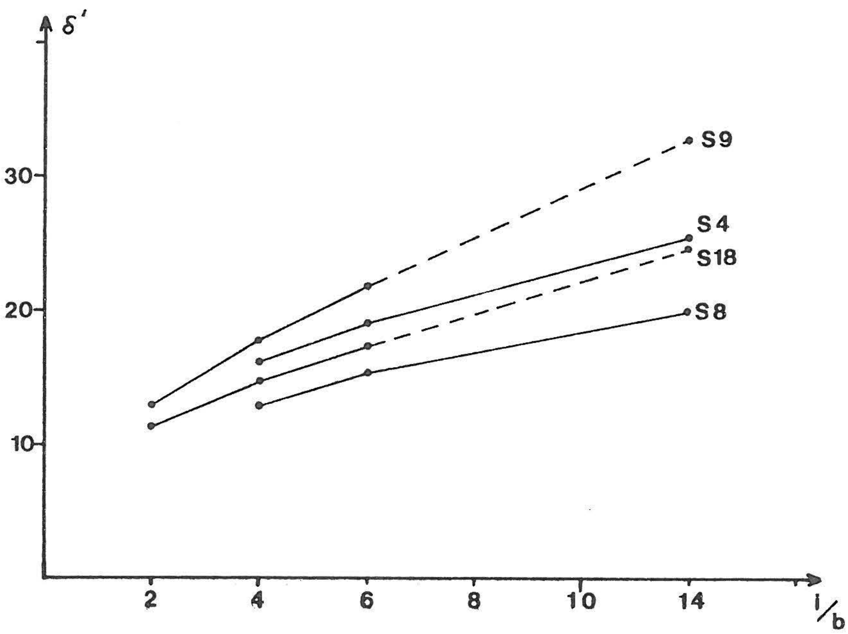


Figure 5 Controllability of vertical control points, single blocks, corner

The lower bounds for detectable gross errors of control point coordinates essentially depend on the control point intervall i. The type of dependency differs between horizontal and vertical control, which can be seen from figures 4 and 5. The blocks S9 and S18 with control point intervall 12 b contain only 4 control points in the corner, not at the border of the block. The values δ_o' are greater about 25 %, than they would be, if the block was greater and had control points at the borders also. Therefore the corresponding lines in figures 4 and 5 are dashed.

The dependency of the lower bounds for control points can be described by the general formula $\nabla_o l_i = \sigma_o \delta_o \sqrt{a + c(i/b)^2}$, the corresponding formula for vertical control points has the form $\nabla_o l_i = \sigma_o \delta_o \sqrt{a + c(i/b)}$. The special coefficients for the different blocks can be found in tables 6 and 7 (see prev.page). For large intervalls i/b the constant term (a) can be neglected. A comparison of the coefficients then leads to the following general rule, which approximates the lower bound for large control point intervalls i/b within 10 %:

$$\nabla_o l_i = \sigma_o \, \delta_o \sqrt{f_c \cdot f_t \cdot (f_l \cdot i/b)^e} \qquad (7)$$

f_t ... factor for tie point pattern
= 1 single points
= 1/2 double points

f_l ... factor for location of control point within the block
= 1 corner
= 1/2 border
= 1/4 interior

f_c ... factor for type of control
= 1/2 planimetry, independent models
= 4 height, independent models

= 1 planimetry, bundles
= $4\sqrt{2}$ height, bundles

e ... exponent
= 1 height
= 2 planimetry

The factors f_t and f_l are easily to be understood, as doubling the number of photogrammetric observations or doubling the sector for control leads to a corresponding increase of the controllability. The exponent araises from the different types of pattern. The factors f_c are found empirically and show again, that bundle blocks are more sensitive against gross errors than independent model blocks. But reffering to the horozontal control, however, the controllability of the heights turns out to be better in bundle blocks. The reason will be the different stability of the mutual connection of the units within a strip.

Eq.(7), divided by σ_o, at the same time gives an approximation for the reliability values $\delta_{o,i}$.

If one looks at the absolute values of controllability and reliability, it is obvious, that , except in the case of very short intervalls i, the control points can not really be checked by the block adjustment. Only a very small part of control point errors is revealed in the residuals, as the redundancy numbers all stay below 1/10.

The horizontal control needs more attention than the vertical control, as the lower bounds increase linearly with the intervall i. The mutual control of the points within the chains offer more possibilities of choosing the control point intervall for vertical than for horizontal control points.

In order to overcome the low controllability, especially for large intervalls, groups of control points can be used also in this case. As their geodetic determination leads to a high correlation between the points within a group, only the control of the photogrammteric identification is improved. Therefore the control points should be measured in at least 2 models or 3 images, that gross errors can be localized. Particularly the corner of the blocks has to be strengthend e. g. as in figure 6.

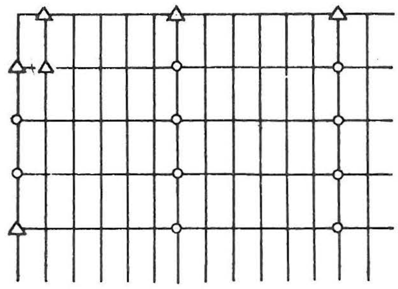


Figure 6 Strengthening of corner

5. Discussion

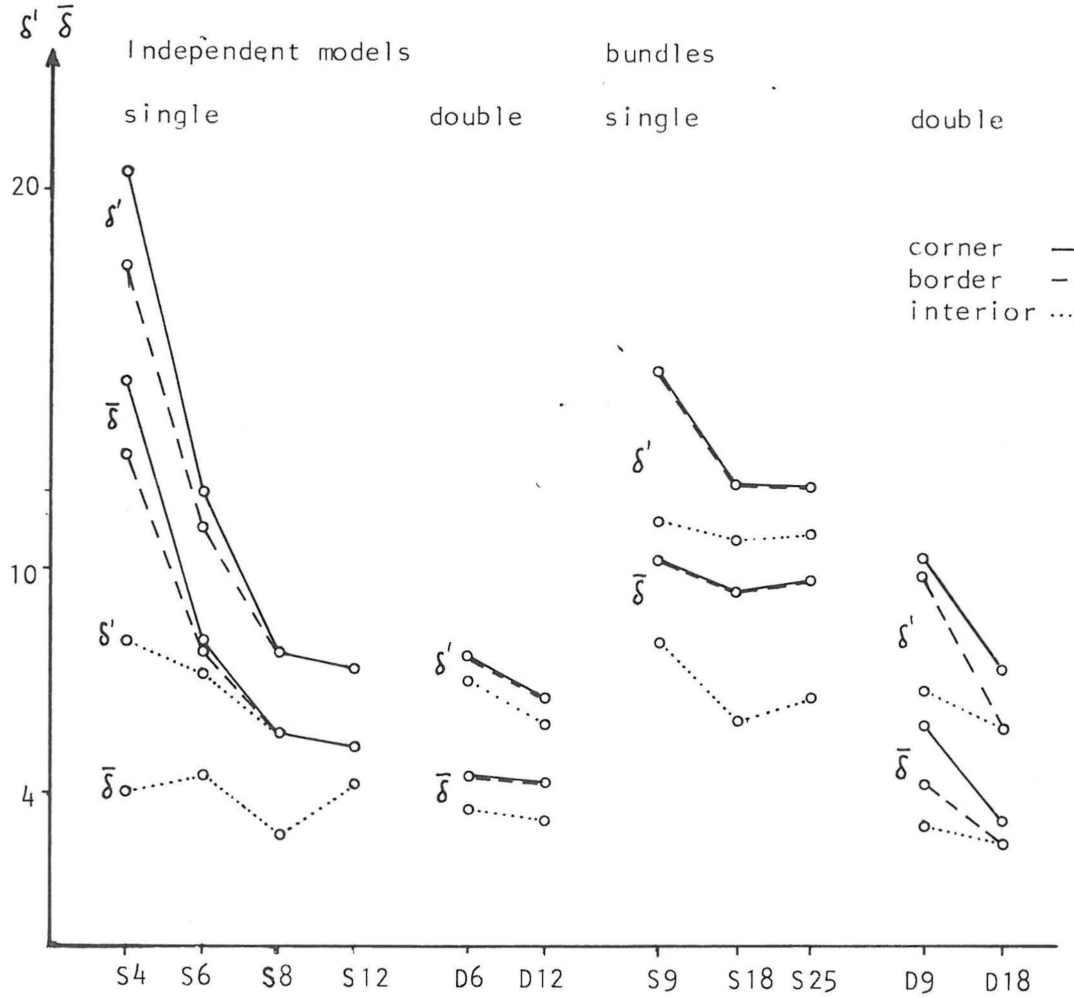
Photogrammetric point determination can reach a high reliability. This is the main result of the study. It also shows the weak points in photogrammetric blocks: the geodetic control, the perimeter of the blocks and the points with 2 or 3 rays in bundle blocks.

The values for controllability and reliability are based on the assumption, that the "data-snooping" test is applied, which needs the redundancy numbers r_i $(\sigma_{v_i}=\sigma_l \cdot \sqrt{r_i})$. For the control point distribution in practice is far from being regular and the controllability is very weak, it seems to be really necessary to apply a statistical test at least for the control points. Other tests, which do not refer to the geometry, are much less sensitive.

On the other hand the predominant part of the observations can be checked by traditional means, if the geometry is made homogeneous, i. e. the reduncancy is evenly distributed on the observations. At the same time the reliability would be improved. Then the programming and the computation of the redundancy numbers could be saved.

A really effective method to increase precision (cf. Ackermann, 1967) and reliability is to use only the interior part of the blocks (cf. figure 7).

Figure 7 Maximum values of controllability and reliability in photogrammetric blocks



This is superior to measuring more points per unit. Independent model block blocks with 20 % sidelap the reach the reliability of double blocks.

Not quite the same gain of reliability can be obtained with this method in bundle blocks. But if one uses aerial triangulation only for the determination of pass points, for subsequent mapping, and if it is possible to restrict the pass points to tie points with 4 ore more rays, bundle blocks can be adviced, which reach a higher precision than independant model blocks.Applying selfcalibration technique is indispensable in this case.

Without much additional effort even the controllability of double blocks with bundles can be increased, if the complete images at the border of the blocks are used in the adjustment (cf. figure 8).

Figure 8 Strenghtening of corner and border of a bundle block with 60 % sidelap, controllability values $\delta'_{o,i}$

usual border

10.	∞	10.	7.1	10.
7.0	9.2	7.7	5.5	7.4
7.1	8.6	8.1	5.9	7.5
5.8	6.2	6.5	5.0	5.8
6.7	7.4	6.9	5.3	6.7

complete images at the border

	∞	14.	∞	7.0	14.
9.1	6.9	6.8	6.8	5.2	6.5
9.9	5.9	7.3	6.7	5.3	6.8
9.1	6.4	7.4	7.0	5.4	7.0
7.0	5.6	5.9	5.8	4.9	5.7
8.6	5.8	6.9	6.6	5.3	6.5

Literature:

Ackermann, F.: On the Theoretical Accuracy of Planimetric Block Triangulation, Photogrammetria, 21, 1966, p. 145-170

Ackermann, F.: The Concept of Reliability in Aerial Triangulation, Ricerche di Geod. Topogr. e Fotogrammetria, Coop. Libr. Univ. d. Polytechnico, Milano, Dicembre 1979, N.1

Baarda, W.: Statistical Concepts in Geodesy, Neth. Geod. Comm.,Vol.2/4,1967

Baarda, W.: A Testing Procedure for Use in Geodetic Networks, Neth. Geod. Commission, Vol. 5/1, 1968

Baarda, W.: Reliability and Precision of Networks, VII Int. Course fo[illegible] Measurem. of High. Prec., Darmstadt, 1976

Ebner, H.: Theoretical Accuracy Models for Block Triangulation, BuL, [illegible]

Ebner, H., Krack, K., Schubert, E.: Accuracy Models for Bundle Block Tr[illegible]gulation, in german, BuL, 45, 1977

Förstner, W.: Die Suche nach groben Fehlern in photogrammetrischen Lageblöcken, DGK C 240, München 1978

Förstner, W.: On Internal and External Reliability of Photogrammetric Coordinates, ASP-ASCM Convention, Wash. 1979

Förstner, W.: Evaluation of Block adjustment Results, ISP Congress, Hamburg 1980

Grün, A.: Gross Error Detection in Bundle Adjustment, Aerial Triangulation Symposium, Brisbane, 1979

Schmitt, E.: Zuverlässigkeit photogrammetrisch bestimmter Höhen, Study, Inst. for Photogrammetry, University Stutgart, 1979