MULTIMODELS INCREASE ACCURACY - SUMMARY OF AN EXPERIMENT

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ABSTRACT

Classical theory of error for photogrammetry divides errors in three groups: Blunders, systematic errors and random errors. Systematic errors are caused by the lacking of fidelity of the functional part of the mathematical model to the real geometric relations. Block adjustment with additional parameters, multiple photographic coverage and snooping after blunders provide results with high reliability, fidelity and precision. This report presents results based on multimodels formed by averaging two or more single stereomodels. The comprising single models are calculated without correction for lens distortion, atmospheric refraction and earth curvature. The improvement of accuracy by forming multimodels is studied. Photography was taken with Hasselblad MK70 from four flying altitudes, with different aircraft speed and flying directions. From differences in some 50-60 check points in some 30-35 stereomodels the accuracy was determined as rms errors, mean errors and standard deviations in planimetry and elevation. The classical theory of error propagation was confirmed. The precision of photogrammetric stereomodels can be decomposed into components related to ground co-ordinates, image co-ordinates and image motion due to aircraft speed. The accuracy improvement by multimodels is proportional to $1/\sqrt{n}$, n = number of models. The multimodel method provides an increase of the accuracy which is similar to the additional parameters in photogrammetric block adjustment, because both methods are based on multiple photographic coverage.

INTRODUCTION

Present studies, within the frame of the ISOK-project conducted by the Swedish Association of Municipalities /3/, have shown that almost all the needs of map users can be satisfied with photogrammetry. However, there are certain special cases where photogrammetric methods for map production, currently in use to-day, do not come up to the high standard of accuracy required. This has inspired the author to conduct a study to determine whether or not the use of several stereoscopic models over the same area would yield a result which would satisfy these especially high accuracy requirements.

In one particular study, /4/, the author has analysed the results of so-called controlled experiments in order to obtain statistical data concerning standard errors in plan and elevation in large scale photogrammetric maps. The study showed that photogrammetric standard errors consist of both systematic and random parts. This is already well known to photogrammetrists, as is the fact that the reason for this is that, in map production, each stereoscopic model is oriented using only a limited number of control points. The study also showed that it should be possible to increase the accuracy, considerably, by using analytical methods with numerical storage of map information in a data bank, instead of analogue methods with the drawing of the map directly coupled to the analogue instrument.

CONCERNING REDUNDANCY IN PHOTOGRAMMETRY

In geodetic triangulation angles are, as a rule, measured by completing the circle several times, advancing the starting point on the circle between each set of readings. By using such a procedure a large part of the theodolite error is limited. On the other hand in photogrammetric stereoscopic mapping only single stereoscopic pair of photographs is used. A stereoscopic pair of photographs may be likened to two angle measurements, each obtained using only half a set of angle readings. Even so, because the cameras and reduction instruments used are of very high quality and are carefully calibrated, and because strict controls are routinely carried out during the measuring process, photogrammetry yields good results. Think of the accuracy that could be obtained if a method similar to that used in geodesy were used in photogrammetry.

It might be said that this has already been tried, in photogrammetric block triangulation. Remaining unknown instrument errors, distortion, and abnormal refraction might be eliminated using extra parameters in the adjustment. However, it would be necessary that the photography be carried out with a lateral overlap of 60%, so that each ground point would appear in at least four photographs, possibly in as many as nine photographs. The use of double strip density, compared with 20% lateral overlap, would result in increased accuracy, not only because it would become possible to eliminate remaining systematic errors, but also because gross errors, or blunders would be more easily detected, localized and eliminated, since each ground point would be measured in at least four photographs, and the adjusted point co-ordinates would be based on a greater number of measurements, than if only 20% overlap were used.

These advantages cannot, as yet, be made use of in detail photogrammetric mapping. Much study and method development are still required in this area. To-day, all stereoscopic mapping is done from single stereoscopic models, and the result is almost always a drawn map. Firstly, it is necessary to go over to analytical or numerical methods. One has to use stereocomparators or analytical stereo-instruments. For numerical photogrammetry there are a number of stereo-autographs with co-ordinate registration. Secondly, measurements from more stereomodels over the same area have to be averaged. However, with these instruments there is no possibility of using a data base for updating, error seeking, averaging, and increasing the accuracy by measuring several stereoscopic models over the same area.

MULTIMODEL METHOD

One way of increasing the photogrammetric accuracy is to use the multimodel method for detail mapping. One condition is the use of analytical or numerical methods. Another is the use of a map data base capable of being successively updated. If these conditions are fulfilled the area to be mapped must be photographed several times using different flight directions. The various models are then measured separately and stored numerically.

The multimodel is the average of the various measured models. Various checks against gross errors can easily be built into the process. For measured objects which consist only of points, it is an easy matter to compare with the co-ordinates of the measured objects. For line objects special routines must be developed. One way would be to store the coefficients of the line equations. Another would be to steer successive measurements from the foregoing, which is possible in the new analytical stereo-instruments (Planicomp, Aviolyt and the like). Digital elevation models offer a number of possibilities of using the multimodel method for height measurement. The elevation models may then be used to generate contour lines, profiles, cross sections, and for mass calculations, etc.

THE MÅRTSBO EXPERIMENT

One basic problem that must be studied in detail in connection with multimodels is, of course, the increase in accuracy that can be obtained. One must know how much can be won by developing a multimodel method for detail measurement. Practical experiments to determine accuracy would require test fields. Since such are very expensive, they are uncommon. There is, however, one test field for detail measurement and the setting out of points, in Mårtsbo, near Gävle. This test field consists of a basic Berliner net of seven points and a grid of 60 points with a 5-meter interval. Responsibility for the Mårtsbo field is in the hands of the Swedish Institute for Building Research (SIB) /2/.

This experiment was intended to show how the accuracy of the multimodel was dependent on:

1 The number of stereomodels used

2 The photograph scale (flying height)

3 The direction of flight for the individual stereomodels

4 The speed of the aircraft

5 The number of control points used.

Photography was carried out from a helicopter, using a Hasselblad MK70, with a Biogon 60 objective lens. The use of a helicopter made it possible to vary the speed of the aircraft, yielding the possibility of studying the effect of lack of sharpness due to the movement of the camera. Four different flying heights and four different directions of flight were used. Unfortunately it was not possible to carry out the experiment in its entirety because of high winds. In the following evaluation 33 stereomodels were used. The consulting engineering firm VIAK AB, Falun, was responsible for photography which was done in co-operation with Sterner Flyg AB and SIB. The photographs were measured in a stereocomparator and co-ordinates calculated by VIAK AB, Gothenburg. Only four of the 25 fiducial marks in the MK70 camera were measured, partly to reduce the time required for measurement, and partly for similarity with a possible future experiment using a Wild measuring camera. Between ten and twenty points were used for relative orientation. Absolute orientation was done in two different ways, firstly with only 3-5 points of the Berliner net, and then with 10-20 points, in which case even a number of grid points were used. After photogrammetric co-ordinates for all test field points were determined, differences between these and the corresponding given values were calculated. The following analysis deals principally with these differences.

Photogrammetric practice has shown that the errors in a stereomodel consist of a random part and a systematic part. The random part varies randomly from point to point. The systematic part is dependent on several factors, partly systematic photograph errors which have a direct effect, and partly systematic and random errors in the observation of the control points and relative orientation points which have an indirect effect. These latter errors are fixed for each individual model, but vary from model to model. Certain systematic photograph errors are the same for all photographs (for example, incomplete correction for the radial distortion of the lens) while others vary, depending on the circumstances (for example, lack of film flatness, shrinkage, refraction). A large part of the following analysis deals with the relations between the systematic and the random errors when one thinks in terms of multimodels instead of single models.

SOME RESULTS

In the limited space available here, only a part of the results can be presented. The complete report /5/ is available for those who wish to read it. For individual models the results are as follows. The fiducial mark transformations show a standard error of unit weight of 4.1 µm, relative orientation 6.4 µm, and the root-mean-square value of y-parallaxes in the remaining points was 7.3 µm. From this it may be concluded that the remaining distortion and refraction are in the order of 3.0 µm. The accuracy, after absolute orientation, may be seen in Table 1. For control points the standard error is given, while from the calculated differences for test field points, a standard error (accuracy) has been expressed as a root-mean-square value, a systematic error (model fidelity) has been expressed as an average, and a random error (precision) as a standard deviation. It may be seen that the precision is independent of the number of control points, that the model fidelity becomes better if the number of control points is increased, and that nothing can be gained by flying lower than that height which corresponds to a photograph scale of 1:4000. At lower flying heights the accuracy is limited partly by the possibility of targeting and identifying the point, and partly by the lack of sharpness due to the speed of the aircraft. In plan the first error component is 5-12 mm and the second 5-15 mm, at a speed of 100 km/h. In elevation the corresponding figures are 27 mm and 21-24 mm. To these must be added the standard error of the photograph co-ordinates the magnitude of which is a function of the scale of the photograph.

A double model is created by taking the average of the point co-ordinates from single models. Double models may arise in several ways:

- From neighbouring models in the same strip (one photograph common)
- From models flown in the same direction
- From models flown in opposite directions
- From models flown in intersecting directions.

It has been observed that the accuracy increases from top to bottom of the above list. The relative increase in accuracy of double models, compared with single models is independent of the scale of the photograph. The relative increase in accuracy is somewhat greater for models with fewer control points. It is the systematic part of the error which is reduced the most. See Table 2.

A triple model is made up of three single models flown in three different directions. The standard error for a triple model is reduced to 59% of that for a single model. The systematic part of the error to 40-50%, and the standard deviation to 60%.

A quadruple model is defined as one made up of four single models flown in four different directions. Because of adverse weather conditions at the time the photography was carried out, only three quadruple models could be made up. Too few to get a good idea of the increase in accuracy. For these models the standard error was reduced to 59% in x, 58% in y, and 50% in z, of that, in each case, for a single model. The percentual change of the systematic and random parts of the error are of the same magnitude.

It is thus clear that multimodels increase the accuracy, compared with single models. As a rule of thumb it could be said that the standard error is reduced by the square root of the number of models, giving 71% for double models, 58% for triple models and 50% for quadruple models.

DISCUSSION

Hasselblads' measuring camera, MK70, yields very good results, and are comparable with those which can be obtained with aerial cameras commonly used for photogrammetric purposes, although the format of the photograph and the camera constant are different. The commonly used aerial camera (The National Land Survey of Sweden uses Wild cameras) covers an area on the ground of 920 x 920 meters square for a photograph scale of 1:4000. For the MK70 this area of coverage is only 210 x 210 meters square. For the same photograph scale the flying height, using a standard aerial camera must be 2.5 times that using the MK70. This means that the results obtained using the MK70 do not necessarily apply to standard aerial cameras and that new experiments should be carried out using these standard cameras.

In order to avoid ambiguity in the accuracy study only targeted points were used in the Mårtsbo experiment. However, it would be of interest to know how the accuracy is affected when measurements are made on those objects which are usually found on photogrammetric large scale maps. Here we meet another problem, namely that of finding an area with sufficient control. Routine measurement of terrestrial detail does not yield acceptable results. In a study by Ageby /1/, more than half of all objects, determined twice by field surveyors, showed a difference of more than 20 mm.

Too, the multimodel method leads to a more complete product. With careful planning of the different strip directions, each of four models could be made to "see" the same area from four different directions so that areas not seen in stereo in one model would appear in stereo in another. Practical experiments should be carried out to determine how much more completely an area can be covered using multimodels.

The above suggests that the multimodel method should be tested using say a Wild aerial camera, over an urban area where accurate terrestrial measurement already exist.

Too, it is of the greatest importance to know which map users are willing to pay for the more expensive and more complete photogrammetric product. The multimodel method will no doubt be more expensive than traditional single model measurements. How much more is one willing to pay to have his demand for accuracy and completeness fulfilled?

Perhaps someone will say that the multimodel method will be two, three, or four times as expensive as conventional photogrammetric methods. But this is not true. For a particular demand it would be possible to use a greater flying height with the multimodel method and thus reduce the number of photographs compared with the single model method. Here the cost relation between aerial photography and model evaluation will be of great importance in reaching an optimum result. Both can be affected; aerial photography through choice of camera (Wild-Hasselblad); evaluation through development of effective computer programs to be used in connection with measurement, and the development of a data base technique for updating.

Let us take an example. We wish to locate, with a standard error of not more than 20 mm, a large number of targeted manholes and other details of utility systems, within an urban area 400 m x 400 m. Using a Hasselblad camera this can be achieved using

- single models (15 in total) at a scale of 1:4000, flying height 260 m
- double models, from 16 single models, at a scale of 1:5900, flying height 350 m
- triple models, from 18 single models, at a scale of 1:7000, flying height 420 m
- quadruple models, from 24 single models, at a scale of 1:7000, flying height 420 m.

Using a Wild camera two single models, at a scale of 1:4000, (flying height 600 m), would cover the area, and from experience would yield the desired accuracy. For double models from a somewhat greater flying height, two single models would suffice. For triple and quadruple models three and four single models respectively would be required.

From the above example it may be seen that the increase in the number of photographs for the multimodel method is not great. However, this increase must be weighed against the advantages that the method yields a more complete set of measurements (a large number of objects are included), and that there are built-in checks against gross errors (reduced field checking). We see that using the Hasselblad camera more photographs must be taken to cover the area. But this does not necessarily mean an increase in cost for photography. The Wild camera costs 20 times as much as the MK70. Similar relations hold for film and diapositive. The lighter camera used in combination with a helicopter gives greater flexibility in time and space, which increases the preparedness for photography and reduces delivery time. The increased number of photographs has only a small negative effect on the cost of evaluation since neither relative nor absolute orientation must be done, when measurements are made in a comparator, but are a part of the calculations. The cost of measurement is instead, mainly dependent on the number of objects measured and the number of times each object is measured. Here again this increase in cost must be weighed against the better quality obtained.

ACKNOWLEDGEMENT

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Table 1 Accuracy using Single Models

Unit: mm on the ground

Photograph Scale / No of Models	Control Points			Check Points									
				rms				Systematic Error			Standard Deviation		
	n	s_{op}	s_{oH}	n	x	y	z	x	y	z	x	y	z
1:2000	3	23	–	43	15	15	58	9	10	38	12	12	45
14 models	11	17	37	43	12	13	47	4	6	19	12	12	44
1:4000	4	26	62	49	19	15	60	9	8	46	16	13	43
5 models	11	24	54	45	17	16	53	7	5	26	16	15	48
1:6500	6	67	210	56	33	30	183	21	14	147	27	27	116
4 models	20	42	150	56	28	27	123	8	8	72	27	27	104
1:8000	5	82	114	55	51	43	186	40	26	167	35	35	98
10 models	19	60	128	55	39	35	110	29	7	59	36	34	95

Table 2 Accuracy using Double Models, expressed in % of above

Directions of Flight	No of Control Points	rms			Systematic Error			Standard Deviation		
		x	y	z	x	y	z	x	y	z
Same Strip	few	–	–	–	–	–	–	–	–	–
	many	82	79	74	76	59	48	86	78	82
Same Directions	few	86	77	74	100	51	41	80	77	80
	many	85	77	75	86	87	80	84	78	77
Opposite Directions	few	74	72	73	61	78	54	75	71	76
	many	76	74	71	74	71	86	74	75	71
Intersecting Directions	few	71	70	70	33	63	70	74	74	75
	many	74	66	73	64	55	70	74	67	74
Average	few	77	73	72	65	64	55	76	75	77
	many	79	74	73	75	68	71	80	74	76

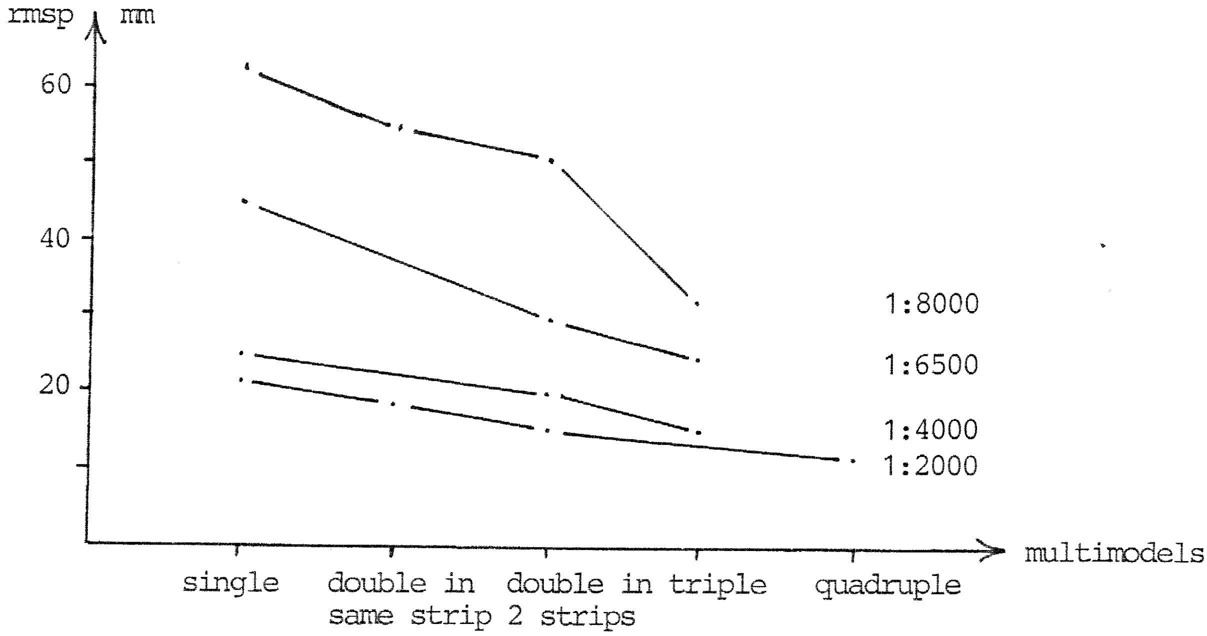

Figure 1
Standard Error in Plan ($rms_p = \sqrt{rms^2{}_x + rms^2{}_y}$)
as a function of the type of multimodel

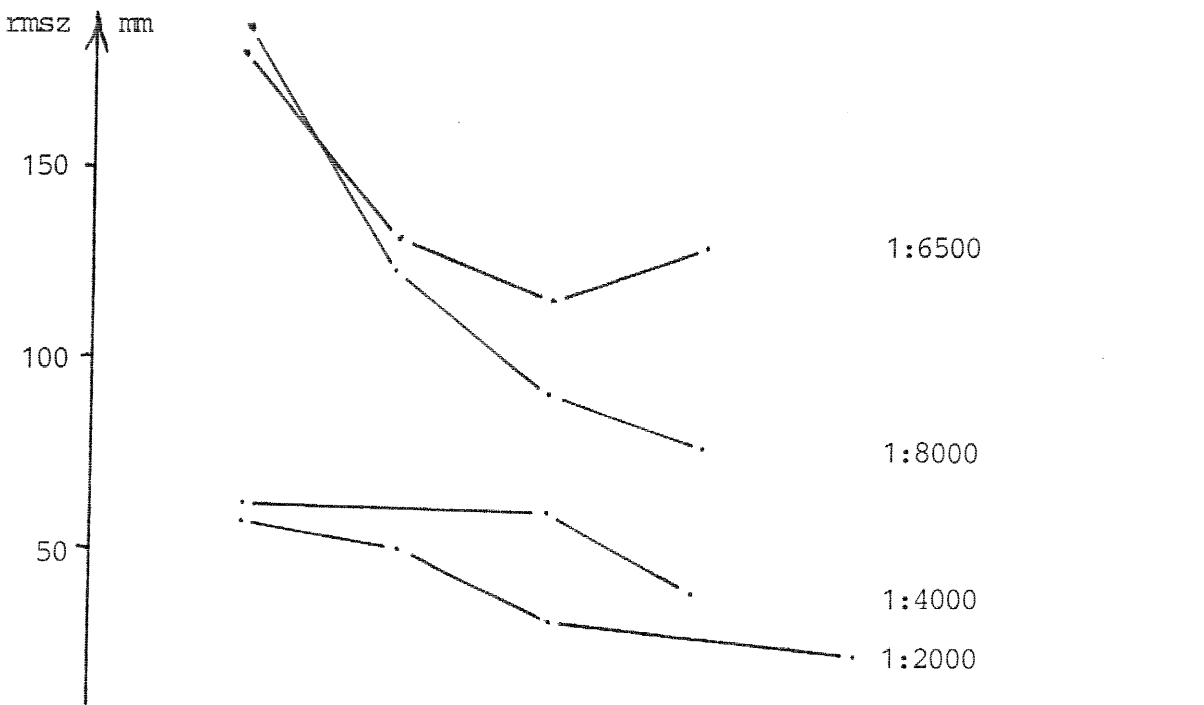

Figure 2
Standard Error in Elevation
as a function of the type of multimodel

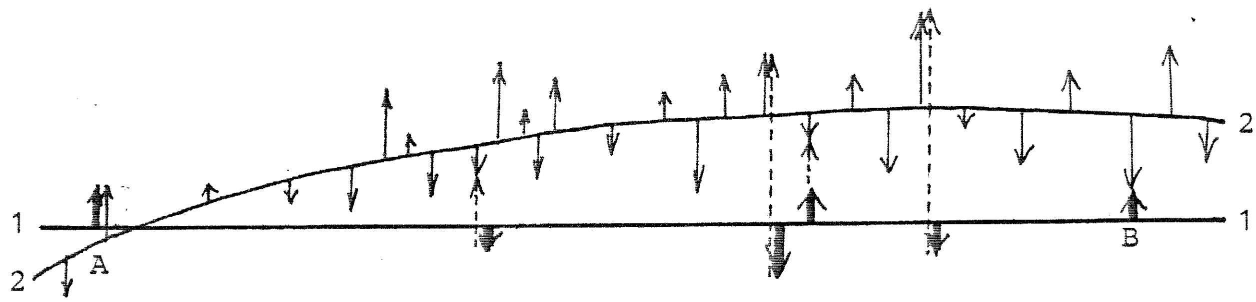

Figure 3

Elevation Error in a Stereomodel after Absolute Orientation on Points A and B

Line 1: correct ("true") profile

Line 2: deformed model after relative orientation

Thick Arrow: error in given co-ordinates for control points A + B and for check points

Thin Arrow: random error dependent only on the measurement of the point

Dashed Arrow: established difference in check point.