TEST OBJECT PHOTOGRAPHS FOR EXPERIMENTAL ESTIMATION OF AERIAL SURVEY CAMERA AND FIELD CALIBRATION OF PHOTOGRAPHS

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Abstract

Results of theoretical and experimental research based on use of test object photographs are given. Mathematical model for field calibration of photographs is formulated. The model enables determination of total calibration corrections for systematic distortions of image at standard grid crosses. Various factors (environmental conditions, random errors of image, number of points in photograph, etc.) that influence accuracy and use of field calibration results are studied. Problems of air cameras measuring properties are considered. Recommendations on how to obtain and make use of test object data are given.

I. Introduction

Improvement of accuracy and quality of photogrammetric models depends very much on individual properties of cameras as well as on the degree of systematic errors compensation. One of approaches to successful solution of the problem is employment of special test object photographs.

Photographs of test object may be used to solve the following problems.

1. Determination of imaging and measuring properties of cameras to ascertain their fitness for various types of aerophototopographical and other operations.
2. Field calibration of photographs for subsequent compensation of systematic errors in air images during analytical photogrammetric modelling.
3. Tests of new photogrammetric instruments, technology and computer programs being introduced into practice by use of standard photographs.

Laboratory test techniques used at present as well as flight tests carried out to determine performance of cameras do not provide for reliable evaluation of the cameras with respect to expected accuracy of photogrammetric models. Availability of test data allows to correctly determine expedient field of application for a camera being tested, to select cameras for stereophotogrammetric survey and to use the best cameras for high precision photogrammetric modelling as a substitution for minor control network and large-scale surveys with small contour intervals. If we have cameras with distinct systematic errors it is expedient to use results of field calibration in analytic aerotriangulation and analytical adjustment of single model.

Besides, there is one more important reason for testing camera by use of test object. When using field calibration (as well as self-calibration) which allows to determine total systematic errors of image (calibration corrections), the reliability of determination and stability of magnitude of the corrections are important. The stability and reliability are directly dependent on stiffness of camera and stability of its operation. If, e.g., characteristics of camera vary under influence of environmental conditions (temperature, pressure, shocks etc.) then effectiveness of total calibration corrections will be greatly decreased.

2. Experimental evaluation of camera

Technology of comprehensive employment of test object photographs that permits to determine camera measuring properties as well as to carry out field calibration of photographs is developed in the USSR.

According to the technology the process of determination of camera measuring properties by test object photographs includes investigation of measuring instrument and contact glass plate printer, evaluation of effect of photographic material deformation and film distortion, evaluation of accuracy of photograph stereoscopic measurements, determination of magnitude and character of errors of single photograph coordinates and single model coordinates. The process of aerial camera measuring properties determination includes two groups of factors which have an influence on accuracy of model coordinates: 1) factors, related to camera measuring properties (lens distortion, film distortion, etc.) and 2) factors not related to aerial camera measuring properties (errors of image points coordinates measurement, systematic and random deformations of film, errors in preparation of glass plates, etc.). To evaluate an aerial camera it is necessary to eliminate errors not related to camera measuring properties from total error which characterizes accuracy of photogrammetric modelling.

To automate the procedure of cameras measuring properties determination a set of programs was prepared. The programs were used for experimental evaluation of a number of aerial cameras. As a result, in the process of plane coordinates and heights determination a broad range of accuracy variations was obtained, hence possibility and necessity appear to select cameras with better measuring properties. The selection allows to gain 20-30% improvement in accuracy of photogrammetric modelling.

3. Mathematical model for field calibration

As a result of experimental and theoretical research carried out, mathematical model for field calibration was formulated. It differs from the existing models by possibility to take into account random errors of image and measuring instrument as well as by method of transition from calibration corrections determined for points marked on the ground to corrections of standard grid crosses.

According to the accepted mathematical model reduction of image points coordinates to the central projection is carried out taking into account affine deformation of film and instrumental errors of comparator by results of measurements of four or more fiducial marks or ~~in addition~~ taking into account random errors of photograph by results of measurement of camera reseau. Determination of absolute and interior orientation elements of photographs and their systematic errors is based on known collinearity equations; linearizing the equations we obtain correction equations of the form

$$\left.\begin{aligned} a\delta X_0 + b\delta Y_0 + c\delta Z_0 + d\delta\alpha + e\delta\omega + f\delta\varkappa + g\delta f + h\delta x_0 + i\delta_{\Delta x} + (x) - x = v_x \\ a'\delta X_0 + b'\delta Y_0 + c'\delta Z_0 + d'\delta\alpha + e'\delta\omega + f'\delta\varkappa + g'\delta f + h'\delta y_0 + i'\delta_{\Delta y} + (y) - y = v_y \end{aligned}\right\}, \qquad (1)$$

where: x, y - measured coordinates; (x), (y) - coordinates of image point calculated from collinearity equations by approximate values of absolute and interior orientation elements of the image; $\delta X_0, \delta Y_0, \delta Z_0, \delta\alpha, \delta\omega, \delta\varkappa, \delta f, \delta x_0, \delta y_0, \delta_{\Delta x}, \delta_{\Delta y}$ - corrections to approximate values of absolute and interior orientation elements and total calibration corrections correspondingly; a, b, ... i' - partial derivatives with respect to corresponding variables.

Problem of total calibration corrections determination is solved in several steps; approximate values of orientation elements and other values, defined more exactly at the previous step, are used in each of them. Every step, in its turn, includes several iterations. At the same time rejection of gross errors is done at various stages of processing.

At the first step of the problem solution correction equations (1) are used as original equations for each photograph calibrated. Parameters of the equations related to coefficients g, h, i, g', h', i' are taken as equal zero. This step corresponds to system of normal equations of the form

$$N_{6,6} \cdot X_{6,1} + I_{6,1} = 0 \qquad (2)$$

In the process of iteration elements of absolute orientation are defined more exactly and at the same time points with unadmissible errors are eliminated.

At the second step corrections to approximate (taken from results of laboratory calibration) values of interior orientation are determined and at the same time absolute orientation elements are redefined. This step makes sense in case photographs of mountainous test object are calibrated. The following system of normal equations corresponds to the step:

$$N_{6M+3,\,6M+3} \cdot X_{6M+3,\,1} + L_{6M+3,\,1} = 0, \qquad (3)$$

where M - number of calibrated photographs. Elements of interior orientation are not refined for test objects located in flat country. Corrections to approximate values of the unknown are obtained by solving (3) under condition $[PV^2] = \min$. After several interpretations non-linearity of original system is practically eliminated; evaluation of accuracy of the unknown is carried out by use of results of the last approximation.

At the final step of the problem solution calibration corrections are calculated for each K-cross of generalized image of standard net:

$$\Delta x_K = \frac{\sum\limits_{j=1}^{M} \sum\limits_{i=1}^{n_j} \Delta x_{i,j} \cdot p_{i,j}^{K}}{\sum\limits_{j=1}^{M} \sum\limits_{i=1}^{n_j} p_{i,j}^{K}}; \quad \Delta y_K = \frac{\sum\limits_{j=1}^{M} \sum\limits_{i=1}^{n_j} \Delta y_{i,j} \cdot p_{i,j}^{K}}{\sum\limits_{j=1}^{M} \sum\limits_{i=1}^{n_j}} \qquad (4)$$

on condition that

$$|S^{\kappa}_{i,j}| < R, \qquad (5)$$

where n_j - number of points in j-th photograph;

$$S^{\kappa}_{i,j} = \sqrt{(x_\kappa - x_{i,j})^2 + (y_\kappa - y_{i,j})^2}; \qquad p^{\kappa}_{i,j} = \frac{1}{(S^{\kappa}_{i,j})^{\tau}}, \qquad \tau = 1, 2, 3 \ldots$$

In these formulae R is a radius circumscribing a circle within which points in all photographs are used for calculation of calibration corrections. To evaluate accuracy of calibration corrections determination the values of $\Delta x_{\kappa,j}, \Delta y_{\kappa j}$ are calculated for all crosses in every image under condition (5) and than RMS values $m_{\Delta x}$, $m_{\Delta y}$ characterizing stability of calibration corrections for the same points of calibrated images are calculated. RMS value $\mu_{\Delta x,\Delta y}$ that characterizes accuracy of calibration corrections by M-number of photographs is calculated as well.

4. Investigation of field calibration method

On the basis of the mathematical model described above a program for ES-series computer was prepared. The program was used for experimental investigation of partial field calibration method. Photographs of special test object were employed for the investigation.

There are 339 geodetic points in the 2.4 x 2.0 km test object. The points plane coordinates and heights were determined with geodetic measurements to an accuracy in the order of 2 and 0.5 cm respectively. All the points are fixed in the form of Maltese cross; each arm of the cross is chaped as isosceles triangle, the foot of the triangle is equal to 0.5 m, height - 1.0 m. The arms of the cross are painted white, the background between the arms is painted black. The relief of the test object terrain is flat.

Aerial survey of the test object was carried out with several aerial cameras; their frame size was 18 x 18 cm. Coordinates of image points were measured with Stecometer and Ascorecord accurate to 2.5 - 3.5 μm.

Table I

Type of aerial camera; f, mm	Variant	Date of survey	Scale of survey	Mean integral value of calibration correction $\vartheta_{\Delta x,\Delta y}$, μm	Parameters of interpolation		Accuracy of corrections determination $\mu_{\Delta x,\Delta y}$, μm
					R, mm	r	
ТЭС-10, 100	1	10.10.76	1:5000	6.6	20	1	1.9
	2	11.10.76	1:10000	7.7	20	1	1.9
ТЭС-10М, 100	3.1	13.08.79	1:10000	5.6	15	1	1.8
	3.2			6.5	10	2	2.6
	3.3			5.8	20	1	2.4
	3.4			4.3	20	1	2.0
	4.1	23.12.81	1:5000	5.0	15	1	1.6
	4.2			5.4	10	2	2.6

To investigate the stability of calibration corrections two variants of partial field calibration of photographs taken with TЭC-10 aerial camera were carried out; the surveying conditions in each variant (days, hours, heights of flights) were different (Table I). Comparing the total calibration corrections obtained with the two variants it becomes clear that RMS values of their differences $m_{\Delta x,\Delta y}$ for the same points is 4 μm

Two aerial surveys of the test object were carried out with TЭC-10M camera at 1:5000 scale. The interval between the two surveys was 2.5 years (Variants 4.1, 4.2, Table I).

To evaluate the influence of number of points in a photograph on accuracy of calibration corrections calculation the values of the latter were obtained for the net of points spaced in the photograph at 1 and 2 cm intervals. It was found out that if number of points in each of 8 photographs decreases from 230 to 80 points, the values of absolute orientation linear elements change on the average by 2.8 μm at the photograph scale, and the values of angular elements change on the average by $2.5\cdot 10^{-7}$.

Results of total calibration corrections determination for four types of aerial cameras obtained under various parameters of interpolation are given in Table I. Data in the table point at considerable (1.4 - 1.8 times) change in accuracy of calibration corrections determination: changes are more considerable if value of R is greater and r = 1. It can be explained by the fact that as number of points by which Δx and Δy are determined increases, the value of calibration correction random component caused by measurement errors and random errors in photograph decreases. We ascertained that optimum parameters of interpolation are individual for each given aerial camera, that is why investigation by means of test object photograph must precede the choice of optimum variant of interpolation.

To investigate how random errors of photograph influence the accuracy of determination and effectiveness of allowing for total calibration corrections, an additional calibration of photographs taken with TЭC-10M camera was carried out; coordinates of points in the photograph were in advance corrected for random errors by measurements of reseau (Variant 3.4, Table I). As a result the mean integral value of calibration correction was reduced by a factor of 1.4; the value of $\mu_{\Delta x,\Delta y}$ reduced by a factor of 1.6 as well.

Allowing for new values of calibration corrections for single models and simultaneous compensation of photographs random errors by reseau resulted in insignificant (10 - 15%) improvement of quality in comparison with errors without allowing for random errors (but applying calibration corrections).

Table 2 contains data on six different aerial cameras. The data characterize effectiveness of use of field calibration results for single terrain models and blocks of aerial triangulation adjustment. Here the calibration corrections were used that were obtained under optimum parameters of interpolation; modelling was carried out with photographs that are not used for calibration.

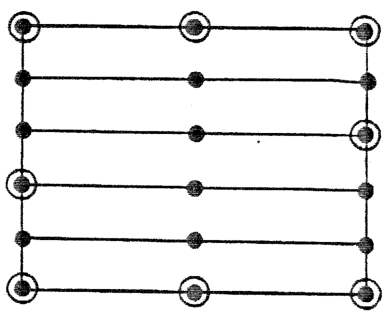
Aerial triangulation blocks construction was carried out with test area photographs at 1:10 000 scale. The 6 x 6 km test area had 60 check and control points in it. Plane coordinates of the marked points are determined accurate up to 4 cm;

heights are determined accurate up to 2 cm.

Table 2

Type of aerial camera	Type of models	Number of stereo-pairs	Number of points: check points / total	Accuracy improvement	
				horizontal	vertical
ТЭС-10М	single model	8	582	1.5	1.3
	block	45	42 / 725	1.0	1.0
ТЭ -100	single model	8	662	1.3	1.3
	block	45	42 / 753	1.0	1.2
ТЭ -70	single model	6	634	1.2	1.4
	block	48	42 / 818	1.2	1.1
ТЭС-10	single model	8	712	1.1	1.0
ТЭС-7	single model	6	496	1.4	2.5
ТЭС-5М	single model	6	352	1.5	1.8

Photographs of test area were taken with three aerial cameras: ТЭС-10М, ТЭ -100; ТЭ -70, two weeks after aerial survey of test object. Chemical and photographic processing of films was done in accordance with accepted production procedure. The arrangement of horizontal and vertical control points used for block adjustment is shown below.



● -vertical control points

○ -horizontal control points

As a result of the investigation a dependence between effectiveness of accounting for systematic errors of image and magnitude of the errors (especially in relation to heights) was established, i.e. effectiveness for cameras with high measuring capabilities (ТЭС-10, ТЭС-10М) is lower than that for cameras with greater errors.

5. Conclusion

The investigation carried out by us permits to draw some conclusions and give the following recommendations.

Substantial differences in accuracy of aerial camera systems point at possibility and necessity to select cameras with better measuring properties. Field calibration provides an average 20 - 30% increase in accuracy of photogrammetric modelling in case cameras with decreased measuring qualities are used.

The magnitude and character of image errors determined in the process of aerial camera measuring properties evaluation must be taken into account when choosing method of image geometrical errors compensation and when planning photogrammetric operations.

Disagreement in calibration corrections values for photographs taken at different seasons may be considerable, that is why surveying of test object and production aerial surveys are advisable to carry out within one season, in as short period as possible.

Reliable determination of calibration corrections in relation to the mathematical model described above is possible if number of points in each photograph is no less than 70-80. Interpolation parameters have a considerable effect on magnitude of difference of calibration values calculated for the same points in different photographs but they have much less effect on effectiveness of allowing for calibration correction for photogrammetric modelling.

Correction for random errors of photograph ensures decrease of integral value of total calibration corrections and improvement of accuracy of their determination. Effectiveness of combined use of field calibration results and measurements of reseau is not high (comparing to use of calibration alone) and at the same time amount of image measurements increases considerably.

Improvement of photogrammetric modelling accuracy taking into account calibration corrections is not the same for different cameras. That is why special investigation by use of test object photographs to obtain data on effectiveness of allowing for calibration corrections must precede mass employment of results of calibration.