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Accuracy of Stereo Models by Simulation

ABSTRACT: *Simulation technique has been used to investigate the accuracy of different approaches to the photogrammetric treatment of single models. The simulation technique has also been used to investigate error properties of models for different combinations of control points and for cases where the control points are not assumed to be error free. Also the influence of a weight variation in the image coordinates on the model is investigated.*

INTRODUCTION

IN ORDER TO INVESTIGATE the accuracy of different photogrammetric models a series of simulations has been made. Three different mathematical approaches will be described here and the accuracy of them investigated. The methods treated are:

1. The restitution is divided into relative orientation followed by absolute orientation.
2. Rigorous solution of the double point resection in space considering parallax conditions for the bundle of rays.
3. Single point resection of the two cameras without using the parallax conditions.

The simulation technique has also been used to investigate the effect on the stereoscopic model when the control points are not free from errors. Also different combinations of geodetic control is investigated.

As there are reasons to expect that the image coordinates do not have equal weight over the whole image area the effect of such a weight variation has also been investigated.

METHOD

For the computations, flat terrain and vertical photography taken with a wide-angle camera and with the normal 60 percent overlap of the pictures have been assumed. Six points in the characteristic locations have been used where the y-parallax condition is accomplished (relative orientation) and five completely determined control points have been used to fit the models into the geodetic coordinate system (absolute orientation).

135 additional points located in a regular grid with a spacing of 15 mm have been used as checkpoints where the accuracy is investigated. In order to study the effect of irregular errors in the image coordinates on the orientation elements and on the terrain points, an error in every image coordinate has been introduced. These errors have been obtained with a random number generator. The irregular errors have been chosen here so that they are normally distributed with mean of zero and a standard deviation of 10 microns. The results which are given below thus assume a standard error of unit weight in the image coordinates of 10 microns.

Where the irregular errors have been introduced in the image coordinates, the calculations are made as if real pictures had been used. As the exact locations of the points are known it is possible after every model computation to calculate the true errors in the terrain coordinates as well as in the orientation elements. By repeating the computations for a number of different models, a statistical estimation of the accuracy can be obtained. The accuracy in the estimation of the standard errors is, of course, increased with an increased number of simulated models. For instance for 50 models the 95-percent confidence interval is obtained from the χ^2-distribution and is

$$0.84\cdot s < s < 1.24\cdot s$$

and for 100 models we have

$$0.88\cdot s < s < 1.16\cdot s.$$

These confidence intervals are valid for the elements of exterior orientation and also for the accuracy of the standard error of one

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point. For the values obtained for the entire model (135 points), the following confidence intervals are obtained from the t-distribution:

For 50 models $0.983 \cdot s < s < 1.017 \cdot s$

For 100 models $0.988 \cdot s < s < 1.012 \cdot s$.

Separate Relative and Absolute Orientation

This method of treatment of photogrammetric models is the most common in use. Besides, it also follows the photogrammetric procedure in analog instruments and, therefore, is of special interest. For relative orientation the following error equation is used:

$$y' - y'' = x' d\kappa_1 - \frac{x'y''}{c} d\phi_1 - x'' d\kappa_2 + \frac{x''y'}{c} d\phi_2 - \left(1 + \frac{y'y''}{c^2}\right) c\, d\omega_2.$$

And for absolute orientation the differential formulas are:

$$dX = dX_0 - S\,y\,d\alpha - S\,z\,d\eta + x\,dS$$
$$dY = dY_0 + S\,x\,d\alpha + S\,z\,d\xi + y\,dS$$
$$dZ = dZ_0 + S\,y\,d\xi - S\,x\,d\eta - z\,dS.$$

Usually the model treatment is not done quite rigorously. When the relative orientation is completed and the model coordinates have been calculated the discrepancies in the control points are treated as observed quantities and these are adjusted as equally weighted observations. To get a more nearly correct treatment of the adjustment one ought to take into consideration that the model coordinates after the relative orientation do not have the same accuracy and also the fact that they are algebraically correlated with each other. The calculations which have been made here, however, are made regardless of these facts. The theory of errors for stereoscopic models which are treated using this method have been investigated thoroughly by Hallert with the help of algebraical derivations.[1,2,3]

Where the relative and absolute orientations have been completed and the terrain coordinates have been calculated, the final discrepancies between measured and given coordinates of the control points and of the 135 check points have been calculated. Finally, in every model the root-mean-square errors have been calculated for the control points and for the check points.

The calculations have also yielded the standard error of unit weight in the relative and absolute orientations as well as the root-mean-square values in the residual parallaxes for the check points. The errors in the final data of the outer orientation of the cameras are functions of the elements of the relative and absolute orientation and have been obtained in the following way:

Left camera	*Right camera*
$X_{01} = dX_0$	$X_{02} = dX_0 + b \cdot dS$
$Y_{01} = dY_0$	$Y_{02} = dY_0 + b \cdot d\alpha$
$Z_{01} = dZ_0$	$Z_{02} = dZ_0 - b \cdot d\eta$
$\kappa_1 = d\kappa_1 + d\alpha$	$\kappa_2 = d\kappa_2 + d\alpha$
$\phi_1 = d\phi_1 + d\eta$	$\phi_2 = d\phi_2 + d\eta$
$\omega_1 = d\xi$	$\omega_2 = d\omega_2 + d\xi$

In this way 100 models have been simulated. From these calculations the accuracy of the elements of the outer orientation and also the accuracy of every single point within the model area are obtained.

Rigorous Solution of the Double-Point Resection in Space

H. Schmid has shown[5] how to handle aerial triangulations rigorously. This approach is of course valid not only for triangulations in strips and blocks but also for treatment of single models. The method can be described briefly in the following way. Six orientation elements are introduced as unknowns for every camera and one unknown for every unknown terrain coordinate, that is as a rule three unknowns for each point. In this way four observation equations are obtained for one point which is seen stereoscopically. At the same time the number of unknowns is increased by three if the coordinates of the points are not known. The condition of intersecting rays in space is at the same time fulfilled. It is very easy to take into consideration a weight variation in the image coordinates as those are the observations which are to be adjusted.

For a model with five completely known control points and six points for the relative orientation, 12 unknowns are obtained for the exterior orientation of the two cameras and 18 unknowns for the 6 relative orientation points; in all, 30 unknowns and 44 observation equations. The error equations for the control points are:

$$dX = dX_0 + \frac{x}{h} dZ_0 - y\,d\kappa - \left(1 + \frac{x^2}{h^2}\right) h\,d\phi + \frac{xy}{h} d\omega$$

$$dY = dY_0 + \frac{y}{h} dZ_0 + x\,d\kappa - \frac{xy}{h} d\phi + \left(1 + \frac{y^2}{h^2}\right) h\,d\omega$$

where $x = X - X_0$; $y = Y - Y_0$; $h = Z_0 - Z$.

For every point (i) where the parallax condi-

TABLE 1. STANDARD ERROR IN THE MODEL COORDINATES AND ROOT MEAN SQUAR ERROR IN THE CONTROL POINTS. THE CONTROL POINTS ARE FREE FROM ERRORS

	Model coordinates			*Control points*		
	X	*Y* *microns*	*Z*	*X*	*Y* *microns*	*Z*
Relative and abs. orient.	11.9	17.6	30.2	9.6	12.7	18.3
Double point resection	11.2	15.9	28.6	7.1	11.8	17.1
Single point resection	11.1	15.7	28.7	6.8	11.6	17.0

tion shall be fulfilled the above expressions are supplemented with

$$dX = \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot - dX_i - \frac{x}{h} dZ_i$$

$$dY = \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot - dY_i - \frac{y}{h} dZ_i.$$

It is noted here that the number of unknowns can be considerably reduced. If the approximate values of the model coordinates for the relative orientation points are determined from the model by intersection, then the dX-equation will not give any information for the determination of the unknowns and can thus be ignored. The dY-equation can be reduced to a parallax equation

$$P_y = dY_{\text{left}} - dY_{\text{right}} \quad \text{with weight } 1/2$$

Thus the unknowns dX_i, dY_i and dZ_i are eliminated and only the 12 unknowns for the outer orientation will remain. In this way the parallax condition can be introduced in an arbitrary number of points without increasing the number of unknowns. It must be observed that the X-axis of the given coordinates must go in the direction of the base if the above formulas are used. The same reduction in the unknowns can be made in triangulations.

Then the equation system is solved, the exterior orientation elements are calculated and the model coordinates are obtained with the help of intersection. The corresponding data which are described above for Method 1 are also calculated here. There is a difference in the methods due to the fact that the elements of exterior orientation are obtained directly in this case where the equation system is solved. Thus also the standard error in the orientation elements is obtained from the weight coefficient matrix. In addition the standard errors of the model coordinates can be obtained with the help of the law of error propagation. Here, however, the accuracy in the model coordinates has been obtained in the same way as described for the relative and absolute orientation treatment. Fifty models have been simulated for this case.

SINGLE POINT RESECTION OF THE TWO CAMERAS

In this case the parallax condition of intersecting rays has not been used at all. The two cameras have been separately resected in space with the help of the five control points and the determination of the model coordinates is made by intersection. The two camera orientations are uncorrelated with each other. The standard errors in the terrain coordinates are obtained as described earlier and not by means of the law of error propagation, which method also would be possible. One hundred models have been simulated in this case.

RESULTS FROM THE CALCULATIONS

The results from the three methods of model treatment are compared in Tables 1 and 2.

Some other data which can be of interest is the standard error in the base which was 36.0, 28.5 and 37.0 microns respectively, The root-mean-square of the residual parallaxes

TABLE 2. STANDARD ERROR IN THE EXTERIOR ORIENTATION

	x_0	y_0 *microns*	z_0	μ	ϕ *sec. of arc.*	ω
Relative and abs. orient.	46.7	61.0	17.0	49^{cc}	184^{cc}	189^{cc}
Double point resection	$\underline{23.6}$*	$\underline{23.3}$	$\underline{10.0}$	$\underline{33^{cc}}$	$\underline{92^{cc}}$	$\underline{72^{cc}}$
Single point resection	$\underline{26.7}$	$\underline{27.2}$	$\underline{11.7}$	$\underline{38^{cc}}$	$\underline{105^{cc}}$	$\underline{83^{cc}}$

* Underlined values indicate that they are obtained from weight coefficients.

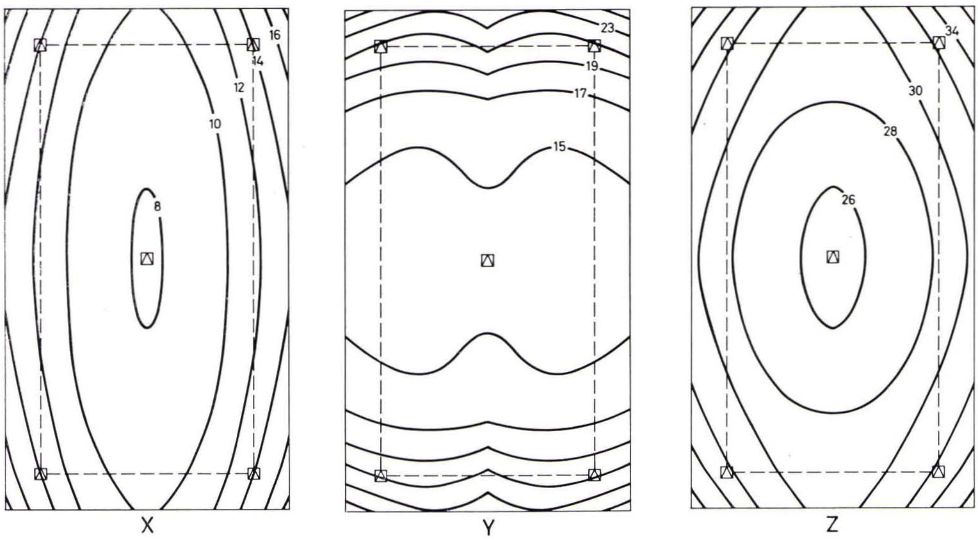

FIG. 1. Standard errors of the terrain coordinates at the image scale. Six points are used for the relative orientation and five points for the absolute orientation. $s_0' = 10$ microns.

was 18.9, 18.0 and 19.7 microns for the three methods. From the tables is seen that in spite of the fact that Methods 2 and 3 give much better determination of the elements of the exterior orientation compared with the relative and absolute orientation method, the increase in accuracy in the terrain coordinates is modest. The explanation for this will be given below. Figure 1 illustrates how the accuracy in the terrain coordinates varies in different parts of the stereoscopic model when the relative and absolute orientation method is used for the model treatment. The simulations according to Method 1 show that the accuracy in the final terrain coordinates can be given by the following expressions:

$$s_X = s_0' \cdot \frac{h}{c} \cdot 1.19 = s_0 \cdot \frac{h}{c} \cdot 0.84$$

$$s_Y = s_0' \cdot \frac{h}{c} \cdot 1.76 = s_0 \cdot \frac{h}{c} \cdot 1.24$$

$$s_Z = s_0' \cdot \frac{h}{c} \cdot 3.02 = s_0 \cdot \frac{h}{c} \cdot 2.14$$

where s_0 is the standard error of unit weight in the image coordinates and s_0' is the standard error of unit weight in the vertical parallaxes.

The area over which the accuracy has been calculated here is a little larger than that which has been used by Hallert in his derivations of the expected accuracy in the terrain coordinates. To make the values more nearly comparable the corresponding expressions have been calculated for the area inside the relative orientation points, i.e. *neat model*. These expressions are

$$s_X = s_0' \cdot \frac{h}{c} \cdot 1.04 = s_0 \cdot \frac{h}{c} \cdot 0.74$$

$$s_Y = s_0' \cdot \frac{h}{c} \cdot 1.62 = s_0 \cdot \frac{h}{c} \cdot 1.15$$

$$s_Z = s_0' \cdot \frac{h}{c} \cdot 2.96 = s_0 \cdot \frac{h}{c} \cdot 2.09.$$

Corresponding expressions given by Hallert are

$$s_X = s_0 \cdot \frac{h}{c} \cdot 1.1$$

$$s_Y = s_0 \cdot \frac{h}{c} \cdot 1.2$$

$$s_Z = s_0 \cdot \frac{h}{c} \cdot 1.9.$$

The differences in the expressions are explained by an approximation which has been made in the algebraic derivations. It was assumed there that the model coordinate accuracy at the image scale is equal to the image coordinate accuracy, and also equal to the standard error of unit weight of the y-parallaxes. This assumption gives the strongest influence in the X-coordinates. The reason for this is that if an error dx' is introduced in an image coordinate the effect of this error is reduced through the elevation error introduced at the same time. This is illustrated in Figure 2.

Separation of Errors from Different Sources

It is of interest to investigate from which part of the model treatment the errors arise and to see if there are possibilities to reduce them. The following separation is appropriate for such a discussion.

A. Direct influence from the irregular image coordinate errors.
B. Indirect influence of the irregular image coordinate errors through the elements of absolute orientation. Due to the image coordinate errors in the control points the elements of absolute orientation are disturbed. This introduces errors in the model coordinates.
C. Indirect influence of the irregular image coordinate errors through the elements of relative orientation. The image coordinate errors in the points for relative orientation have caused model deformations which in case of redundant control points can not completely be compensated for in the absolute orientation. Remaining model deformations contribute to the errors in the terrain coordinates.

Each of these sources of errors is proportional to the irregular image coordinate errors and they are not correlated with each other.

For the neat model we obtain the following separation:

$$s_X = s_0' \cdot \frac{h}{c} \sqrt{0.72 + 0.29 + 0.07}$$

$$s_Y = s_0' \cdot \frac{h}{c} \sqrt{1.28 + 0.67 + 0.67}$$

$$s_Z = s_0' \cdot \frac{h}{c} \sqrt{5.52 + 2.27 + 0.97}.$$

The errors under A are completely independent of the mathematical approach. They are obtained from the following expressions:

$$dX = \frac{h}{c}\, dx' = \frac{Xh}{bc}\,(dx' - dx'')$$

$$dY = \frac{h}{2c}\,(dy' + dy'') - \frac{Yh}{bc}\,(dx' - dx'')$$

$$dZ = \frac{h^2}{bc}\,(dx' - dx'')$$

The errors under B and C can however to a certain extent be influenced. If an increased number of points are used for the relative orientation, the errors under C are somewhat reduced. Correspondingly, the errors under B are somewhat reduced when the number of points for the absolute orientation are increased. An uninpressive increase in accuracy is obtained even if the points for relative and absolute orientation are increased very much. The direct influence of the irregular image coordinate errors dominate. Table 3 illustrates this more obviously for $s' = 10$ microns.

Another conclusion which follows from this is that it is not possible to improve the

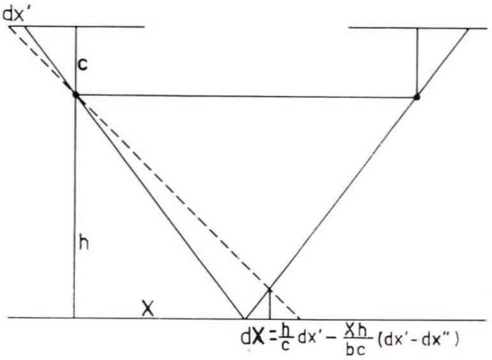

FIG. 2. The effect of an x'-coordinate error is reduced by the corresponding elevation error introduced.

accuracy by using a more refined mathematical approach. If however less than five control points are used for the absolute orientation, the errors under B will of course increase. This will be shown below for two other combinations of control points.

INFLUENCE FROM ERRORS IN THE CONTROL POINTS

In order to investigate how errors in the control points influence the accuracy of the model treatment, simulations have been made where irregular errors have also been introduced in the control points. The assumption that the errors in practice are irregular is of course an approximation but will probably apply to a certain extent in those cases where photogrammetric triangulation has been used to determine them. In each of the methods 50 models have been simulated. Here the results will be shown where the irregular error in each of the control points had a standard deviation corresponding to 20 microns in each of X, Y and Z. In Method 1 the relative orientation is of course not influenced by these errors which are first introduced in the absolute orientation. In Methods 2 and 3, on the other hand, the errors in the control points will deform the photogrammetric model. Tables 4 and 5 show the results obtained with the three methods.

TABLE 3. INFLUENCES OF A-, B-, C-TYPES OF ERRORS

	Error influence from			
	$A+B+C$	$A+B$	$A+C$	A
s_X	10.4	10.0	8.9	8.5
s_Y	16.2	14.0	14.0	11.3
s_Z	29.6	27.9	25.5	23.5

TABLE 4. STANDARD ERROR IN THE MODEL COORDINATES AND ROOT MEAN SQUARE ERROR IN THE CONTROL POINTS. ERRORS IN CONTROL POINTS

	Model coordinates			*Control points*		
	X	*Y* *microns*	*Z*	*X*	*Y* *microns*	*Z*
Relative and abs. orient.	17.2	20.6	33.6	19.4	20.9	25.0
Double point resection	16.8	23.3	33.8	16.5	23.1	23.6
Single point resection	16.4	22.6	34.6	17.2	25.0	24.4

From the above it may be seen that the less accurate model formation from Methods 2 and 3 primarily affects the Y-coordinates. In X somewhat better results are obtained. The determination of the elements of the exterior orientation is approximately of the same quality in the three methods. The low values in Y_0 and ω from the Method 1 are not significantly different from the corresponding values obtained from the other methods. The standard error in the base was 48.4, 56.7 and 60.0 microns respectively and the root-mean-square value of the residual parallaxes was 18.6, 26.0 and 30.7 microns respectively.

INFLUENCE OF A VARIATION IN THE ACCURACY OF THE IMAGE COORDINATES

Several investigations in Sweden have shown that the accuracy of the image coordinates is not constant over the whole picture but varies considerably. The standard error increases with the distance from the center of the picture. Thus it is of interest to investigate how such a weight variation in the image coordinates will influence the accuracy in the photogrammetrically determined points.

Morén stated[4] that the standard error of the image coordinates obtained from calibrations using the grid method varies with the radius according to following expression:

$$s_0' = 2.1 + 0.053\, r + 0.00023\, r^2,$$

i.e., 2 microns in the center of the picture and about 15 microns in the corners. In order to obtain a root-mean-square value of 10 microns over the entire picture, these values have been enlarged a little. The function used is then

$$s_0' = 2.3 + 0.058\, r + 0.000254\, r^2.$$

In the coordinates used for the simulations, the standard deviation of the generated random error varies over the image according to the expression above. The further calculations have been made as described before. The results are shown in Tables 6 and 7 for the method with relative and absolute orientation.

The standard error in the base was 52.1 microns and the root-mean-square value of the residual parallaxes was 18.4 microns. The standard error of unit weight (parallaxes) was 14.9 microns.

TABLE 5. STANDARD ERROR IN THE EXTERIOR ORIENTATION

	x_0	y_0 *microns*	z_0	μ	ϕ *sec. of arc.*	ω
Relative and abs. orient.	65.7	53.0	27.4	76^{cc}	267^{cc}	160^{cc}
Double point reseection	61.1	62.2	26.9	74^{cc}	242^{cc}	202^{cc}
Single point resection	64.9	66.1	24.4	92^{cc}	255^{cc}	202^{cc}

TABLE 6. STANDARD ERROR IN THE MODEL COORDINATES AND ROOT MEAN SQUARE ERROR IN THE CONTROL POINTS. THE ACCURACY OF THE IMAGE COORDINATE IS ASSUMED TO VARY WITHIN THE IMAGE

	Model coordinates			*Control points*		
	X	*Y* *microns*	*Z*	*X*	*Y* *microns*	*Z*
Relative and abs. orient.	9.9	18.4	30.3	9.2	14.1	17.4

TABLE 7. STANDARD ERROR IN THE EXTERIOR ORIENTATION

	x_0	y_0 *microns*	z_0	μ	ϕ *sec. of arc.*	D
Relative and abs. orient.	52.6	57.9	19.7	50^{cc}	215^{cc}	174^{cc}

The results show that it is not possible to deduce from the standard error of unit weight in the relative orientation, nor from the discrepancies in the control points, that there exists a weight variation in the image coordinates. The root-mean-square value of the discrepancies in the coordinates over the model area is not changed very much. However there is a great difference between the standard errors in different parts of the model. The weight variation of the image coordinates has a marked influence upon the model coordinates. The standard errors in different parts of the model under the assumption of a weight variation in the image coordinates are shown in Figure 3.

LESS THAN FIVE CONTROL POINTS FOR ABSOLUTE ORIENTATION

Above it was concluded that the inherent accuracy in the photogrammetric model is well utilized when five control points are used for the absolute orientation. If less points are used the errors in the final coordinates will, of course, increase. Two cases are investigated here according to Method 1. In the first case four completely determined control points in the corners of the *neat model* are used. In the second case minimum number of control is used, i.e., two horizontal points and three in elevation. In this case two completely determined control points are situated in the corners of the left side of the model and one elevation point under the right projection centre. The results shown in Tables 8 and 9 were obtained from 200 simulated models in each case. The standard error of the base was 47.1 and 49.8 microns respectively.

If the values obtained for four control points are compared with those obtained for five control points it is seen that the decrease in accuracy is very modest. Thus, the point in the centre of the model is not necessary but can of course serve as a check of systematic model deformations. The error distribution in the model in this case is very similar to that shown in Figure 1.

If a minimum number of control points is used the decrease in accuracy is more marked. The error distribution in the model for the combination of control points used is shown in Figure 4.

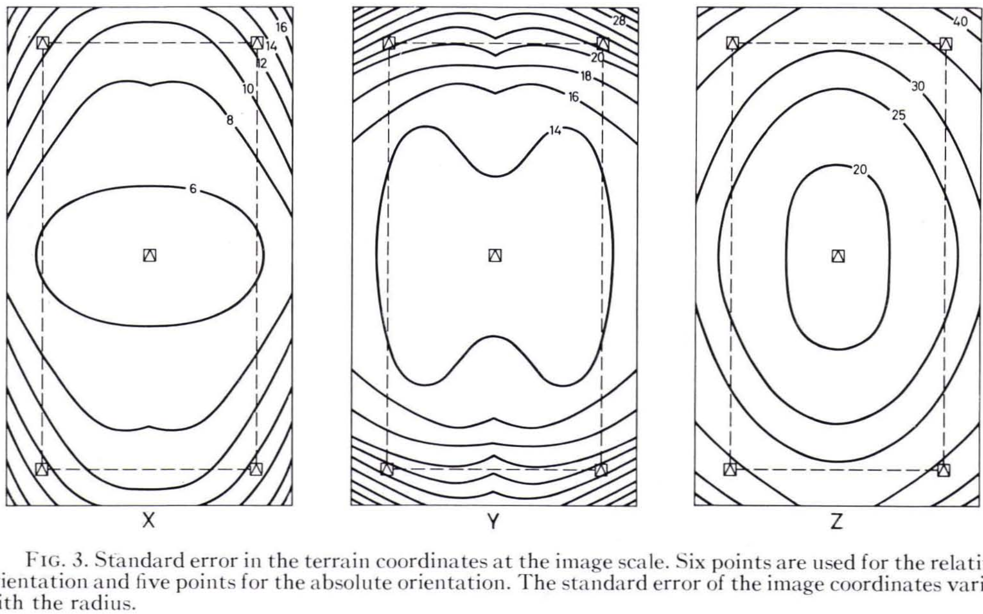

FIG. 3. Standard error in the terrain coordinates at the image scale. Six points are used for the relative orientation and five points for the absolute orientation. The standard error of the image coordinates varies with the radius.

TABLE 8. STANDARD ERROR IN THE MODEL COORDINATES AND ROOT MEAN SQUARE ERROR IN THE CONTROL POINTS

	Model coordinates			*Control points*		
	X	Y *microns*	Z	X	Y *microns*	Z
Four control points	12.4	18.8	30.9	10.2	12.6	15.5
Minimum control	14.9	24.0	34.4			

TABLE 9. STANDARD ERROR IN THE EXTERIOR ORIENTATION

	x_0	y_0 *microns*	z_0	μ	ϕ *sec. of arc.*	ω
Four control points	52.0	64.1	18.6	55^{cc}	204^{cc}	192^{cc}
Minimum control: left	64.5	72.0	12.1	48^{cc}	258^{cc}	223^{cc}
right	54.8	70.0	36.4	104^{cc}	241^{cc}	185^{cc}

CONCLUSIONS

From the investigations related here it may be seen that the standard error in photogrammetrically determined points is to a great extent independent of the number of control points exceeding four, and also of the number of points where the parallax condition is to be fulfilled. In order to increase the accuracy it is necessary to reduce the irregular image coordinate errors, the effect of which dominate.

From the above it follows also that it is not possible to increase the accuracy in the model coordinates through a more rigorous mathematical approach. This is also apparent from the simulations made here. The method to be preferred can, instead, be chosen otherwise. A slight increase in accuracy is obtained in the case of rigorous double or single-point resection in space. When it comes to the determination of the elements of exterior orientation the increase in accuracy is much more marked in these cases.

Through the introduction of a weight variation in the image coordinates it is seen from the simulations that the exterior orientation is only slightly influenced. The weight variation will, however, influence very strongly

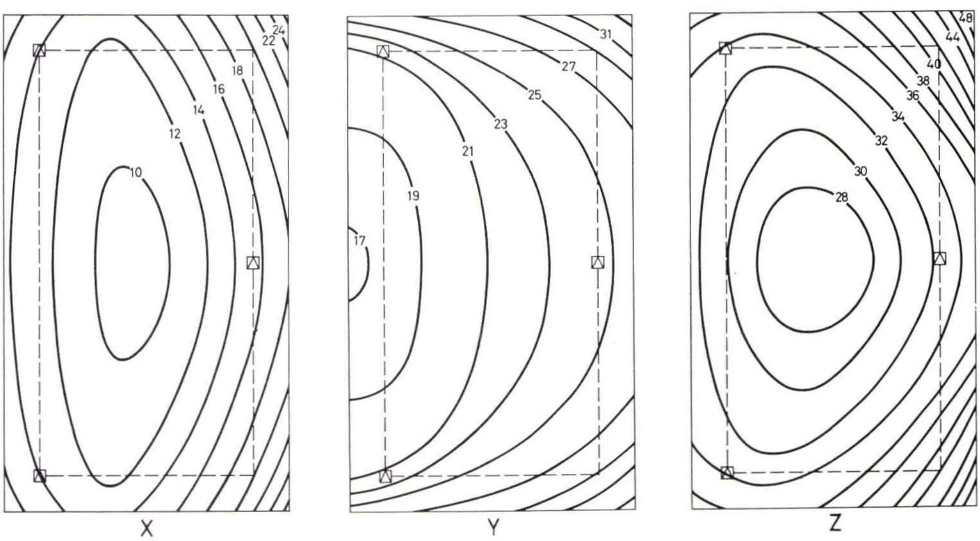

FIG. 4. Standard error of the terrain coordinates at the image scale. Six points are used for the relative orientation and the minimum number of control points for the absolute orientation. $s_0' = 10$ microns.

the accuracy of the terrain coordinates in different parts of the model.

The last fact in a way brings up the question of how reliable these theoretical investigations are in practice. They are of course valid only if the underlying assumptions are true. Through correction of image coordinates for systematic errors one tries in practice to obtain a normal distribution of the residual errors. This can in most cases be obtained. However not enough information exists at this time on the weight distribution and the physical correlation between adjacent points. The simulation technique, however, gives a rather easy way to investigate the effect of various assumptions. As an example, the time used for simulating 200 models was approximately 3 minutes. The calculations were made on a CDC 3600 computer from Central Data Corporation, USA.

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REFERENCES

1. Hallert, B. *Über die Herstellung photogrammetrischer Pläne*. Stockholm 1944.
2. Hallert, B. Contribution to Theory of Errors for Double Point Intersection in Space. *Transactions of the Royal Institute of Technology*, No. 35, 1950.
3. Hallert, B. Über die Genauigkeit der Luftphotogrammetrie. *Transactions of the Royal Institute of Technology*, No. 99, 1956.
4. Morén, A. Summary of Tests of Aerial Photographs of the Öland Test Field. *Photogrammetria*, No. 20, 1965.
5. Schmid, H. Eine allgemeine analytische Lösung für die Aufgabe der Photogrammetrie. *Bildmessung und Luftbildwesen*, No. 4, 1958.