A Low Cost Close Range Photogrammetric Technique for Stability Evaluation of the Reinforced Concretes

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Abstract:

The objective of this paper is to introduce a low cost digital close range photogrammetric system as applied in a structural engineering project. This system employs an amateur camera for stereo coverage of industrial objects. The acquired images are scanned by a desktop scanner. The digitized images are then fed into a desktop computer for photogrammetric processing developed in Matlab6.5 environment. Processing includes the solution of approximate interior orientation of the camera followed by the Moniwa self calibration space resection/intersection strategy. Imperfections due to the camera and the scanner instable geometry are compensated by the self calibration parameters. The reliability and stability of the solution of the space/resection intersection equations are secured by a priori constructed control network whose coordinates are determined by a geodetic surveying method. Our system is evaluated by measuring nearly 100 points located on a piece of reinforced concrete for a structural engineering project. It is well known that the performance of the concretes under stress is enhanced when mixed with uniformly and randomly distributed steel fibers. The main objective of the project was to determine numerically the steel fibers distribution in reinforced concretes. First experiments carried out by our photogrammetric system for measuring the end points of the randomly distributed steel fibers within pieces of concrete blocks indicate positioning accuracy within 2mm (rmse) for the check points. This accuracy was considered to be adequate for the project requirement.

1 Introduction

In the last two decades, industrial application of close range photogrammetry has gained considerable attention due to its cost effectiveness, simplicity of the data processing and the ease and speed of its data acquisition. As regards the economical aspects, the utilization of amateur cameras in close range applications can still further reduce the project cost provided that the required accuracy is compromised. A simple inexpensive camera may be installed in a predefined network of imaging stations for the stereo coverage of the object. The low accuracy of the amateur camera due to the large amount of lens distortions, film shrinkage, platen non-flatness, etc., can be somehow compensated by a suitable mathematical model. These models have been already investigated in the field of photogrammetry and their merits and demerit reported (see for example: Slama, 1980; Fraser, 1984; Fryer, 1994; Mason, 1995a,b). The main intention of this paper is to introduce the working principle of our software system "*Parmehr*" designed to serve as a low cost close range photogrammetric software package to be used for the 3D metric information extraction of small objects. The system makes use of an amateur low-cost camera in an off-line solution for the industrial photogrammetric applications. The following sections describe the overall configuration of the system. This is then followed by a report of the first series of experiments made on a piece of reinforced concretes mixed with steel fibers.

2 Data acquisition

The general workflow of the data acquisition procedures is as follows:

a) Construction of the control network to be used for the camera calibration,
b) Selection of an appropriate film sensitivity,
c) Determination of the camera placement for the stereo coverage of the object,

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d) Photography and processing,
e) Scanning, and
f) Monoscopic image point measurement.

The camera calibration is performed by means of a control network whose coordinates are determined by geodetic surveying method. The object to be measured is placed in front of the control network in such a way that the control points cover the periphery of the object. These control points are photographed simultaneously with the object and are utilized for the determination of the camera internal geometry as well as the camera exterior orientation parameters.

The photography is carried out under the strict condition of the object and the camera being in stationary mode. Thus, the image resolution can be improved by choosing slow speed high resolution films.

Our system operates on digitized images; therefore, scanning analogue negative images is indispensable. A photogrammetric scanner may be employed for the digitization process. Alternatively, a desktop scanner may be used for this purpose provided that scanner is calibrated for its distortion pattern. Scanning pixel size is determined based on the lens/film overall resolution.

The image coordinates of the target points are measured via a cursor controlled by a mouse in a menu driven monoscopic pointing environment developed in Matab6.5.

3 Data processing

In the initial stage, an approximate interior orientation is carried out by means of corners of the image frame. These corners are determined by intersecting the perpendicular lines of the frame edges. These lines are determined by a simple least squares line fitting to series of points marked on the frame edges by the operator (figure 1). The corner points then serve as quasi-fiducial marks. The coordinates of these fiducials are then determined with respect to the nominal principal point coordinate system. The principal point is defined as the point of intersection of the lines that join two opposite quasi-fiducials (Fryer, 1993). The approximate interior orientation process is then completed by transferring the measured coordinates of the arbitrary points, acquired during the data acquisition stage, into the principal point coordinate system. This transformation is just a simple coordinate shifts in the x and y directions respectively (Cruz, 2000).

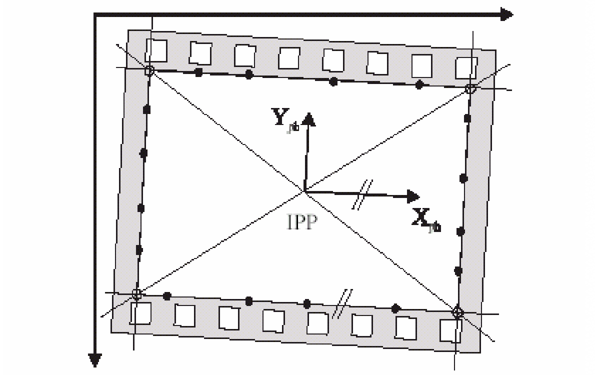

Figure 1. Interior orientation stage.

Having performed the approximate interior orientation, a simultaneous space resection/intersection is pursued using Moniwa self calibration approach (Moniwa, 1977) given by:

$$x - x_0 + \Delta x_p = -c \frac{(X - X_c)m_{11} + (Y - Y_c)m_{12} + (Z - Z_c)m_{13}}{(X - X_c)m_{31} + (Y - Y_c)m_{32} + (Z - Z_c)m_{33}}$$
$$y - y_0 + \Delta y_p = -c \frac{(X - X_c)m_{21} + (Y - Y_c)m_{22} + (Z - Z_c)m_{23}}{(X - X_c)m_{31} + (Y - Y_c)m_{32} + (Z - Z_c)m_{33}} \qquad (1)$$

in which:

$$\Delta x_p = dr_x + dp_x + dg_x$$
$$\Delta y_p = dr_y + dp_y + dg_y$$
$$dr_x = (x - x_0)(K_1 r^2 + K_2 r^4 + K_3 r^6)$$
$$dr_y = (y - y_0)(K_1 r^2 + K_2 r^4 + K_3 r^6)$$
$$dp_x = p_1(r^2 + 2(x - x_0)^2) + 2p_2(x - x_0)(y - y_0)$$
$$dp_y = p_2(r^2 + 2(y - y_0)^2) + 2p_1(x - x_0)(y - y_0)$$
$$dg_x = A(x - x_0)$$
$$dg_y = B(y - y_0)$$

where c = focal length
x, y = image coordinates
x_0 ، y_0 = principal point coordinates
X_c, Y_c, Z_c = coordinates of projection center
X, Y, Z = object coordinates
m_{11}, m_{12}, m_{13}, m_{21}, m_{22}, m_{23}, m_{31}, m_{32}, m_{33} = elements of orientation matrix
Δx_p, Δy_p = function of additional parameters
dr_x, dr_y = radial lens distortion correction
dp_x, dp_y = tangential lens distortion correction
dg_x, dg_y = film deformation correction
K_1, K_2, K_3 = radial lens distortion parameters
p_1, p_2 = tangential lens distortion parameters
A, B = film deformation parameters

The self calibration parameters are intended for the modeling of remaining errors of the interior orientation parameters as well the imperfections of the internal geometry of the camera under the condition that the camera internal geometry is time invariant. The scanner geometric distortion is also compensated by the self calibration parameters.

For the solution of the self-calibration equations, approximate values for the unknown parameters are required. This is achieved by a direct linear transformation (DLT) method (Abdel-Aziz, 1971; Cattafesta, 1996). The well-known DLT is given by:

$$x = \frac{L_1 X + L_2 Y + L_3 Z + L_4}{L_9 X + L_{10} Y + L_{11} Z + 1} \qquad (2a)$$

$$y = \frac{L_5 X + L_6 Y + L_7 Z + L_8}{L_9 X + L_{10} Y + L_{11} Z + 1} \qquad (2b)$$

where $L_1, \ldots, L_{11}$ = transformation coefficients
x, y = image coordinates
X, Y, Z = object coordinates

The approximate values for the exterior orientation parameters are then calculated by:

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} = -\begin{bmatrix} L_1 & L_2 & L_3 \\ L_5 & L_6 & L_7 \\ L_9 & L_{10} & L_{11} \end{bmatrix}^{-1} \begin{bmatrix} L_4 \\ L_8 \\ 1 \end{bmatrix}$$

$$\omega = \tan^{-1}(-L_{10} / L_{11})$$

$$\phi = \sin^{-1}\left(-L_9 \Big/ \sqrt{L_9^2 + L_{10}^2 + L_{11}^2}\right)$$

$$\kappa = \cos^{-1}\left((L_1 - x_0 L_9) \Big/ \left(c \cdot \cos\phi \cdot \sqrt{L_9^2 + L_{10}^2 + L_{11}^2}\right)\right)$$

where X_c, Y_c, Z_c = coordinates of projection center

ω, ϕ, κ = orientation angles of camera

4 TEST RESULTS

Our system is evaluated by measuring nearly 100 points located on a piece of reinforced concrete for a structural engineering project. It is well known that the introduction of randomly and uniformly distributed steel fibers throughout the concrete mix transforms the hardened concrete material into a more flexible composite system while maintaining its stability. This stability is a function of the distribution and direction of the steal fibers. The main objective of the project was to quantify this relationship. The project was, therefore, concerned with the measurement of the distribution and direction of the randomly located steel fibers (about 4 cm in length) reinforced throughout pieces of concrete blocks. The photogrammetric measurement procedures are described below:

4.1 Data Acquisition

A Zenit 122 amateur camera conducts data acquisition stage (Fig. 2). This is a low cost amateur 35 mm camera.

The camera is placed in predetermined stations for optimum accuracy. The stereo coverage is acquired for an intentionally broken concrete piece. Fig. 3 shows the broken concrete, which indicates the direction and distribution of the reinforced steel fibers. In order to find the distribution and the direction of these bars it was necessary to numerically determine the coordinates of the two end points for each individual steel fiber.

Figure 2. Zenit 122 amateur camera

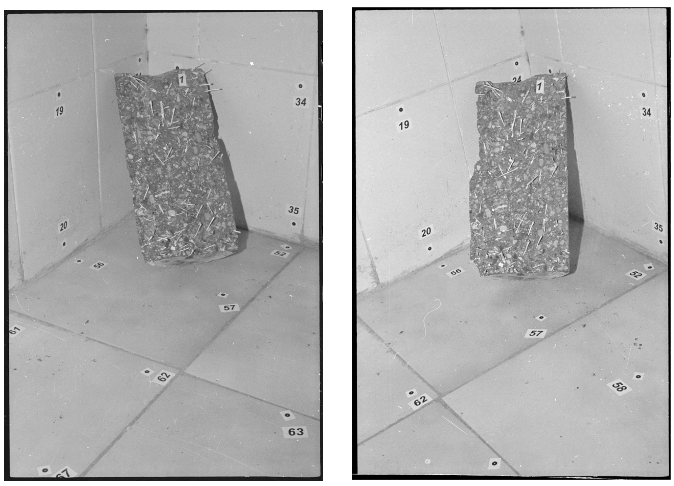

Figure 3. The concrete block and the corresponding photogrammetric network

To determine the camera exterior orientation parameters a control network is established by series of regularly distributed target points fixed on the surface of walls supporting the concrete (Fig. 3).

The concrete piece is placed on the wall corners so that it is surrounded by the control network. To avoid ill-conditioning problem during the solution of Eq. 1, the control network is arranged in non-planar positions (see Fig. 4). Fig. 5 indicates the planimetric position of the control points and the location of the camera stations with respect to these points.

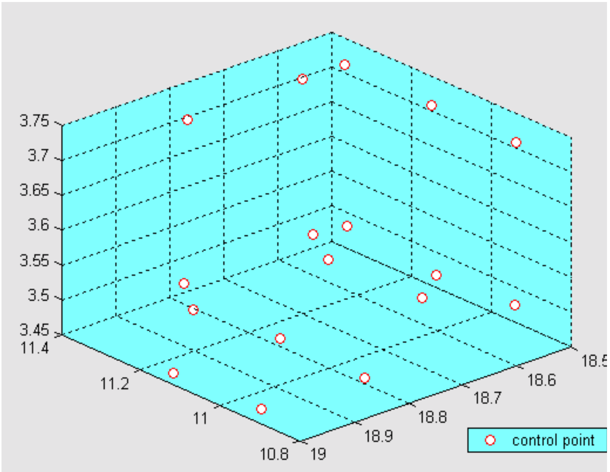

Figure 4. Distribution of control points

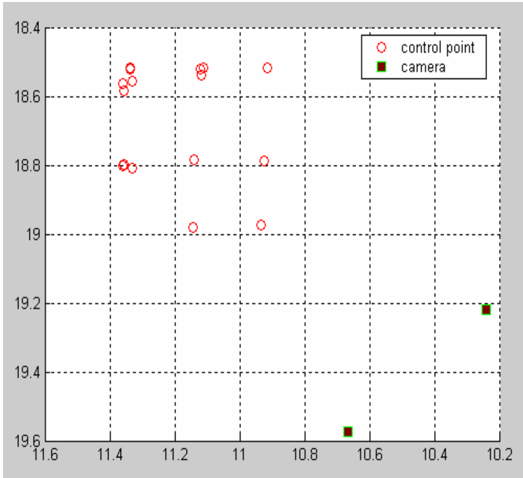

Figure 5. Camera positions with respect to the control points

The coordinates of the control points are determined by the Sokkia Power Set 1000 total station using reflector sheets. A posteriori evaluation indicates accuracies of ± 0.1 mm and ± 1 second for the distance and the angle measurements respectively.

The stereo images (Fig.3) were scanned by a desktop scanner and the image coordinates of the control points were measured manually via a cursor controlled by a mouse. The image coordinates of the two end points of the steel fibers are also measured monoscopically on the digital stereo pair.

4.2 Data Processing

As mentioned in the earlier sections, the initial values of the orientation and translation parameters were determined by non-iterative solution of Eq.2. To correct systematic distortions due to the camera lens distortion, film shrinkage, scanner instability, etc., Eq. 1 was linearized with respect to both camera exterior orientation as well as the Moniwa self calibration parameters. The approximate and the final values of the exterior orientation parameters are given in Table 1 for both photographs.

Table 1. Approximate and final values of the exterior orientation parameters.

Photo	Mathematical model	X_c (m)	Y_c (m)	Z_c (m)	ω (d)	ϕ (d)	κ (d)
Left photo	DLT	10.673	19.569	4.085	-57.835	-26.388	26.375
	Self-calibration	10.666	19.573	4.084	-57.846	-26.289	26.358
Right photo	DLT	10.252	19.217	4.039	-47.334	-49.645	35.795
	Self-calibration	10.241	19.218	4.038	-46.613	-50.875	36.449

In the final stage, space intersection is carried out using the exterior orientation and the self calibration parameters determined in the previous stage and the object coordinates of the two end points of the steal fibers are generated. Fig. 6 shows a 3D view of the generated object coordinates of the two end points of the steel fibers. The red dots and blue circles indicate the start and the end points of the fibers respectively. These measured points exhibit numerically the distribution and the direction of the steel fibers (Fig. 6 gives a graphical representation).

The overall accuracy for the object coordinates of the points is within 2mm (rmse) evaluated on the check points. This accuracy figure was considered to be adequate for the project.

The entire process was repeated for several other concrete blocks with different distribution and direction of the steel fibers. The generated coordinates of the object points made possible the determination of the concrete stability in terms of the steel fibers distribution and direction.

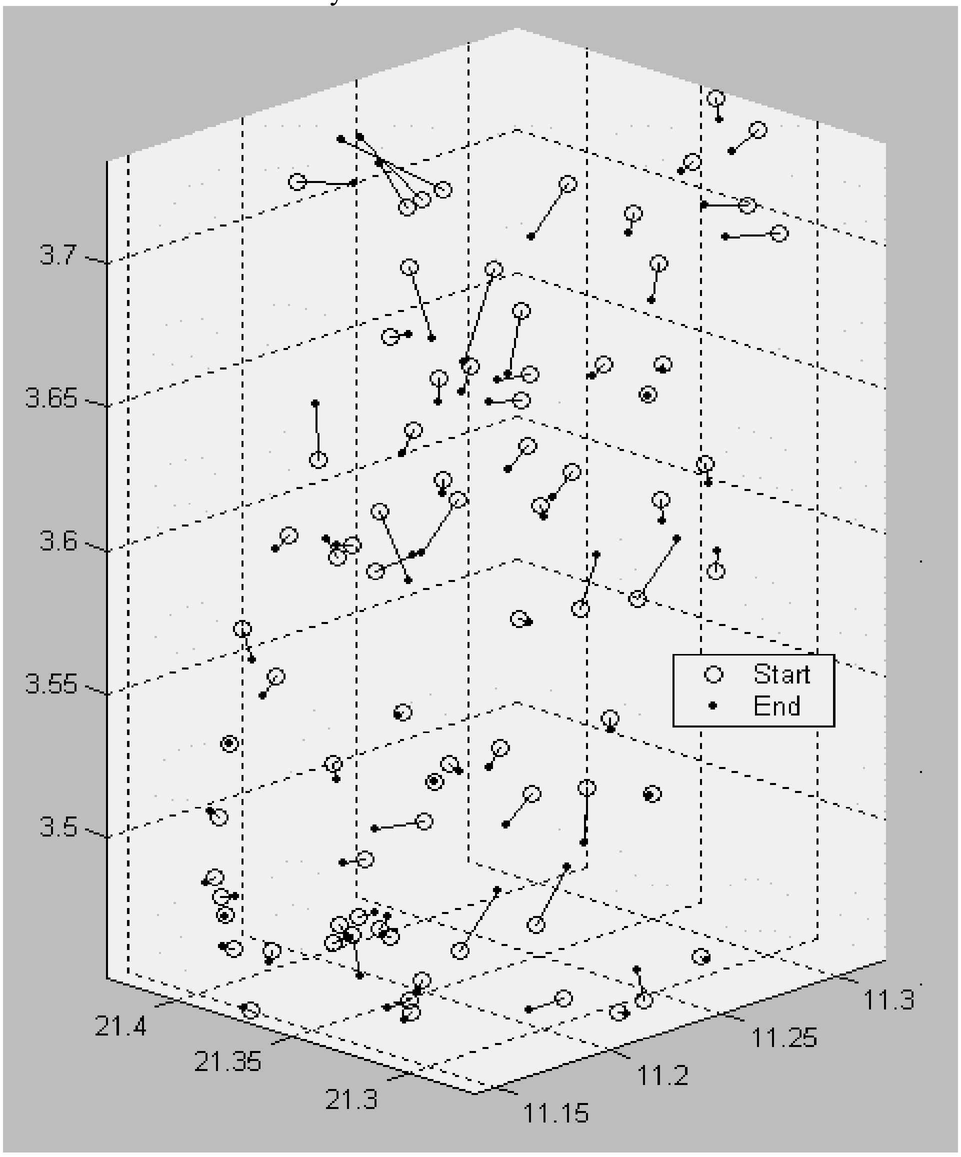

Figure 6. Object coordinates of the start and the end points of the steel fibers.

5 Conclusion

The first experiments conducted by our system reported in the proceeding sections indicate that a low cost photogrammetric system can indeed reliably perform the 3D coordinate extraction in a structural engineering project. The implemented mathematical model in our system makes use of a self-calibration collinearity equation that incorporates calibrating targets. The photogrammetric approach for determining the distribution and direction of the steel fibers demonstrated superiority in terms of speed, ease and accuracy as compared with the traditional cumbersome manual determination of the steel fibers distribution.

The functionality and the user friendly environment of our system are under further development and enhancement. More details about the enhanced version of the system will be reported in due course.

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