USEFULNESS OF LONG-FOCUS NONMETRIC CAMERAS IN PRECISION MEASUREMENTS

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1. Introduction

In some photogrammetry engineering applications the use of nonmetric instead of conventional cameras is fully justified because of the formers availability, lower price and servicing facility. The disadvantages of these systems cannot however be overlooked. The lack of definition of interior orientation, systematic errors affecting image coordinates and their time changes are the major obstacle in the use of these systems in more accurate photogrammetric measurements. Consequent on the development of analytical photogrammetric methods a number of approaches exist presented in [2] , [8] , [13] in which simultaneously with object measurement parameters defining the interior geometry of photographs are determined, but these require complicated computer programs and the maintenance of specific conditions of measurement. In many instances, such methods, although undoubtedly effective, may possibly prove to be too complicated for general application. It seems consequently justified that for some particular uses long-focus nonmetric cameras in which the effect of most of image errors is considerably reduced and part of them is negligible should be employed. The methods of processing photographs made with these systems become considerably simplified. Whereas distortions of photographs made with shorter-focus objectives must be defined and eliminated by fairly complex mathematical models for their appropriate approximation [9] , [15] , distortions of photographs made with long-focus objectives /lens/ are contained within measurement accuracy limits and are therefore insignificant 4 . In long-focus nonmetric systems requirements concerning the accuracy of determining interior orientation are less. Instability connected with focussing or objective unscrewing is less serious. Application of such systems is especially advantageous in the case of registration of small objects or fragments of major constructions.

2. Results of Calibration of Photographs

This paragraph presents results of calibration of photographs made with a Pentacon-Six nonmetric camera with three types of long-focus objectives /180, 300 and 500 mm/. To determine the degree of repetition of interior orientation parameters and image distortions due to radial and tangential objective distortions and negative deformations, test fields were registered on successive photographs. Two types of spatial test-fields and one two-dimensional test were used. Their parameters and the type of negative materials are shown in Table 1.
Depending on the tests used, only image distortions or also interior orientation parameters were determined. Two computer programs were employed. In the first partial calibration-two dimensional test the coordinates of test-field points were transformed by linear relation to image plane and subsequently

Table 1

Kind of objective	Kind of test-field	Image scale	Number of photographs - kind of film
Sonnar I-copy c - 180 mm	two-dimensional	1:10	7 - Orwo NP 15 7 - Fotopan SR 24
	three-dimensional version I	1:40	12 - Fotopan NB 01
Sonnar II-copy c 180 mm	two-dimensional	1:10	7 - Orwo NP 15 6 - Fotopan SR 24
Orestegor c 300 mm	two-dimensional	1:10	4 - Orwo NP 15
	three-dimensional version I	1:40	12 - Fotopan NB 01
Orestegor c 500 mm	three-dimensional	1:20	6 - Orwo NP 15

Notes: two-dimensional test-field - size 50 x 60 cm, 110 points
three-dimensional test-field version I - size 150 x 150 x 50 cm, 100 points
three-dimensional test-field version II - size 30 x 50 x 15 cm, 25 points

the differences between them and the coordinates of points which had been measured on the photographs were approximated by the following polynomials:

$$dx = \left(x - x_o\right)\left(k_1 r^2 + k_2 r^4 + k_3 r^6 + \dots\right) + p_1\left[r^2 + 2\left(x - x_o\right)\right]^2 + 2p_2\left(x - x_o\right)\left(y - y_o\right) + A\left(y - y_o\right) \qquad (1)$$

$$dy = \left(y - y_o\right)\left(k_1 r^2 + k_2 r^4 + k_3 r^6 + \dots\right) + p_2\left[r^2 + 2\left(y - y_o\right)\right]^2 + 2p_1\left(x - x_o\right)\left(y - y_o\right) + B\left(y - y_o\right)$$

where: k_1, k_2, k_3 ....., P_1, P_2 - are coefficients defining the radial and tangential components of objective distortion, A B - coefficients defining the affine image deformation.

In the second approach, all calibration parameters were determined by photogrammetric intersection. For every particular image point, the following equations were derived:

$$F x_{i,j} = \left[\left(x_{i,j} - x_{o,j}\right) + dx_{i,j}\right] M_{3,j} + C_j M_{1,j} = 0 \qquad (2)$$

$$F y_{i,j} = \left[\left(y_{i,j} - y_{o,j}\right) + dy_{i,j}\right] M_{3,j} + C_j M_{2,j} = 0$$

were: $\left[M_1, M_2, M_3\right]^T = \left[R\right]_j \left[\left(X_i - X_{s,j}\right), \left(Y_i - Y_{s,j}\right), \left(Z_i - Z_{s,j}\right)\right]^T$

$\left(X,Y,Z\right)_i$ - coordinates of "i" test-field point

$\left(x,y\right)_{i,j}$ - image coordinates of "i" point on "j" photograph

$\left(X_s,Y_s,Z_s\right)_j$ - coordinates of "j" projection center,

$\left[R\right]_j$ - orthogonal matrix of "j" photograph,

$\left(x_o,y_o,c\right)_j$ - interior orientation parameters of "j" photograph,

$\left(dx,dy\right)_{i,j}$ - corrections defined by Eg. 1

Results of partial calibration /first approach/ show that for photographs made with a Sonnar 180 objective /visual angle $\alpha = 24^\circ$/, mean values of discrepancies after linear transformation are of the order of ± 30 um /in photograph scale/ and after polynomial transformation ± 10 um. For photographs made with a Oresteger 300 objective ($\alpha = 14^\circ$), discrepancies after linear and polynomial transformation are the same and equal to ± 10 um this corresponds to the observation accuracy of the photographs made . Figures 1 a,b and c show the mean values of residual discrepancies before and after polynomial transformation /on vertical axis/ for two Sonnar objectives /c = 180 mm/ and one Oresteger objective /c = 300 mm/. On the horizontal axis a variable number of terms in Eq /1/ was marked /from three to nine/. The number "0" corresponds to the mean values of discrepancies occurring after linear transforma-

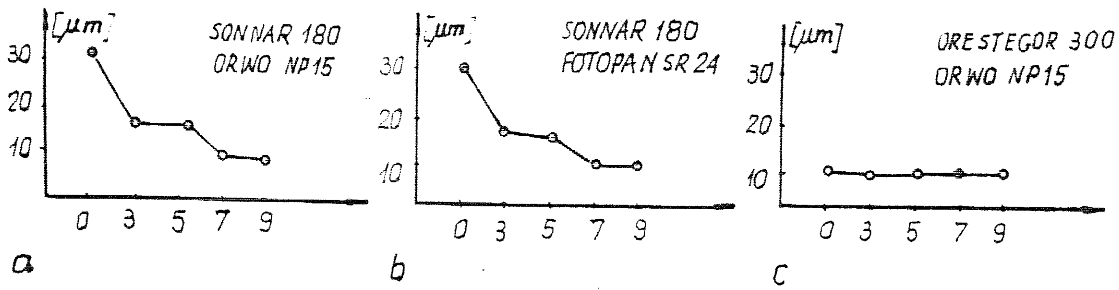


FIG. 1

tion. Figures 2 a,b show deviations in the situation of points

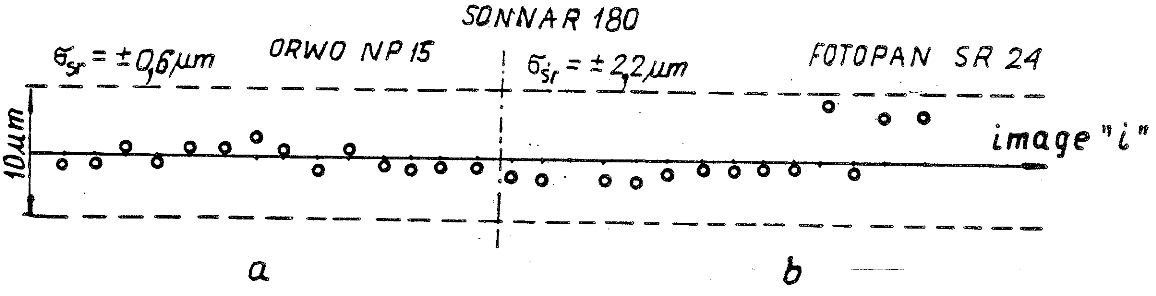


FIG. 2

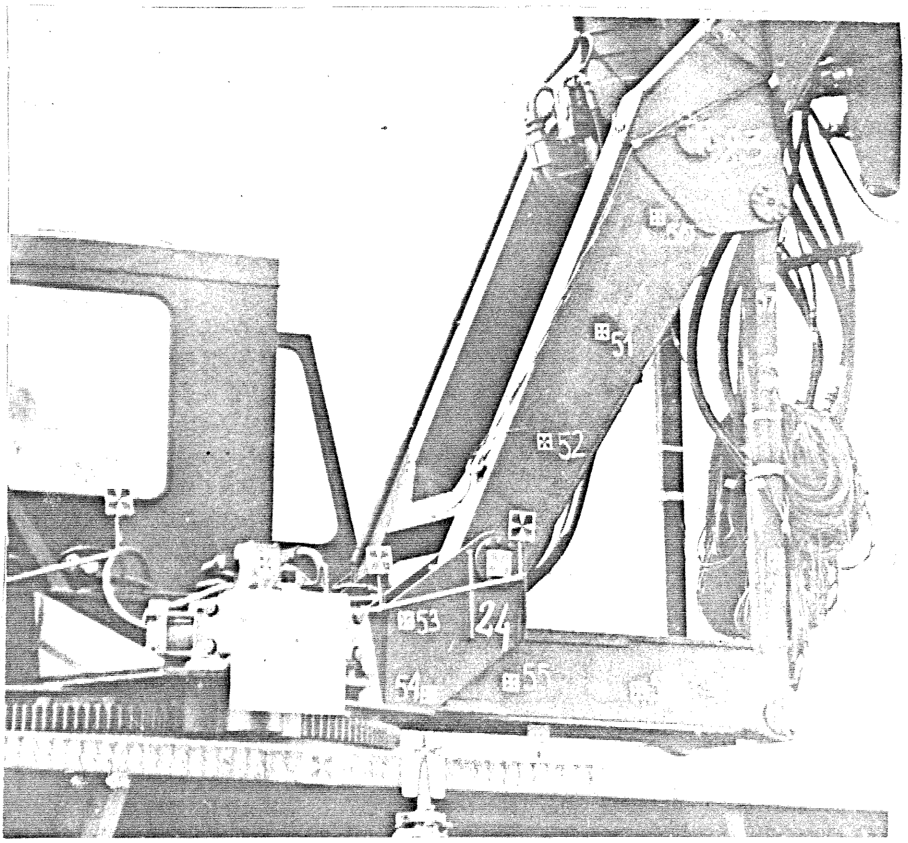
on successive photographs made with two Sonnar objectives with the use of two types of negative materials. Individual points in the diagram represent deviations of the mean residual discrepancies of successive "i" images from their average values. Analysis of results shows that the average values of these deviations are several times less than the observation accuracy of stereocomparator points. It can therefore be assumed that with the same photographic conditions being maintained, the distribution of discrepancies in a series of photographs is similar. In objectives with a focus distance of 300 mm and longer($\alpha \leq 14^{0}$), the effect of systematic image errors is insignificant. The next calibration method was used for examining three photograph series. With stable and variable focussing and with the objective removed and then again fitted were made (the photographing distance was unaltered). The results show that in the whole series of Sonnar 180 objective photographs, mean values of discrepancies before and after polynomial transformation are ± 20 um and ± 15 um, respectively. The mean values of discrepancies of Oresteger 300 objective photographs are the same and equal ± 8 um. The distribution of discrepancies of all images before and after polynomial transformation has a similar character and reveals the local effect of systematic errors of some test-field points /the average error of coordinates of spatial test points is ± 7 um and the maximal error ± 20 um/.

The average divergences of determined principal distances of successive photographs are for the Sonnar 180 objective ± 0.4 mm Oresteger 300 objective ± 1.1 mm, Oresteger 500 objective ± 2.0 mm. In accordance with the analysis conducted in [10], [15], these divergences are contained in theoretically determined quantities for this type objectives, the geometry of photographs and test fields and the accuracy of observations. Hence it follows that interior orientation parameters of long-focus objectives need not be determined during the measurement of the object, but only occasionally checked in test fields. Distortions influenced by image errors of photographs made with nonmetric cameras with principal focal distance c = 300 mm and longer /visual angle $\alpha \leq 14^{0}$ / in no way reduce the accuracy of photogrammetric measurements. When the visual angles are larger, but not more than 30-35°, distortions can be determined on the basis of two dimensional test fields in initial procesing.

The general conclusion that follows there from is that in the application of long-focus objectives selfcalibration methods need not, even in measurements of greater precision, be employed.

3. Examples of employment of longfocus nonmetric objectives

Analyses presented in the preceding paragraph have shown the usefulness of long-focus nonmetric objectives for precision measurements. Because of the small visual angles of such systems, they can be suitable for making photographs of small objects, such as details of mechanical equipments or of large engineering constructions. The first group of applications mentioned can be exemplified by measurement of an articulated joint of the crane /Fig.3/, [4] , [11] .



RMS error of coordinates X and Y is ±15 um (0.6 mm on the object) , and in Z direction /photographic distance/ ±18 um /+ 0.7 mm on the object/. These results are competitive in relation to the accuracies obtained with the use of an UMK Zeiss Jena camera. An example of the other group of applications can be the measurement of changes in expansion gaps of industrial halls [6] . The measurement accuracy obtained is, on account of differential measurement, contained within limits of 4-5um in photograph scale.

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