COMMISSION V

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A PROCEDURE FOR CLOSE RANGE CAMERA CALIBRATION

Abstract

A condition for the use of most applications of close range photogrammetry is the calibration of the basic geometric characteristics of the camera. In the most accurate measurements the calibration can be extended to using self calibrating analytic methods. In this article there is presented a simple calibration procedure. This procedure is based on the use of a test field and further the procedure can be applied for the calibration of metric and non-metric cameras.

Introduction

The use of close range photogrammetry has become prevalent in various fields of science and technology. A part of applications is based on analogical methods, when the function of a camera must correspond to the geometric central projection with sufficient accuracy. Depending on the requirements for accuracy, general metric cameras can be applied as well as non-metric cameras. Because in analogical applications only the main terms of inner orientation (principal point and camera constant) can in general be taken into account, at the calibration only these parameters and also the accuracy of a picture shall be determined according to this model. In analytical applications the function of geometric central projection is not required from the camera, but instead of that the camera must be of sufficient stability. The exact calibration assumes, that in addition to the main parameters of inner orientation, also the radial and tangential distortion will be determined. The distortion depends on the distance of the object within the photographic field and on relative aperture. These factors are essential in the most accurate measurements.

At the calibration procedure treated now those are not, however, properly taken into account, because the purpose has been to produce a simple procedure that is sufficient for the most general needs. The calibration of cameras with focussing abilities must be done by using at least 2...3 different focussed distances /1,2/.

The photogrammetric test field

At the calibration there will be used a plane point net. The position of points will be measured with sufficient accuracy. In connection with the determination of the coordinates of test targets there will also be determined the coordinates for the taking positions of test pictures. At Tampere University of Technology this was carried out as follows: Onto the vertical wall the targets (Fig. 1) were fastened according to Fig. 2. On the floor the centering bolts were fastened according to Fig. 2.

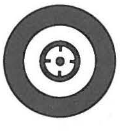


Fig. 1. The target.

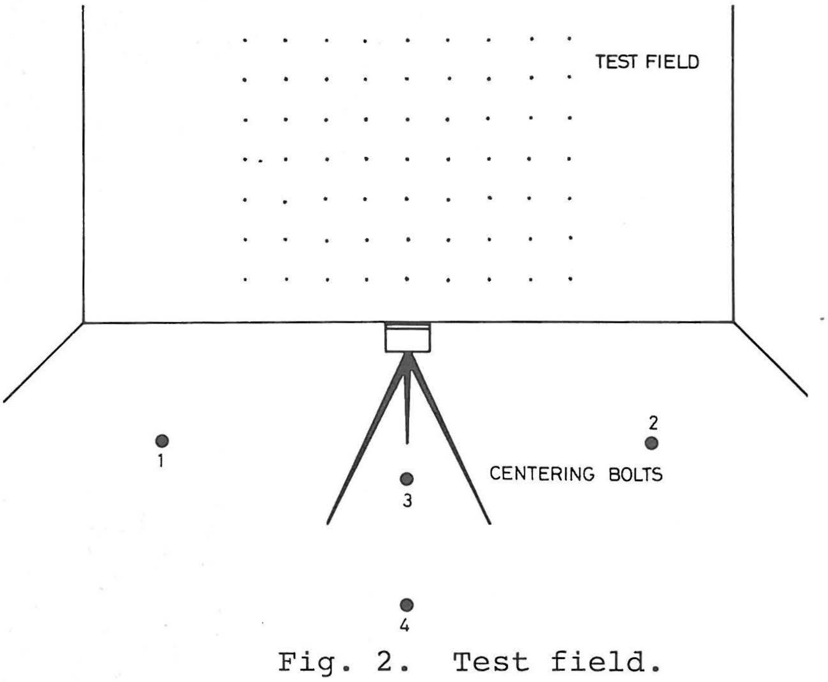


Fig. 2. Test field.

From the centering bolts 1 and 2 were observed by one-second theodolite the horizontal and vertical angles to wall points, floor points and end marks of the invar subtense bar in front of the wall. Observations were adjusted as simultaneous block adjustment /3/.

Test photographs

In order to decrease the correlations between the inner and outer orientation, the pictures are mainly taken so that part of the elements of outer orientation are measured by direct methods. This is processed by centering the outer perspective center of the camera above the station point with known coordinates. /4/. As auxiliary equipment there will be used a cross slide and 1...3 theodolites (Fig. 3.).

The height of perspective center can be determined by using the vertical angle measurement made by a theodolite. A good device is the levelling instrument equipped with a micrometer stativ and/or an optical micrometer (Fig. 4).

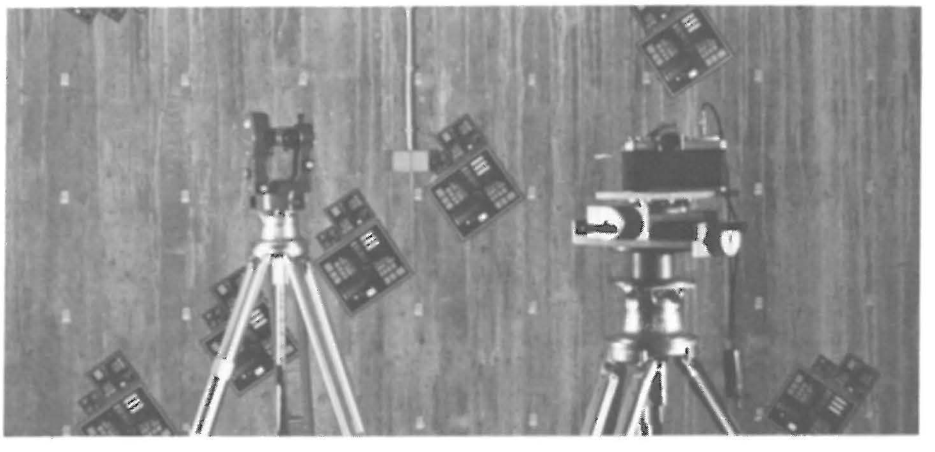


Fig. 3. Centering the camera.

Fig. 4. Measuring the height of perspective center.

The height of perspective center can be measured in relation to the points of the test field, or the test field can be equipped with a fixed levelling rod for this purpose.

The inaccuracy of centering is at the maximum in the direction of optical axis. Thus the inaccuracy effects most on the value of camera constant. Test photographs are taken in 2 or 4 different rotation positions in steps of 90°. These pictures are processed in simultaneous computation. If the camera has sighting and levelling devices, the test pictures will be taken levelled and directed at the center point of the field. Thus these devices for exterior orientation will be checked as well.

With metric cameras the centering accuracy especially on optical axis might become critical. In that case the calibration can be done by using oblique pictures. In addition to two perpendicular pictures (the difference of the rotation position being 90°) there will be taken the equivalent pairs of test pictures from one side, or in order to increase accuracy and reliability, from both sides on the angle of about 45°. (Fig. 5). The exterior orientation can be treated in computation as unknown. The exterior orientation doesn't correlate too strongly with the main terms of inner orientation.

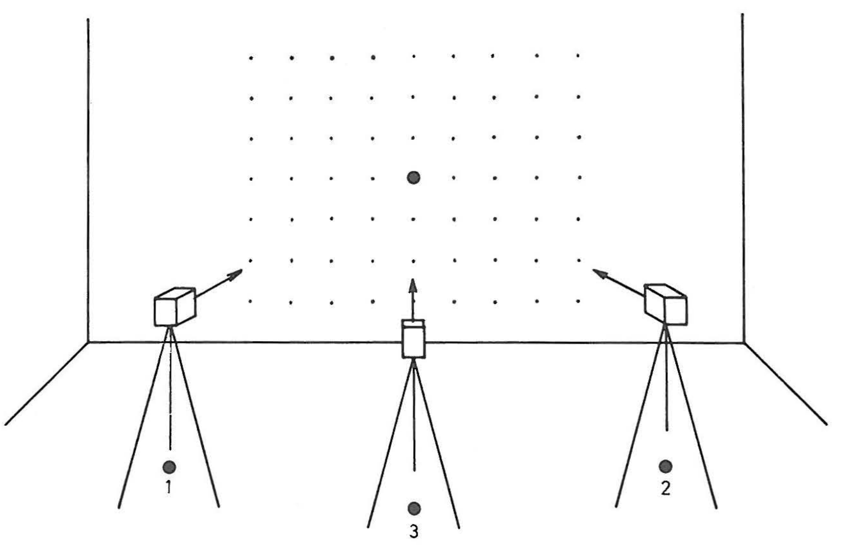


Fig. 5. Taking oblique test pictures.

In the introduction there was stated the dependence of distortion on focussing and on the distance of the object. If these qualities are expected to be examined, the calibration is to be repeated with the wanted parameters prevailing. The distortion can essentially be dependent on the above mentioned factors. In practice at the calibration one, however, often has to be satisfied with the circumstances wich best serve the operating circumstances. Further, one has to notice that metric cameras are in general focussed for fixed distances.

Comparator measurements

The test pictures are to be measured by a sufficiently accurate comparator. The standard deviation of image coordinates is often of the magnitude of 2...5 μm. The standard deviation of measurement of image coordinates should not exceed 1 μm.

In the metric camera the fiducial marks determine the coordinate system of the picture. At Tampere University of Technology the system similar to Fig. 6 has been introduced. The coordinates of fiducial marks in this coordinate system are determined as mean of the results received from various pictures.

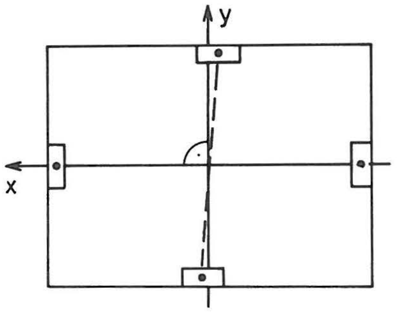


Fig. 6. Coordinate system of the metric camera (a positive picture).

The comparator observations of single metric pictures are transformed to the coordinate system of the camera by a three-parameter transformation (translations and rotation). When proceeding in this way the inaccuracy of the observations of the fiducial marks has been controlled.

As to the non-metric pictures, the coordinate system of the camera will be determined separately for each picture according to Fig. 7.

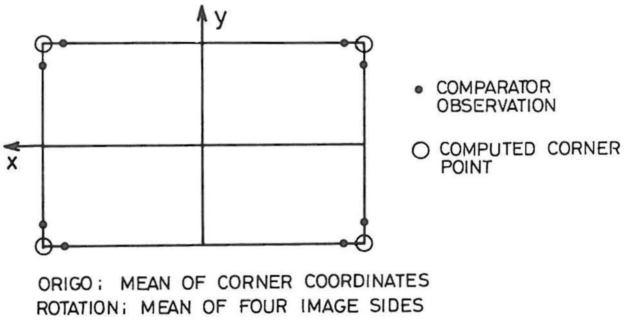


Fig. 7. Determination of the coordinate system of the non-metric camera.

Computations

For calibration there has been developed the computer program of PDP 11/70 Fortran IV Plus language. As unknown can be chosen any combination of six quantities of exterior orientation of each picture and any combination of ten common parameters of interior orientation of pictures. The parameters of interior orientation are as follows:

- Radial error

  $$dr = a_1 r\ (1 - r_o/r) + a_3 r^3\ (1 - r_o/r) + a_5 r^5\ (1 - r_o/r)$$

  where r is the radial distance

  where r_o is the radial distance of zero-distortion

- Tangential erros

  $$dx = p_1\ (r^2 + 2x^2) + 2p_2 xy$$
  $$dy = 2p_1 xy + p_2\ (r^2 + 2y^2)$$

- Principal point
- Camera constant
- Affinity (scale difference and orthogonality)

Normally the computation proceeds as follows:

In the first stage the angles of exterior orientation of pictures are unknown. The coordinates of perspective center are either fixed or free unknowns depending on the situation. The adjustment will be repeated, until the orientation parameters don't get any more significant improvement. The significance of improvements will be tested by t test and the decrease of standard error of unit weight by F test. Furthermore, the correlations between the unknowns exceeding a certain limit are listed.

In the next stage the main terms of interior orientation or the position of perspective center (principal point and camera constant) are added as unknowns. If the pictures of the camera in question are used for analogical measurement, the interior orientation thus obtained is final. The continuation is only the analyses of residual errors. In analytical measurement the interior orientation can be determined more completely. For the main terms of interior orientation the values can be determined in connection with the determination of radial and tangential distortion. In Fig. 8 there is presented the block diagram of computation.

Some results

In the next some results are presented which have been obtained by the procedure described above. An example is the metric camera using a glass plate and the usual non-metric camera.

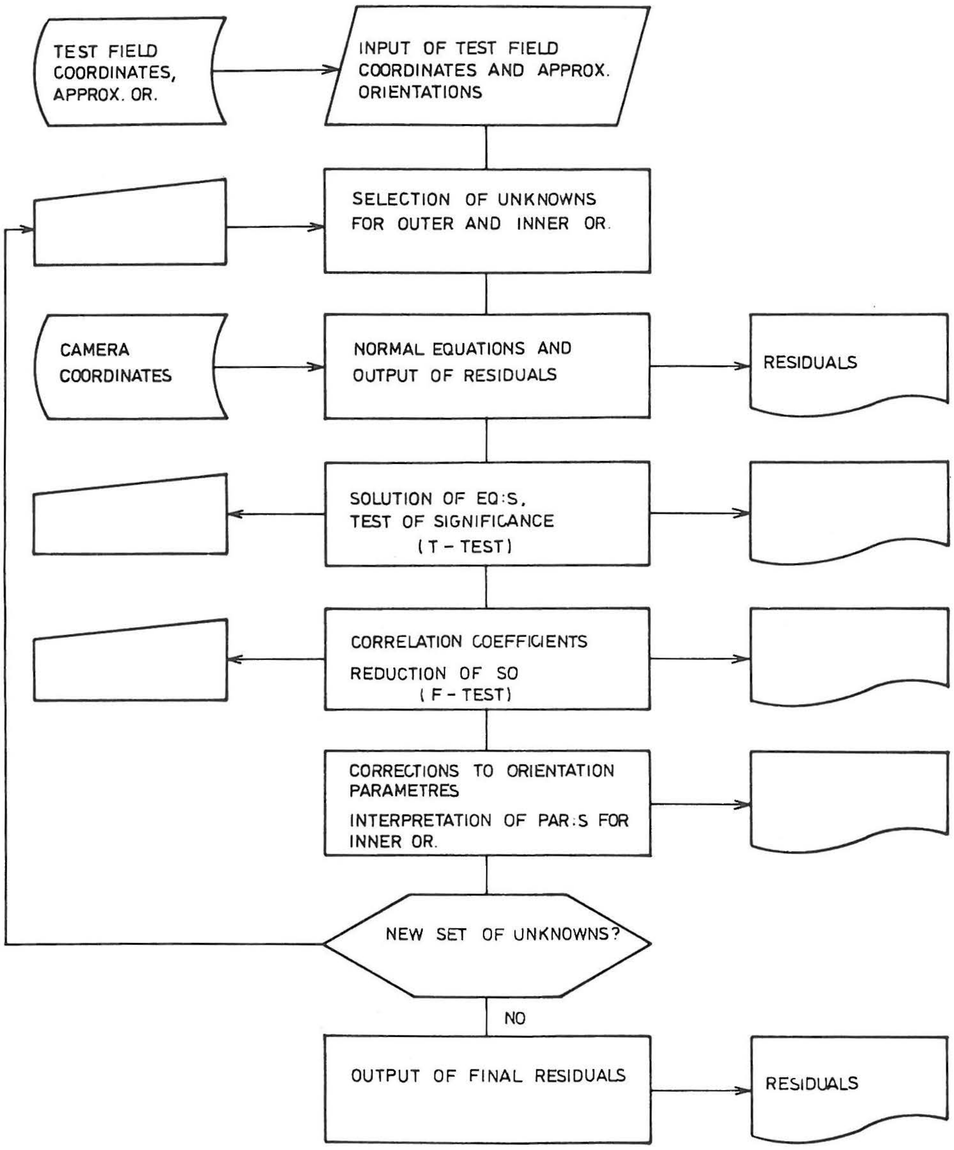


Fig. 8. Block diagram of the calibration procedure.

Non-metric camera

Photo size 24 mm x 36 mm, nominal focal length 55 mm. Four orthogonal test photographs, fixed perspective centers.

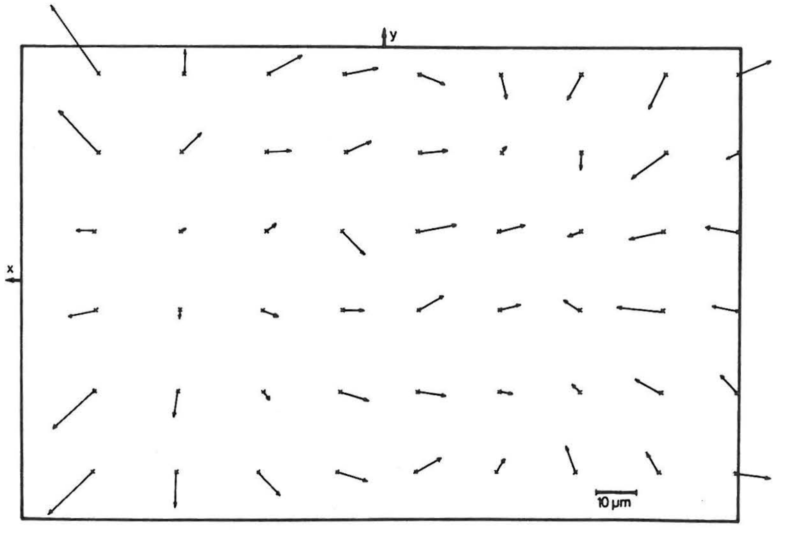
1. Determination of the principal point and camera constant

$$dx = 0.100 \pm 0.008 \text{ mm}$$

$$dy = -0.031 \pm 0.012 \text{ mm} \qquad s_o = 4.1\ \mu m$$

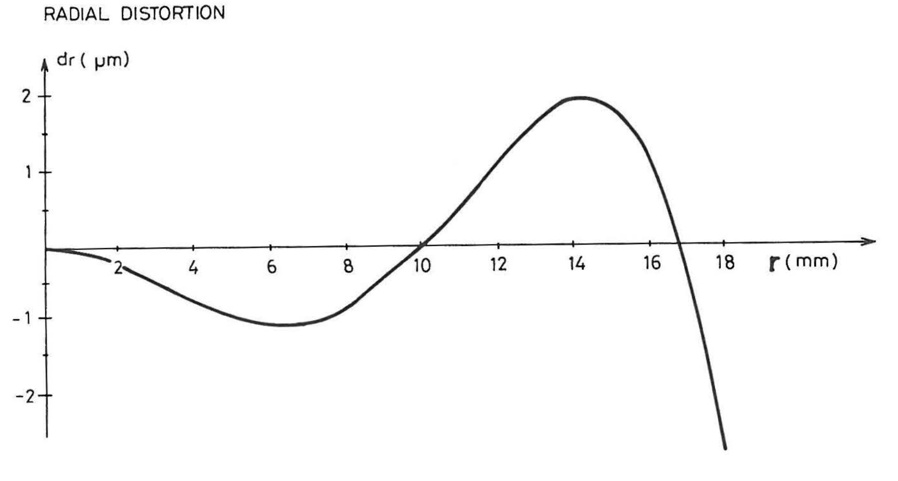
$$c = 55.584 \pm 0.001 \text{ mm}$$

Residual errors on one test photograph.



2. Determination of radial and decentering distortion

$s_o(\text{rad}) = 3.5\ \mu m$ $\qquad$ $s_o(\text{rad + dec}) = 3.4\ \mu m$



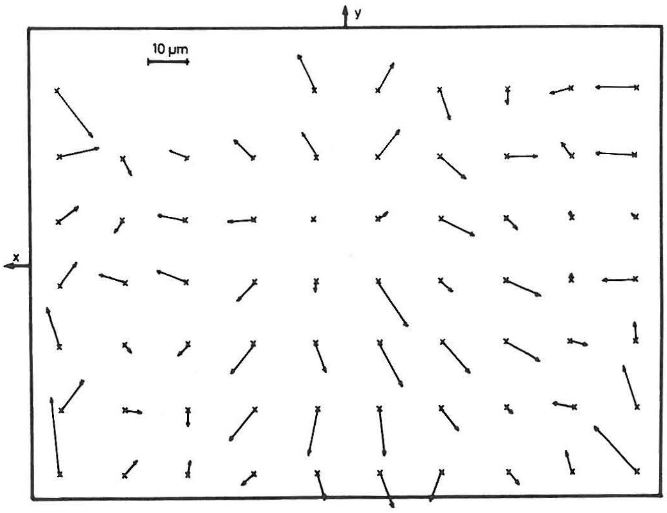
Metric camera

Photo size 120 mm x 165 mm, nominal focal length 99 mm.
Focussing distance 3.6 m (c = 102.05 mm)
Six test photographs (3 stations, two rotated positions)
Free outer orientation

1. Outer orientation of test photographs

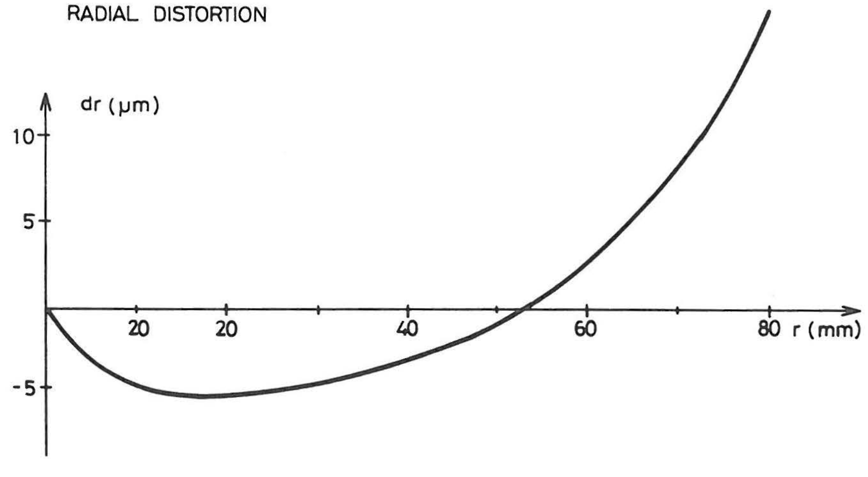
   s_o = 4.6 μm

   Residual errors on one test photograph

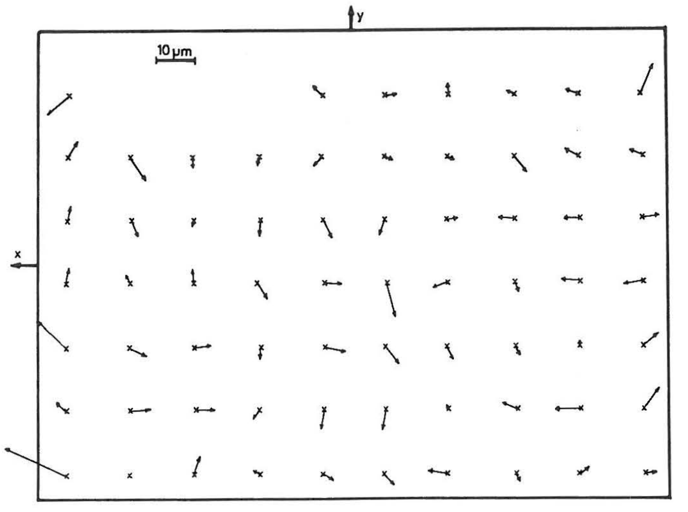


2. Determination of the principal point, camera constant and radial distortion

   dx = 0.009 ± 0.003 mm
   dy = 0.029 ± 0.003 mm s_o = 3.0 μm
   dc = −0.016 ± 0.006 mm



Residual errors on one test photograph.



3. Comments

Due to the limited size of the test field there were no test targets on the borders of the oblique test photos.

The coordinates of the perspective centers of test photographs were also measured geodetically. No systematic discrepancy between measured and calculated coordinates was found. The RMSE of discrepancies was 0.6 mm.

Concluding remarks

The calibration procedure described in this article has been introduced at Tampere University of Technology. The test field used now is too small for the calibration of cameras focussed on long distance. However, the procedure has proved to be fast and useful.

References

/1/ Brown, D.C.: Close-Range Camera Calibration. Photogrammetric Engineering, No. 8, 1971.

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/3/ Salmenperä, H.: Block Adjustments Using a Minicomputer of the Helsinki University of Technology. Presented Paper, ISP Commission III Symposium, Moscow 1978.

/4/ Hallert, B.: Perspective Center Determination. Photogrammetric Engineering, No. 10, 1969.