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. Va-
rious 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 mo-
dels 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 employ-
ment of special test object photographs.

Photographs of test object may be used to solve the follow-
ing problems.
1. Determination of imaging and measuring properties of ca-
meras to ascertain their fitness for various types of aeropho-
totopographical and other operations.
2. Field calibration of photographs for subsequent compen-
sation 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 res-
pect to expected accuracy of photogrammetric models. Availabil-
ity 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 con-
tour 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 ca-
mera by use of test object. When using field calibration (as
well as self-calibration) which allows to determine total sys-
tematic errors of image (calibration corrections), the reliabili-
ity of determination and stability of magnitude of the correc-
tions are important. The stability and reliability are direct-
ly dependent on stiffness of camera and stability of its ope-
ration. If, e.g., characteristics of camera vary under influ-
ence 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 pho-
tographs 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 in-
cludes investigation of measuring instrument and contact glass
plate printer, evaluation of effect of photographic material
deformation and film distortion, evaluation of accuracy of pho-
tograph stereoscopic measurements, determination of magnitude
and character of errors of single photograph coordinates and
single model coordinates. The process of aerial camera measu-
ring properties determination includes two groups of factors
which have an influence on accuracy of model coordinates:
1) factors, related to camera measuring properties (lens dis-
tortion, 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 relat-
ed to camera measuring properties from total error which cha-
acterizes 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 obtain-
ed, 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 car-
ried out, mathematical model for field calibration was formu-
lated. It differs from the existing models by possibility to
take into account random errors of image and measuring instru-
ment as well as by method of transition from calibration correc-
tions 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 instru-
mental errors of comparator by results of measurements of four
or more fiducial marks or in addition taking into account ran-
dom errors of photograph by results of measurement of camera
 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

\[ \begin{align*}
    a\delta x_0 + b\delta y_0 + c\delta z_0 + d\delta \omega + e\delta \epsilon + \sum \delta x + g\delta f + h\delta x_0 + i\delta \lambda x + (x) - x = \nu_x, \\
    a\delta x_0 + b\delta y_0 + c\delta z_0 + d\delta \omega + e\delta \epsilon + \sum \delta y + g\delta f + h\delta y_0 + i\delta \lambda y + (y) - y = \nu_y,
\end{align*} \]

(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; \( \delta x_0, \delta y_0, \delta z_0, \delta \omega, \delta \epsilon, \delta f, \delta x_0, \delta y_0, \delta \lambda x, \delta \lambda y \) - corrections to approximate values of absolute and interior orientation elements and total calibration corrections correspondingly; \( a, b, \ldots, i' \) - partial derivatives with respect to corresponding variables.

Problems 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 equation 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

\[ N_{6,6} \cdot X_{6,1} + I_{6,1} = 0 \]

(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:

\[ N_{6M+3,6M+3} \cdot X_{6M+3,1} + L_{6M+3,1} = 0, \]

(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 \([FV]^2 = \text{min.}\). 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:

\[ \Delta x_K = \sum_{j=1}^{M} \sum_{i=1}^{n_j} \Delta x_{i,j} \cdot \rho_{i,j}^K, \quad \Delta y_K = \sum_{j=1}^{M} \sum_{i=1}^{n_j} \Delta y_{i,j} \cdot \rho_{i,j}^K \]

on condition that
\[ |S_{ij}^k| < R, \]

where \( n_j \) - number of points in \( j \)-th photograph;

\[ S_{ij}^k = \sqrt{(x_k - x_{ij})^2 + (y_k - y_{ij})^2}; \quad p_{ij}^k = \frac{1}{(S_{ij}^k)^2}, \quad \gamma = 1, 2, 3 \ldots \]

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 \( \Delta x_{ij}, \Delta y_{ij} \) are calculated for all crosses in every image under condition (5) and than RMS values \( m_{ax}, m_{ay} \) characterizing stability of calibration corrections for the same points of calibrated images are calculated. RMS value \( m_{ax, ay} \) 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 shaped 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 \( \mu \text{m} \).

<table>
<thead>
<tr>
<th>Type of aerial camera; f, mm</th>
<th>Variant</th>
<th>Date of survey</th>
<th>Scale of survey</th>
<th>Mean integral value of calibration correction ( U_{ax, ay, \mu \text{m}} )</th>
<th>Parameters of interpolation ( R, \mu \text{m} )</th>
<th>Accuracy of corrections determination ( M_{ax, ay, \mu \text{m}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>T9C-10, 100</td>
<td>1</td>
<td>10.10.76</td>
<td>1:50000</td>
<td>6.6</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>11.10.76</td>
<td>1:10000</td>
<td>7.7</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>T9C-10M, 100</td>
<td>2.1</td>
<td>13.08.79</td>
<td>1:10000</td>
<td>5.6</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td></td>
<td></td>
<td>6.5</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>2.3</td>
<td></td>
<td></td>
<td>5.8</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2.4</td>
<td></td>
<td></td>
<td>4.3</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>4.1</td>
<td>23.12.81</td>
<td>1:50000</td>
<td>5.0</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>4.2</td>
<td></td>
<td></td>
<td>5.4</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>
To investigate the stability of calibration corrections two variants of partial field calibration of photographs taken with T3C-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 $\delta x, \delta y$ for the same points is 4 $\mu m$.

Two aerial surveys of the test object were carried out with T3C-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 $\mu m$ at the photograph scale, and the values of angular elements change on the average by 2.5 $\cdot 10^{-6}$.

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 $\Delta x$ and $\Delta y$ 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 T3C-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 $M_{\delta x, \delta y}$ 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

<table>
<thead>
<tr>
<th>Type of aerial camera</th>
<th>Type of models</th>
<th>Number of stereo-pairs</th>
<th>Number of check points</th>
<th>Accuracy improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>total</td>
<td>horizontal</td>
</tr>
<tr>
<td>T3C-10M</td>
<td>single model</td>
<td>8</td>
<td>582</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>block</td>
<td>45</td>
<td>42</td>
<td>1.0</td>
</tr>
<tr>
<td>T9 -100</td>
<td>single model</td>
<td>8</td>
<td>662</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>block</td>
<td>45</td>
<td>42</td>
<td>1.0</td>
</tr>
<tr>
<td>T9 -70</td>
<td>single model</td>
<td>6</td>
<td>634</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>block</td>
<td>48</td>
<td>42</td>
<td>1.2</td>
</tr>
<tr>
<td>T9C-10</td>
<td>single model</td>
<td>8</td>
<td>712</td>
<td>1.1</td>
</tr>
<tr>
<td>T9C-7</td>
<td>single model</td>
<td>6</td>
<td>496</td>
<td>1.4</td>
</tr>
<tr>
<td>T9C-5M</td>
<td>single model</td>
<td>6</td>
<td>352</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Photographs of test area were taken with three aerial cameras: T3C-10M, T9 -100; T9 -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.

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 (T3C-10, T9C-10M) 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 aver-
age 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.