EXAMINATION OF THE GEOMETRY OF TERRESTRIAL CAMERA PHOTOGRAPHS

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1. Introduction

Photogrammetry is being increasingly frequently used to precision measurements of engineering objects. On such measurements are generally placed high requirements of accuracy [2]. Precise determination of spatial coordinates is achieved by using a multiple solution of independent ray bundles. This method is based on the exact reconstruction of the homologous ray bundlex [3]. This requires the use of terrestrial cameras ensuring an accurate definition of intererior orientation parameters or making selfcalibration of photographs in the actual processing procedure. Selfcalibration of photographs permits determination of actual geometric parameters of ray bundles utilized in the photogrammetric measurement. Methods are however generally being used based on the assumption of stability and knowledge of the homologous ray bundle. Investigations of the geometry of photographs made with terrestrial cameras, carried out by the present author, have shown that in many instances instantaneous interior orientation parameters are characterized by systematic deviations from production specifications. This paper discusses investigations of the geometry of photographs made with P-31 Wild, UMK-10/1318 and Photheo 19/1318 Carl Zeiss, Jena, cameras. The results of repeatibility of photograph geometry presented are representative of the camera types investigated. Knowledge of these characteristics enables the appropriate choice of a terrestrial camera, as well as of the processing method depending on the a priori-postulated accuracy of the photogrammetric measurement.

2. The method of photograph calibration used

For controlling the geometry of the photographs made with terrestrial cameras, a spatial test field was been arranged at the Warsaw Technical University Institute for Photogrammetry and Cartography. This object constitutes 49 signalled points distributed so that they should uniformly be photographed on the surface of the investigated picture /fig.1/

Situation of the test field in a closed room and the making of a permanent signalling arrangement ensures the formers geometric stability within an extended time interval. The situation of the field points in the reference system adopted has been determined by measurement of the horizontal and vertical angles. In this measurement a T3 Wild theodolite was used. Measurements made thus far /four times in a period of years/ have not shown angular changes greater than 10^{cc}. The field arranged is characterized by considerable field depth. Distances from projective centre to the points towards the photographing axis amount to from 10 to 40 m. Such a considerable test field depth permits also the determination of the geometry of photographs made with the camera objective being focussed to different photographing distances.

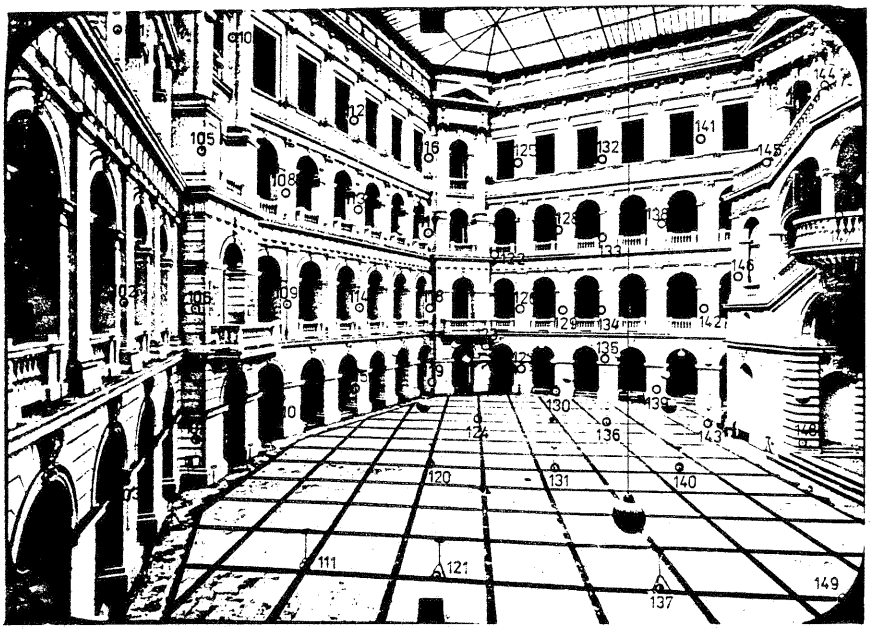

Fig. 1

The method of field calibration of photographs consists in the analytical comparison of the corresponding homologous ray bundles [5] .

A ray bundle in object space is, as already mentioned, by measurement of the horizontal and vertical angles / and / for each field point in the adopted reference system /X,Y,Z/.

Measurement of image coordinates of points /x,y/ with the use of monocomparator determines the shape of the ray bundle in image space.

Comparison of the two ray bundles leads to the derivation for each observation of two equations of the type:

$$x + v_x = f(\alpha, x_o, c_k, \omega, \varphi, \varkappa, X_s, Y_s, Z_s, dx)$$

$$y + v_y = f(\alpha, \beta, y_o, c_k, \omega, \varphi, \varkappa, X_s, Y_s, Z_s, dy)$$

where the unknown are:

x_o, y_o - coordinates of the principal point,

c_k - principal photograph distance,

$\omega, \varphi, \varkappa$ - interior orientation angles, ,

X_s, Y_s, Z_s - projection centre coordinates in the adopted reference system /X,Y,Z/,

dx, dy - systematic photograph errors.

Unknowns are determined by solving the normal equation set by by the least square method. Programming of this method enables in the calculating process the assumption of arbitrary unknowns as constant. Accuracy of determination by this method of the photograph interior orientation parameters depends on the geometry and precision of the test field and the accuracy of measurement of the point image coordinates on the monocomparator. Assuming RMS error of image coordinates $mx = my = \pm 2\ \mu m$, the test field presented enables, for example, for a wide-angle /wide-focus/ photographci camera the determination of the interior orientation parameters with an accuracy of $mx_o = mc_k = \pm 3\ \mu m$, $my_o = \pm 4\ \mu m$.

3. Resuts of Calibration of selected Terrestrial Cameras

Interior orientation parameters of a camera constitute a basis for reconstruction of a homologous ray bundle. Its final shape is however determined by a number of factors, such as:
- objective distortion, - deformations and unflatness of negative film, - photographic errors /e.g., boundary phenomenon/
- errors of monocomperator instruments.

The effect of these factors with the use of the other negative materials and the monocomparator may prove repeatable for a whole series of photographs.

To determine the effect of the above factors on the geometry of photographs during investigations, attempt was made to reproduce the conditions of typical photogrammetric measurement. Execution of test field photograph on standard negative films and the measurement of image point coordinates on the instruments used in analytical processing gives the obtained results a commercial character.

Photographs of the test field were made with each investigated copy of the camera, with different camera's operation variants taken into account. A series of three photographs was additionally made in the basic position /with focussing at / to determine the repeatability of the interior parameters. Levelling and orienting the camera before each exposure enabled also the assessment of the camera's angular orientation. The test-field image point coordinates were measured on photographs using a precision stereocomperator. Accuracy of measurement of the coordinates was 2 ÷ 3 µm for each component. Results of calculation are listed in Tables 1-3. Each table contains, for a given camera and type of negative film, corrections to the manufacturer's interior orientation parameters of the camera's, together with the mean values of errors of their determination /mx_o,my_o,mc_k/. These tables include no exterior orientation angles of the photographs. Repeatability of these values for all investigated cameras was similar. It can generally be stated that levelling and orienting the camera defines the exterior angular orientation with an accuracy of 60^{cc}.

In Figures 2-4 are presented histograms of the discrepancies of photographs for the investigated types of cameras. It should be emphasized that photographs made with the other camera have discrepancies of the same distribution. From the analysis of the results listed in the Tables and of the histograms the following conclusions can be drawn:

1° The interior orientation parameters of the photographs made with the investigated cameras differ systematically from the factory specifications. In the UMK 10/1318 camera, with a change of the type of the negative film employed /glass platesroll film/, a change in photograph principal distance occurs.

Table 1

focussing	Camera P31 nr 2591 + negative glass plates AVIPHOT PAN 33						Camera P 31 nr 2592 + negative glass plates AVIPHOT PAN 33					
	dx_o [µm]	dy_o [µm]	dc_k [µm]	mx_o [µm]	my_o [µm]	mc_k [µm]	dx_o [µm]	dy_o [µm]	dc_k [µm]	mx_o [µm]	my_o [µm]	mc_k [µm]
∞	-6	-58	-4	5.7	8.2	7.3	-5	+9	-27	4.9	7.5	6.1
	-12	-60	-11	5.4	7.7	6.8	-19	+12	-35	3.7	5.3	4.7
	-2	-46	-30	5.3	7.0	6.7	-12	+7	-22	4.6	6.6	5.8
	-7	-55	-15				-12	+9	-28			
7m	-25	-77	+5	8.1	11.5	10.2	-19	+29	-8	7.6	10.8	9.6
	+9	-42	+9	8.4	11.6	9.8	-15	+15	-13	5.7	7.7	6.3
	-8	-38	+14	6.4	9.1	8.1	-25	+9	-16	6.8	10.3	8.3
	-8	-52	+6				-20	+18	-12			

Table 2

location of objective [mm]	Camera Photheo 19/1318 nr 218178 + negative glass plates Topo Platte To 1						Camera Photheo 19/1318 nr 218177 + negative glass plates Topo Platte TO 1					
	dx_o [µm]	dy_o [µm]	dc_k [µm]	mx_o [µm]	my_o [µm]	mc_k [µm]	dx_o [µm]	dy_o [µm]	dc_k [µm]	mx_o [µm]	my_o [µm]	mc_k [µm]
0	+26	+12	+19	22.2	25.5	23.5	+5	+21	+7	18.0	23.1	18.9
	+55	-47	+54	21.2	24.3	22.3	+29	+22	+44	16.4	21.1	17.3
	+8	-54	-1	20.2	23.2	21.8	0	+6	+10	15.1	19.6	16.2
	+22	-39	+39				+11	+16	+30			
+15	+54	-22	+88	13.1	10.7	12.8	+30	-13	-2	12.7	10.3	12.2
+30	+31	-82	+34	13.4	13.8	12.8	+2	+11	+25	13.6	13.9	12.9
-15	+39	+13	+3	22.7	32.3	23.3	-11	+38	+40	21.2	30.0	21.6
-30	+30	+5	-9	34.0	57.0	32.9	-33	+82	+18	30.3	50.8	29.2

Table 3

focussing	Camera UMK 10/1318 nr 7370536											
	+ negative glass plates AVIPHOT PAN 33						+ negative film AVIPHOT PAN 33					
	dx_o [μm]	dy_o [μm]	dc_k [μm]	mx_o [μm]	my_o [μm]	mc_k [μm]	dx_o [μm]	dy_o [μm]	dc_k [μm]	mx_o [μm]	my_o [μm]	mc_k [μm]
∞	-17	+23	+26	6.1	8.6	9.0	+9	+29	+55	3.7	4.8	4.1
	-51	+81	+34	5.3	9.3	7.7	+15	+28	+37	3.0	4.2	5.5
	-9	+39	+29	5.5	9.7	7.9	+1	+29	+50	4.1	5.4	4.6
	-26	+49	+30				+8	+29	+47			
	Camera UMK 10/1318 nr 249041/A											
	+ negative glass plates Mikro Platte MO 1						+ negative film AVIPHOT PAN 33					
∞	-58	-13	+25	5.2	7.4	5.8	-49	-32	-17	5.2	7.3	5.7
	-32	-2	+58	4.4	6.2	4.8	-48	-29	-17	5.4	7.5	6.2
	-37	-14	+45	3.3	4.7	3.6	-39	-14	-20	4.2	5.7	4.9
	-42	-10	+43				-45	-25	-18			
25m	-51	-4	+55	4.9	7.0	5.5	-50	-35	-21	4.8	6.8	5.3
12m	-41	-22	+35	4.3	6.2	4.8	-42	-14	-15	5.3	7.5	5.9
8m	-44	-6	+43	4.1	5.8	4.5	-43	-32	-16	7.7	11.1	8.9

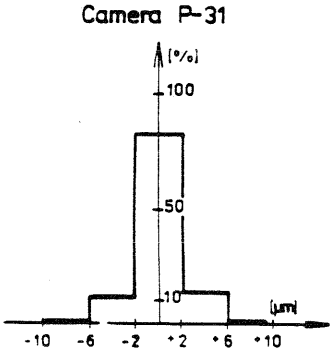

FIG. 2

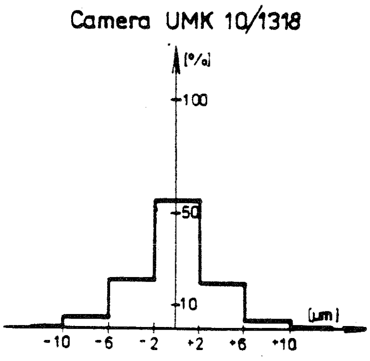

FIG. 3

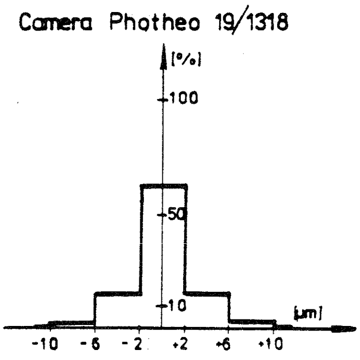

FIG. 4

2° The best approximation of perspective projection occurs in the P-31 camera. For this camera 83 percent of postcalibration residual discrepancies is contained in the measurement accuracy of image point coordinates, i.e., 2 um. In the other cameras, deviations of the ray bundle from its nominal shape are of the same order, amounting, on the average, to $3 \div 5$ µm.

2° Repeatability of interior orientation parameters for the series of photographs made with the P-31 camera characterized by average divergences is $mx_o = \pm 8$ µm; $my_o = \pm 10$ µm, $mc_k = \pm 7$ µm.

In the UMK camera with image registration on film the consistency of accuracy of determined parameters is close to that of their determination, and amounts to $mx_o = \pm 4$ µm, $my_o = \pm 5$ µm, $mc_k = \pm 5$ µm, respectively. This evidences a satisfactory technical solving of the adapter's function to the roll film. With the glass plates used in this camera, the repeatability of photograph geometry in the series worsens /$mx_o = \pm 13$ um, $my_o = \pm 15$ µm, $mc_k = \pm 8$ µm/. This suggests that insufficient pressing down of the glass plates to the image frame occurs. Similar results have been obtained for the photograph series made with Photheo 19/1318 camera /$mx_o = \pm 18$ µm, $my_o = \pm 15$ µm, $mc_k = \pm 25$ µm/

4° Change of focussing in P-31 and UMK 10/1318 cameras causes no significant change in the situation of the principal point, and the change in the photograph principal distance is consistent with the manufacturer's correction. Shifting the lens in the Photheo camera changes the situation of the principal point and photograph principal distance within limits of errors $mx_o = \pm 25$ µm, $my_o = \pm 42$ µm, $mc_k = \pm 32$ µm, respectively. The presented investigation results in relation to the UMK 10/1318 and Photheo 19/1318 are to be recognized as representative. In the course of the last few years, more than a dozen copies of the cameras mentioned have been tested with in most cases similar characteristics being obtained.

4. Example of Application

The method of determining the camera's interior orientation parameters discussed has been used in the photogrammetric measurement of the radar antenna. The purpose of this measurement was the determination of contact of the antenna dish reflector, of dimensions 9 x 12 x 5 m, and of the radiator's situation in immobile working position. This task amounted to the determination of the spatial coordinates of some 1400 points with an a priori-established accuracy of 1 mm of each component. To implement the design, the method of independent ray bundle 6. Schut program was used /6/. This program practically assumes the knowledge of the interior orientation parameters of the photographs. To obtain the best reconstruction of the shape of the homologous ray bundles, calibration of the measuring camera was made based on the described test. The camera's geometric characteristics thus defined were employed in designing measurement by numerical simulation method. In the numerical design process were established:

- the number of photographs and positions of cameras,
- the number and location of points, and their accuracy.

The measured points of the object were signalled by signs attached, to the reflector surface with a special adhesive mass /Fig. 5/.

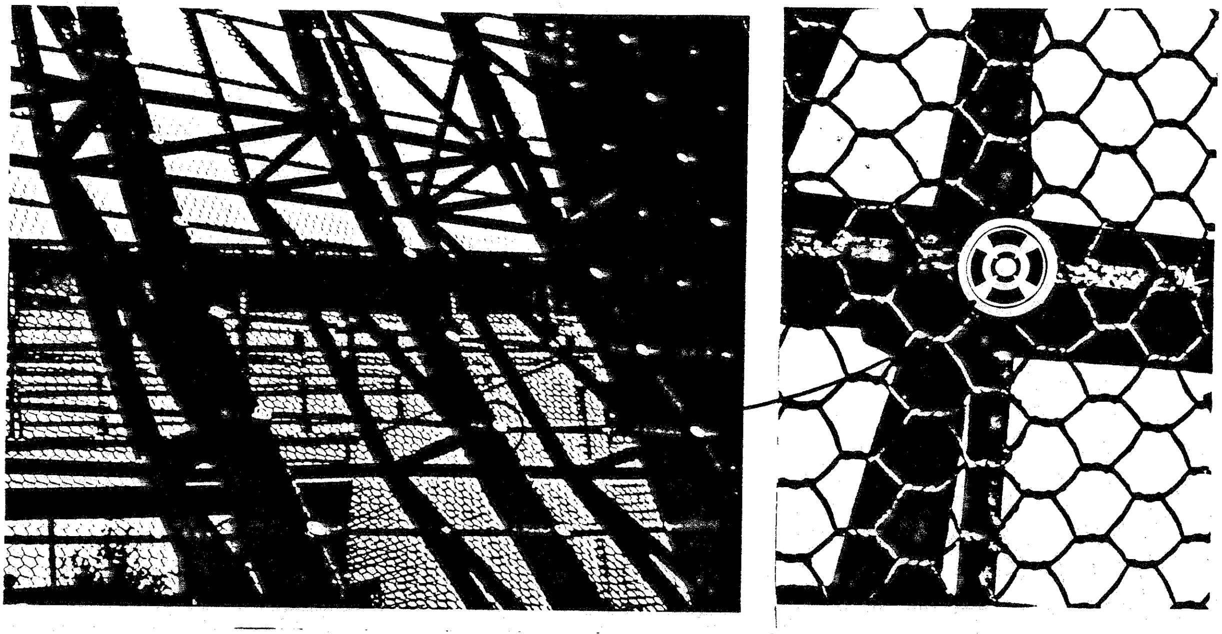

Fig. 5

The spatial coordinates of control points were determined from the angle-linear network measured with a DKM-2 theodolite and a 3000 Mekometer.

For photogrammetric processing, 6 photographs were made with the UMK 30/1318 camera from three ground and three elevated positions from a hoist about 10 m high. The approximate scale of the photographs was 1:130. Measurement of the image point coordinates on photographs was made on a Stecometer with an accuracy of 2 µm. Time of observing a single photograph with so large a number of points /some 1400/ amounted to about 12 hours. The processing program employed enabled wfighing the control and determined points. Correlation of the observations was made on the basis of the analysis of adjusted of the control points and the results of numerical design of measurement. In the example quoted, RMS error of coordinates X , Y and Z are was mX=± 0.4 mm, mY = ±0.4 mm, MZ = ± 0.5 mm, which corresponds to the value of 3 µm in photograph scale.

5. Conclusions

Investigations described in this paper indicate the need for controlling the geometry of photographs realized with terrestrial photographic cameras. Results of these investigations have shown systematic deviations of interior orientation parameters from the factory specifications. The exemplificatory application presented has confirmed the neccesity of the camera calibration in a separate process and its result should be taken into account in photogrammetric measurement.

The measurement of the object with taking photographs by P-31, UMK 10/1318 cameras can be carried ouf with about ±5 µm in image scale.

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