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Remarks on the Imaging Systems of Calibration

Abstract

The paper presents some practical experiments of imaging systems calibration which were carried out in the Institute of Photogrammetry of Warsaw Technical University. The results of the following imaging systems of calibration are presented; metrical and non-metrical cameras, underwater imaging system, TV - system and X-Ray photographs.

1. Introduction

A dynamic development of photogrammetry enables solving of various tasks which reguire an application specific technics of imagery. In many cases the conventional cameras can not be used. Some tasks require non - conventional imagery like TV cameras, X-Ray systems and other. Sometimes the nonmetric cameras substitute the conventional ones, because of the lower price general availability and flexibility of the focusing range.

Precision of the photogrammetric measurement depends upon accuracy of imagery, precision of the photogrammetric instruments and adequate date processing. The precision of the imagery is conditioned by geometry of the system and other external factors. An influence of most of the factors is known and may be described with a proper mathematical model. The accuracy of imagery is mainly limited by the factors which decrease resolving power of imagery like electronical and optical distrubances etc. In this paper there will be presented results of calibration of some selected systems which have been carried out in the Institute of Photogrammetry and Cartography at the Warsaw Technical University.

2. Description of the applied method of calibration.

A number of the calibration methods used for various sytems will be presented in this section. Due to a considerable stability of most of the systems the methods adopted have been based on separation of the calibration from the measuring process.

The first method applied has been based on the spatial test and has allowed to determine the interior orientation parameters, i.c. principial point, principial distance, radial symmetry and tangential lens distortion and image deformations each photograph. The computed program which was developed at the Department of Surveying Engineering at the University of New Brunswick and adapted at the Warsaw University for Cyber 70 computer has used two fundamental equations, namely colinearity and coplanarity [4], [6]. The colinearity equation has been a mainly function of the solution, while the coplanarity provides a supplementary consolidation of the geometrical configuration of stereophotographs.

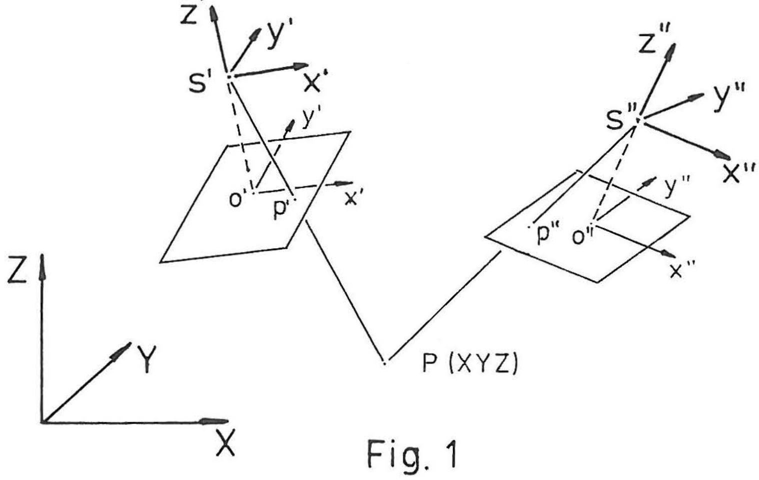

Fig. 1

The colinearity and coplanarity have been expressed as:

$F(X,L) = 0$

where $X = (k_1, k_2, k_3, p_1, p_2, A, B, x_0, y_0, c_k, x_s, y_s, z_s, \omega, \varphi, \varkappa)$

$L = (X, Y, Z, x, y)$

and $G(X,L) = 0$

where $X = (k_1', k_2', k_3', p_1', p_2', A', B', k_1'', k_2'', k_3'', p_1'', p_2'', A'', B'', x_0', y_0', c_k', x_0'', y_0'', c_k'', X_s', Y_s', Z_s', \omega', \varphi', \varkappa', X_s'', Y_s'', Z_s'', \omega'', \varphi'', \varkappa'')$

(k_1, k_2, k_3) – the coefficients describing the radial symmetric distortion,

$(p_1 p_2)$ – the coefficients describing the tangential distortion,

(A, B) – the coefficients describing the affinity and non – perpendicularity of axes,

(x_0, y_0, c_k) – principal point and principal distance

$(X_s, Y_s, Z_s, \omega, \varphi, \varkappa)$ – parameters of external orientation

$(x', y', x'', y'')_i$ – image coordinates "i" – point

Normal equations have been formed under the condition that the weighted square sum $V^T P V$ has been minimized.

In the second method which has been used the bundles of rays in space – object and space – image have been comparised [7].

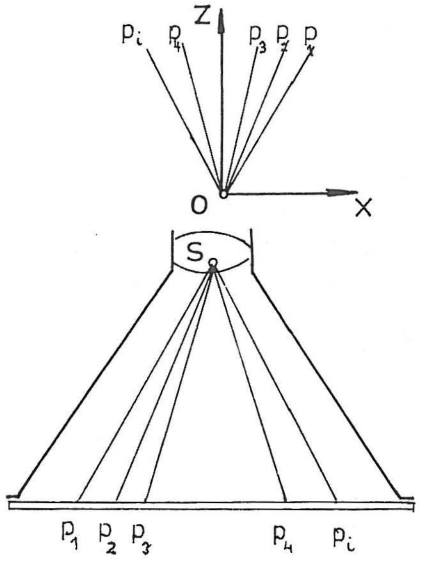

Fig. 2

A bundle of rays in space-object has been created by measurement of the direction to points of the object. A bundle of the space-image has been reconstructed on the basis of the image points. The following parameters of calibration have been de-

termined:
- calibrated principal distance c_k,
- principal point,
- parameters of external orientation ($X_s, Y_s, Z_s, \omega, \varphi, \varkappa$,)
- coefficients of the polynomial describing symmetrical distortion ($a_1 \ldots a_n$) and deformation of negative ($b_1 \ldots b_n$)

The bundle of rays in space-object has been assumed as faultless The calibration parameters have been determined in iterative process by the realization of the following equations

$$F(X,L) = 0$$

where $X = (a_1 \ldots a_n, b_1 \ldots b_n, x_o, y_o, c_k, X_s, Y_s, Z_s, \omega, \varphi, \varkappa)$

$$L = (x - x', y - y')$$

$$x_i = c_k \cdot tg\,\alpha_i$$

$$y_i = \frac{c_k}{\cos\alpha_i} \cdot tg\,\beta_i$$

where ; α_i, β_i - horizontal and vertical direction to "i" point

In the third method applied systematic errors of image and basic parameters of interior orientation have been determined in two seperate processes[1],[8]. In order to define errors of the image the plane-test has been photographed. The comparison of the test - points with their images has permited to define coefficients describing radial symmetry and tangential distortions as well as image deformations. Basic interior orientation parameters have been determined on the basis of a comparison of the points of different kind of spatial tests and their corrected images.

3. Results of the colibration of some systems.

3.1 Terrestrial cameras

An accurate analytic elaboration of tasks of the Close-Range Photogrammetry require actual and precise interior orientation of the conventional metric cameras. It has been proved in practice that the precision of interior orientation indicated in the parameters of the manufacture of Zeiss Jena 19/1318 and UMK 10/1318 cameras /mostly used in Poland/, have not ensure accuracy of measurement. A spatial test has been carried out for determination of actual calibration parameters of those cameras and the method described in section 2 has been used[9].

An examination of number of Phototheo and UMK cameras with a plate negative has permitted to draw the following conclusions:
- the use of cameras nominal parameters of the interior orientation for reproduction of the bundle of rays brings in effect the systematic image errors in the range of $\pm 15 \div 20 \mu m$ depending on an example of the camera used,
- the use of determined parameters calibration for a formation

of the bundle of rays quarantees an accuracy of $\pm$ 6÷8 μm in the scale of the photography for both types of the above cameras,

- the determination of interior orientation in self-calibration permits to correct an accuracy of about 30% /4÷5 μm in the scale of image/.

The same method of calibration has been used in testing of one UMK camera with the PAN 33 Agfa Gevaert film. The results have been compared with tests of the same camera with TO 1 ORWO plates. It has been stated that inner coincidence in series of the film photographs has been higher than in plate photographs. Additionaly, a focus distance of a camera with a film has differed from the camera with a plate by 0,03 mm in spite of the fact that film deformation has been taken into account.

3.2 Non - metric cameras

The conventional cameras are not useful for some tasks /for example for precision measurement of some detals of engineering machines/. In such cases long focus distance cameras are more useful because of considerable limitation of systematic errors and large scale of photographs obtained[1]. The interior orientation of those photographs have been obtained by means of two methods presented in section 2. In the first method all the parameters of calibration have been computed simultaneously In the second method systematic errors have been defined in seperate processes. Due to an accepted rule of separation of calibration from the measurement process, it has been of a great importance for those photographs to determine the rate of repetition of the systematic image errors and their dependance on the distance of the camera from the object and the photography format used.

Two, examples of Sonnar 180 obiective and two kinds of negatives /Orwo NP 15, Fotopan SR 24/ have been examined. The divergences of the deformations according to fig.3 have been included in the range of $\pm$ 0.6 ÷ 2.2 μm. The results indicate that the errors can be determined for one series of photographs and refer to other photographs providing they are executed under the same conditions /type of obiective and negative, pro-

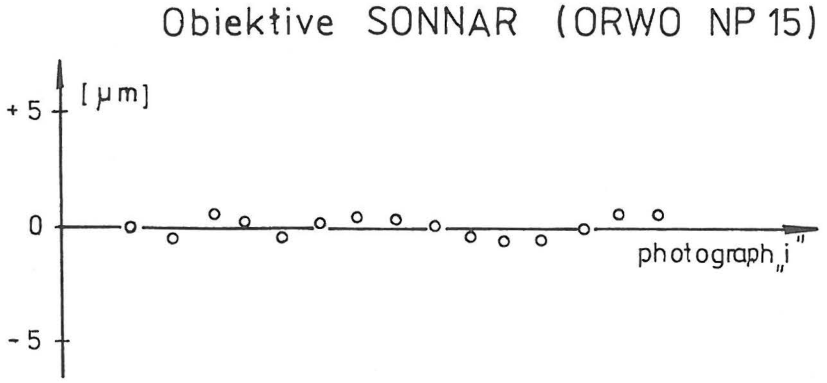

Fig. 3

cessing and geometry of photographs/. Figures 4 and 5 reveal the distortion according to photographing distance and the format used. As the results show the parameters which describe the systematic image errors, should be determined in conditions similar to those in which the object would be measured later.

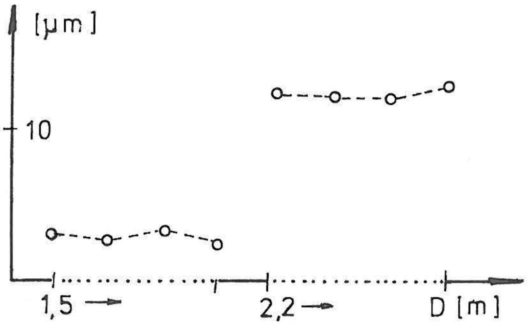

Fig. 4

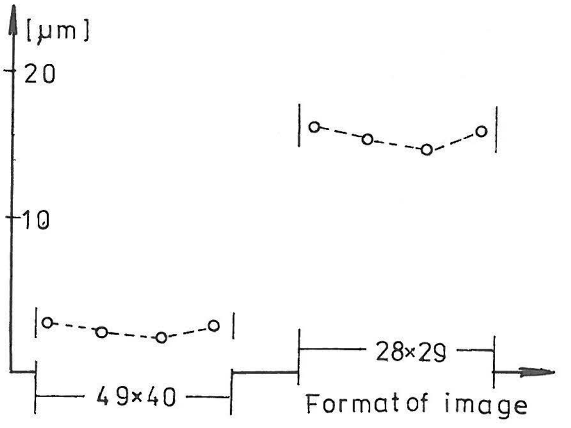

Fig. 5.

3.3 Unterwater photography

An application of close-range photogrammetry for measuring underwater objects requires defining of the interior orientation of images under water. These images are influenced by various factors charakcteristic for water environment /pollution, salt, etc/[5]. For these reasons the calibration process should be carried out just before or right after the measurement of the underwater object.The results of calibration of the Hasselblad camera in an terrestial and underwater position have proved that the focus distance has differed from 50 mm to 70 mm and the image errors have increased of about 60 percent.

The non-linear character of deformation demand an analitic processing of underwater photography.

3.4 TV Photography

In some areas the TV wire transmission systems can be applied for close-range photogrammetry.

Testing of the SONY TV system have shown a great relative stability of the succesive images. So the calibration can be made as a separate process.

Total deformations and basic parameters c_k, x_o, y_o of the TV photographs have been determined on the basis of the plane test a and the spacial test[8].

The results of calibration permit to draw the following conclusions:

- total deformations of TV photography have reached up to five TV screen lines,
- a five degree polynomial transformation /described by 21 parameters/ should be applied in order to correct deformations to an accuracy of a half of the TV screen line,
- an alteration of the parameters of the operation of the TV system (for example - focussing) produces an additional affine deformation up to 3 TV screen lines.

3.5 X - Ray Photography

The X - Ray photography can be treated like the perspective projection because the straight lined rays are getting out from the focusing point of the system. Howeyer, the X-Ray images are characterized with a low accuracy of the identification and the measurement in consequence of a poor resolving power. Since a deformation of the bundle of rays is considerably lower than the accuracy of measurement of images /on the stereocomparator/, only the basic parameters c_k, x_0, y_0 and external orientation are defined[2]. A spacial test for calibration of the X-Ray stereo--photographs have contained a variety of plexiglas of different lenghts with lead balls on the top. The roots have been ortogonaly located on the aluminium plate penetrable for X-Rays. The accuracy of photogrammetric elaboration of X-Rays photographs have been contained in the range $\pm$ 0,8 mm in the scale of image. When the photogrammetric technique is adopted for measurement of the human bone structure, the scale of image is about one to one.

4. Final conclusions

The methods of calibration which have been selected as examples and presented above, have proved to by fully useful in solving many problems of the close-range photogrammetry and required precision has been obtained. An additional, actual calibration of the conventional terrestrial cameras has almost doubled precision of measurement of the engineering constuctions.

Calibrated images of long focus distance of the non-metric cameras which have been used for measurement of details of mechanical and building constructions have quaranted an accuracy equivalent to the result of metrical cameras[3]. The definition of interior orientation of underwater photographs have permited to determine metrical documentation of an underwater ship-wreck. Calibrated TV images have been used for documentation of the traffic accidents. Definition of geometry of the X-Ray images have allowed to determine spatial deformations of human bones and the spine in particular, which is of a great importance for the rehabilitation process.

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