MEASURING DEFORMATIONS OF A MULTI-STOREY BUILDING WITH A NON-METRIC CAMERA

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ABSTRACT

The deformations of the building are measured photogrammetrically at four corners of each of the floors. The building is photographed with a non-metric camera from 12 stations located around it, so that each building frontage appears on four successive photographs.

A rigorous adjustment of the closed-on-itself photogrammetric strip including a self-calibration of the photographs is performed. Lengths of features of the buildings which remain unchanged are used as control data for the photogrammetric evaluation.

INTRODUCTION

The small changes in the shape of a multi-storey building taking place during a period of time can provide useful information about the stability of the building and its foundations. Determining the spatial coordinates of points on the building by a non photogrammetric measuring method is on many occasions inconvenient mainly because of difficulties in accessing the points at which the building's deformations should be measured. A closed on itself photogrammetric strip can be an adequate solution for that problem, but when the photographs are taken with a non-metric camera there is a need for an on-the-job calibration for each of the photographs.

On-the-job calibration provides satisfactory results only when it is based on proper control data, consisting of an adequate number of control points, accurately determined and suitably positioned. Because of the above mentioned difficulties in accessing various locations on the building it is preferable to establish the control points only on the building's roof and near its ground level. This number and distribution of the control points is sufficient for a mathematical determination of the deformation values, but their accuracy might be inferior. It would be very difficult to improve the accuracy by adding more control points at different levels on the walls of the building since determining their spatial coordinates causes the same problems as the direct measurement of the building's deformations does, besides by increasing the number of the control points the most important benefit of the photogrammetric method is being lost.

Another possible source of control data is called "geodetic measurements", in this case the control data constitute a number of measured distances between the object points. It was shown by Wong (1975) that such data are usually sufficient for determining the calibration and relative orientation of the photographs. This approach is not applicable to the case of a multi-storey building where because of accessibility difficulties, all the measured distances are oriented only in three perpendicular directions, one vertical and two horizontal along the building's walls. However, the combination of a few control points together with the measured distances is sufficient to obtain a reliable solution for the building's deformations values.

DISCUSSION OF THE PROBLEM OF ESTABLISHING MINIMUM CONTROL POINTS

The calibration unknowns consist of three parameters of the interior orientation, the film deformation, the affinity of the photograph and the radial lens distortion, all together at least six unknowns.

Adding the six parameters of the exterior orientation each photograph has twelve independent orientation and calibration unknowns which can be embedded into the twelve independent parameters of the Direct Linear Transformation formulae which were presented by Karara and Abdel Aziz (1974).

$$x = \frac{L_1 X + L_2 Y + L_3 H + L_4}{L_9 X + L_{10} Y + L_{11} H + L} + dx \qquad (1)$$

$$y = \frac{L_5 X + L_6 Y + L_7 H + L_8}{L_9 X + L_{10} Y + L_{11} H + L} + dy$$

$$dx = K\,x\,(x^2 + y^2)$$

$$dy = K\,y\,(x^2 + y^2)$$

where: x,y are the photo coordinates.

X,Y,H are the spacial coordinates.

L_1 to L_{11} are the transformation coefficients.

K is a coefficient for correcting the radial lens distortion.

The values of the twelve parameters in eq. L can be found for each photograph individually from the twelve equations which are obtained by inserting the values of the photo and space coordinates of at least six well distributed homologous points.

However, it is possible to find the values of some of these parameters by taking the photographs of the same object from several (at least three) stations and by using the photogrammetric laws of collinearity and coplanarity for all the photographs simultaneously. The values of the remaining parameters can be calculated by using a few control points and several measured lengths of some of the building's features.

This problem of photogrammetric model construction and non metric photographs self calibration using multiple photographs was investigated by Koelbl (1972), Faig (1975), and Okamoto (1981). In their investigations the object points were well distributed and each point appeared on all the photographs.

It was shown by Okamoto (1981) that under such circumstances applying the coplanarity and collinearity laws, it is possible to solve, without control data of any kind, all but eight parameters of the relative and interior orientations of all the photographs. This ideal situation is not encountered in the closed on itself photogrammetric strip because of the two following reasons:

a. Any one of the object points does not appear on all the photographs but usually only on half the number of them.
b. All the object points which appear on the photographs are usually located on the four planes of the building's facades.

Because of these limitations, there are twelve parameters of relative orientation, interior orientation and photo calibration which can not be derived from the photogrammetric relations only. Together with the exterior orientation parameters the number of the parameters which can not be mathematically determined without control points and/or geodetic measurements is 19. They can be solved by using six horizontal and eight vertical control points (no more than four of each kind should lie in one and the same plane). Alternatively, one of the horizontal and four of the vertical control points can be replaced by one near-horizontal and four near-vertical distances measured between object points.

In some cases, a point on the building's roof and not on one of the planes of the building's facades, for instance, a TV antenna, is recorded on at least half the number of the photographs. In such a case the number of the elements of photo calibration, interior and relative orientation which can not be solved without control points is being reduced to nine. They together with the exterior orientation unknowns can be mathematically determined by using five horizontal and six vertical control points, from which no more than three of each kind are located in one and the same plane. Alternatively, the solution can be based on four horizontal and three vertical control points and on three near-vertical and two near-horizontal measured distances.

EXAMPLE OF THE DEFORMATION MEASUREMENTS

Twelve photographs of a multi-storey building were taken by a Yashica 35J amateur camera. The photographs were tilted upwards in order to photograph the entire building from as close as possible. The positions of the camera stations were chosen so that two of the building's facades appeared on each of the photographs. The same two facades appeared on two other photographs forming thereby a triplet of practically 100% overlapping photographs. Each of these facades appeared also in the successive triplets as it can be seen in Fig. 1.

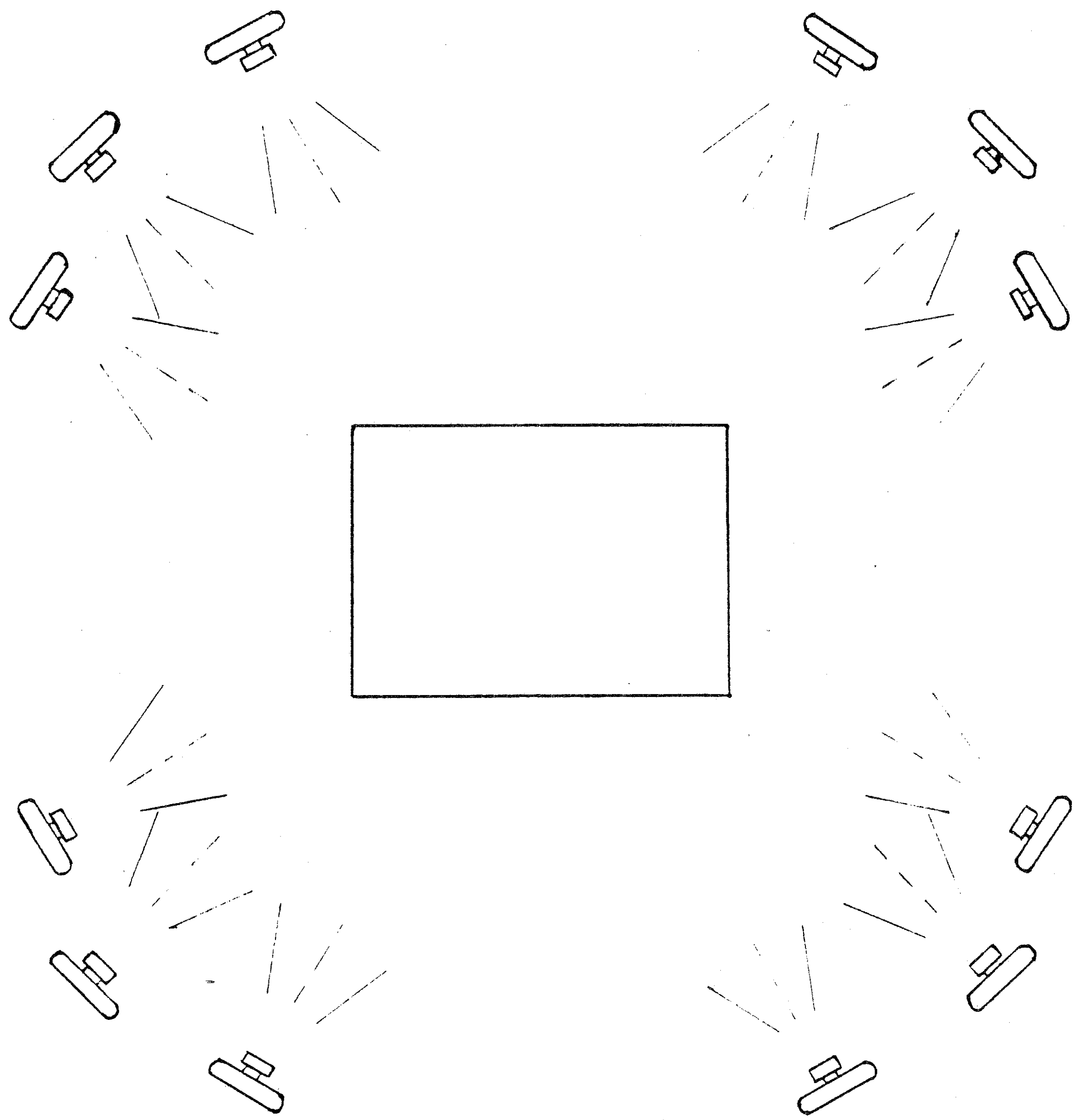

Fig. 1. The Camera Stations Around the Building

Four control points were chosen at the 4 corners of the building's roof. Another control point was at one of the building's corners near the ground level. This number of control points is sufficient due to the TV antenna which is near the center of the building's roof, and appears on eight photographs. In addition, the length of 8 vertical distances and 10 horizontal distances between points on the facades of the building were measured.

The building's deformations deviations from an ideal shape were obtained by a simultaneous adjustment of the photogrammetric closed on itself strip. The deformations of one of the facades are shown in Fig. 2 together with some of the corresponding deformations which were measured by conventional methods. The accuracy of these deformations depend on the number of the photographs in the strip and on the number of the control distances. The mean square error of the determined deformations can be estimated from the variance-covariance matrix obtained from the adjustment procedure. Table no. 1 shows the changes in the values of two elements along the main diagonal of that matrix corresponding to the largest mean square errors, one in the horizontal and the other in the vertical directions, as a function of the number of control distances and photographs in the strip.

The number of control distances		The number of the photos in the strip	The maximal variances of an object coordinate (in sq.m/sq.mm)	
horizontal	vertical		horizontal	vertical
2	3	8	49.3	634.7
2	5	8	6.8	6.3
2	8	8	6.6	6.3
4	3	8	1.9	46.4
4	5	8	1.2	6.3
4	8	8	1.2	6.3
10	3	8	1.8	39.4
10	5	8	1.1	6.3
10	8	8	1.1	6.3
2	3	12	46.5	606.4
2	5	12	5.2	5.0
2	8	12	5.1	5.0
4	3	12	1.4	36.0
4	5	12	0.8	5.0
4	8	12	0.8	5.0
10	3	12	1.3	31.5
10	5	12	0.8	5.0
10	8	12	0.8	5.0

Table 1. The values of the maximal variances of horizontal and vertical coordinates for different numbers of control distances and photographs per strip. (The number of the control points is minimum).

Since the mean square error of measuring the photo coordinates of a point is estimated to be 0.015 milimeters, the maximal mean square errors of the deformations, when using all the control data and all the photographs are:

$$M_h = \sqrt{0.8}\ \text{m/mm} \times 0.015\ \text{mm} = 0.013\ \text{meters}$$

$$M_v = \sqrt{5.0}\ \text{m/mm} \times 0.015\ \text{mm} = 0.034\ \text{meters}$$

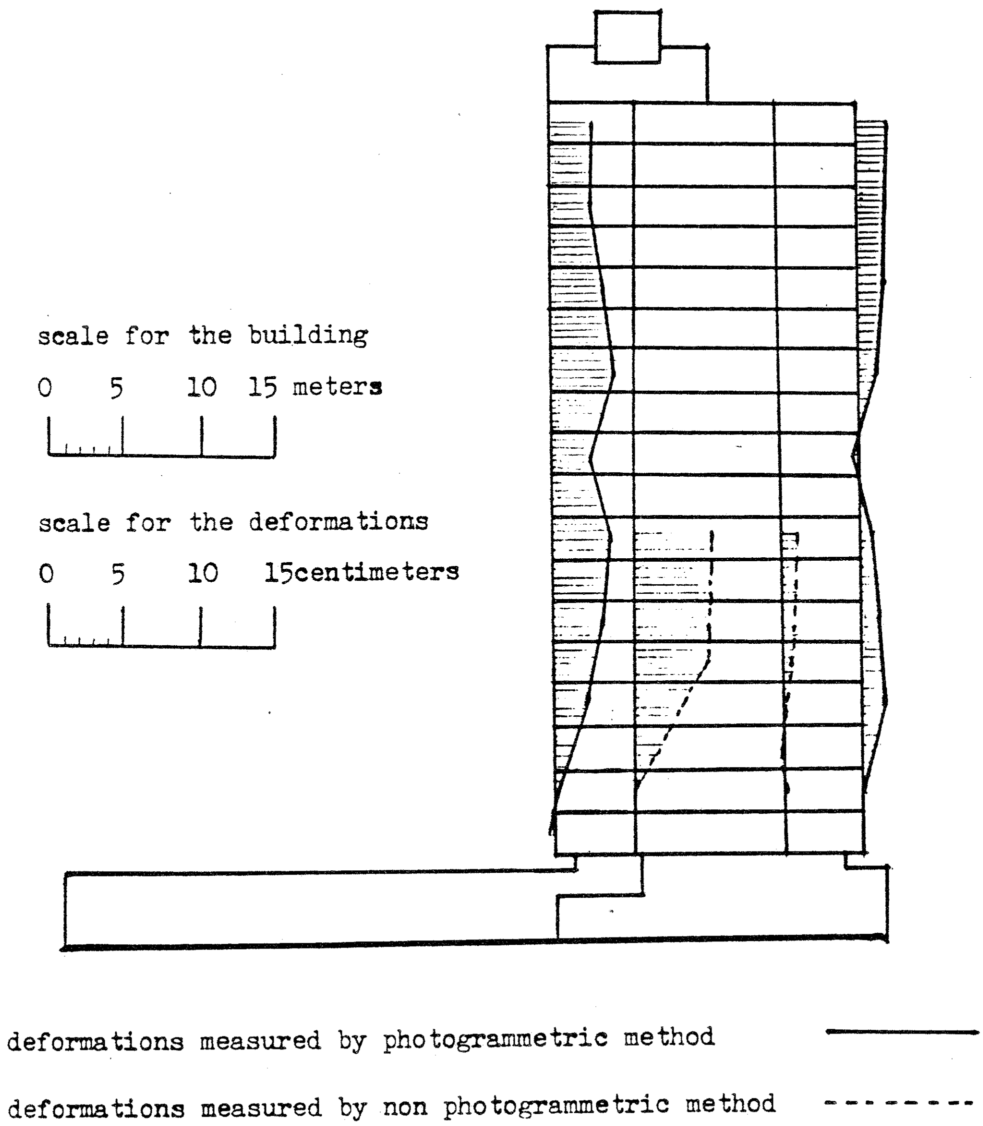

Fig. 2. The horizontal deformations of the northern facade.

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