3D Coordinate Measurement of Dam by Close Range Photogrammetry

A. Shirkhani, Dr M. Varshosaz
Department of Photogrammetry and Remote Sensing, Faculty of Geodesy and Geomatics Engineering, K.N. Toosi University of Technology, Tehran, Iran
alireza.shirkhani@yahoo.com
varshosazm@kntu.ac.ir

Dr M. Saadatseresht
Center of Excellence for Geomantics Engineering and Disaster Management, Tehran University, Tehran, Iran
msaadat@ut.ac.ir

Abstract:

Recent years have seen an increase in the use of digital close range photogrammetry in various engineering projects. By using high-resolution cameras along with a proper network design, camera calibration and bundle adjustment, measurements of high accuracy can be achieved. In this paper, the application of photogrammetry in 3D coordinate measurements of large dams is studied. For this, spillover an embankment dam (245.7m by 62.8m), named Marun, which is located in south of Iran was considered as the case study. A number of targets were fixed to dam body and imaged using high-resolution (8-mega pixel) digital camera. Various tests were carried out to evaluate the capability of photogrammetry in 3D measurements of the target points. The results indicated that within the experimental configurations a precision of 1.88 mm could be achieved, so this method can indicate deformation above this value. The study however, showed that due to complex and difficult conditions surrounding such dams, it is not always possible to use photogrammetry alone in dam 3D point measurements. Photogrammetry can therefore be used at least in combination with surveying techniques especially when a fast and not necessarily too accurate analysis is required.

Key Words: *Dam, Photogrammetry, 3D Measurement, Deformation analysis*

1. Introduction

The most important problem refers to dam is dam safety, which may have grave incidents such as dam fracture. Therefore, Protection, maintenance and precise measurement are so critical and must do with maximum care in dams. Precise measurement in dams can be dividing in two categories:

- Internal and long-term measurements, to determine the affecting forces on dams
- External measurements in order to monitor and analysis any deformation cause by affecting forces.

Internal measurements can evaluate and determine with geotechnical instrumentations such as Inclinometers, Extensometers, Telemeters and piezometers in any critical points on dam. The external measurement can obtain by involving proper surveying methods. In this paper, we focus our attention on external measurements, in order to use it in deformation measurement of dams. Until now the only procedure, which have been widely involve in dam 3D measurement, is Geodesy method. However, by considering environmental and atmospherically situations in Iran (mountainous, high humidity and temperature in most areas), measurement and data processing are so difficult and time

consuming. On the other hand, no procedure can provide the accuracy (2-3 millimeters) in dams with its large dimensions and other limitations.
By considering photogrammetry advantages such as, non-contact direct measurement, rapidity data capture and processing, on-line and off-line automatic or semi automatic measurement, photogrammetry can be involve in many engineer sciences. As have seen in the pervious researches that have done in dam 3D measurements until now, the photogrammetry has involved in some applications too, such as Kersten (1995), Maas (1997). In this paper, by involving high-resolution camera, we want to know which level of accuracy can achieve. In addition, what useful advantages can photogrammetry have beside Geodesy procedure in 3D coordinate measurement on dams?
So the aim of this research can summarize in evaluation of capability of photogrammetry in 3D measurements on dams. For this reason spillover (245.7 by 62.8 m) of Marun dam (figure 1) has selected as case study, and for accurate measurement a digital high resolution camera “Canon EOS 30D” (pixel size: 6.4 µm) has employed. To reach maximum accuracy, retro-reflective targets including environmental situation, and motorize total station for reading number of targets (control points) were involved. All the computations and processing were done by “Australis” software.

Figure 1: spillover of Marun dam

2. Project procedures

As mentioned above, in this paper we evaluate the capability of photogrammetry in dam measurements due to effective forces such as pressure, stress and strain. For this reason the following procedures must accomplish:

A. Network design: In any photogrammetric project**,** this step is the most important factor in order to reach the given accuracy. Network constraints essential in this projects are maximum camera to object distance, target diameter, number and distribution of image points.

B. Targeting and imaging: Targeting and image accusation is a fundamental process of photogrammetry. To do all the photoframmetric’s orientations and reach the maximum accuracy in automatic target recognition by Australis software, number of targets installed on spillover of dam and some points selected manually from natural objects (central areas of spillover) on it, and several images have been taken from spillover.

C. Target measurement: this part has divided into two distinct sections: 1) ground target coordinate measurement, 2) photogrammetric 3D target measurement.

Furthermore in order to test the precision of results, to find out the optimum procedure in this project, two camera calibration methods (pre-calibration and self calibration) were caparisoned and. at last an estimation between surveying and photogrammetry have been accomplished.
Subsequently in the following sections, all above procedures represent in detail. In order to make assurance of the quality and precision of results, different cases and situation have caparisoned to reach the given accuracy.

3. Network Design

The importance of network design in all photogrammetric applications especially in high precision measurement applications cannot be understated. The network geometry is the most significant factor to reach high precision measurement capability. Thus network design involve with satisfaction of some vision constraints, by concerning the workspace limitations, these constraints can be group as maximum camera to object distance, target diameter, number and distribution of image points. Sequentially these constraints explain in detail:

- **Maximum camera to object distance**

In manners, which camera distance to each object points is greater than this distance, the desirable accuracy cannot provide. Thus, this distance can compute from constrains such as workspace limitation, camera resolution and camera field of view of as follows:

A. Workspace constraint: practically this constraint is the operator allowable imaging distance to object. Usually, with satisfaction of camera field of view, this constraint can be solved (saadatseresht, 2006), unless the workspace being underside of the object size (this project). By using wide angel lenses this problem can be solve, so in this project we use 28-milimeter lens.

B. Camera field of view: practically this constraint is the distance to camera, which covers total space or sections of the object. Therefore, in this constraint, the camera distance must be sufficient; otherwise, object may appear in small portion of image. By equation (1), this distance can compute as follows:

$$D_{Fov}^{\max} = \frac{D_0 Sin(\alpha + \varphi)}{2Sin(\alpha)} = 143.2703(m) \qquad (1)$$

$$\alpha = \tan^{-1}(\frac{0.9d_o}{2f}) = 13.55$$

Here, α is half of camera pyramid vertex angle, φ is the incident angle between camera and longest object diameter, D_o: longest object diameter, d_o :minimum camera frame size and f is focal length of the camera.

C. Camera Resolution: To support image menstruation and reach the desire precision (σ), the resolution of object in the imagery must be sufficient. Practically these constraints assume equal to the maximum target pixels in image. Therefore, maximum distance is a function of focal length, pixel size and target diameter (2).

$$D_{\mathrm{Res}}^{\max} = \frac{fD_t Sin\varphi}{I_{\mathrm{Res}} T_{PoINo}} = 113.666(m) \qquad (2)$$

D_t : target diameter, $T_{Pel/No}$ is minimum target pixels in image and I_{Res} is pixel size of the camera. Concerning the following comments, Maximum camera to object distance cab compute as follow (3):

$$D_{\max} = \min(D_{Fov}^{\max}, D_{work}^{\max}, D_{Res}^{\max}) = 113.666(m) \qquad (3)$$

- **Target Diameter**

Concerning maximum camera to object distance, focal length of camera and this assumption that generally in photogrammetry target diameter is 1/1000 object size, in this project we use targets in 120 mm diameter.

- **Number and distribution of image points**

Although the number of targets within a network has little impact on the precision of object triangulation, so long as there is a sufficient number in each image to support exterior orientation, which is typically by standard bundle adjustment in multiple camera networks. Therefore, number and distribution of image points also significantly influences of precision of recovery of sensor calibration parameters in self-calibration (Atkinson, 2001). Practically total amount of 20-50 targets, which 10-15 targets lay down in each image, is recommend (Fraser, 1984).

4. Target installation and imaging

Due to high humidity and temperature ($50^{\circ c}$) of the environment and sun consecutive radiation, in this project we used 60 circular retro-reflective targets with *PVC* cover resistant to the following limitations. To automatic recognition of targets by Australis Software, all targets glued on black background (25 by 25 centimeter) and glued on spillover (figure2.a). To reach maximum quality of images in low light environment with highest level of target illumination due to imagery time (18-19:30) and the camera imagery distance (80 to 100 meters), all images have taken by combination of 2 flashes synchronize on 1/100 seconds and *F/stop:* 5.6 with lens focus at infinity. Also by camera company recommendation in order to increase image quality and reduce noises in images, camera *ISO* select on 100 and the entire images have taken with minimum compression in *JPEG* mode.

Finally by noticing the following comments (network design and camera configuration) and limitations such as mountainous environment and difficult work space conditions, total 110 images from 22 stations (5 image per station) have taken from both side of the spillover (figure 2.b).

(a) (b)

Figure 2: (a) Targets on spillover, (b) Photogrammetric network design view

5. Target measurement

Before measure target coordinates on spillover in order to introduce to the software as control points to unify both coordinate system and evaluate the accuracy and precision of entire measurement, creating of geodetic network around the spillover to determine any movement between to epoch on geodetic stations, is necessary. Therefore coordinate of some targets (figure 3), were computed by intersection, horizon and vertical angles were observed by motorize total station “Trimble 5602 (2" accuracy) with 5 acceptable couples. For further computations, entire images beside all computed coordinates introduced to Australis software.

Figure 3: Ground control points on spillover

By using co-linearity equations to compute points coordinate besides exterior orientation of camera, interior parameter of camera or calibration parameters such as: principle distance (c), principle point coordinates *(Xp,Yp)*, distortion parameters *(k1,k2,k3,p1,p2)* and affinity parameters *(b1,b2)* were computed as follows (4):

$$x_o - x_p + x_{corr} = -c_x\left(\frac{m_{11}(X_j - Xc_i) + m_{12}(Y_j - Yc_i) + m_{13}(Z_j - Zc_i)}{m_{31}(X_j - Xc_i) + m_{32}(Y_j - Yc_i) + m_{33}(Z_j - Zc_i)}\right)$$

$$y_o - y_p + y_{corr} = -c_y\left(\frac{m_{21}(X_j - Xc_i) + m_{22}(Y_j - Yc_i) + m_{23}(Z_j - Zc_i)}{m_{31}(X_j - Xc_i) + m_{32}(Y_j - Yc_i) + m_{33}(Z_j - Zc_i)}\right) \quad (4)$$

$$x_{corr} = x_{meas} - xp + x.dr / r + p1.(r^2 + 2x^2) + 2.p2.x.y + b1.x + b2.y$$

$$y_{corr} = y_{meas} - yp + y.dr / r + p2.(r^2 + 2y^2) + 2.p1.x.y$$

$$r^2 = x^2 + y^2$$
$$dr = k1.r^3 + k2.r^5 + k3.r^7$$

Camera calibration process can be estimate before inception of project (pre-calibration) or can be compute simultaneously with exterior orientation parameter and unknown coordinates points with bundle adjustment (self-calibration). Whereas used calibration method directly effect on measurements, so it is necessary to determine optimum method. After that, co-linearity equations for entire targets and control points formed and computed by least square method. Output of this section is the photohrammetric’s coordinates of all targets in measured ground coordinate system. Due to importance and necessity of determining optimum calibration method, it is necessary to discuss it in detail:

5.1 Determining the optimum calibration method

Firstly, in order to determine optimum calibration method and assurance of any changes in process, pre-calibration have down before and after imagery. In this procedure we used a testfield (4 by 3 meters) as shown in figure (5-above) and a total of 22 images from 11 stations were taken (figure 5-below).

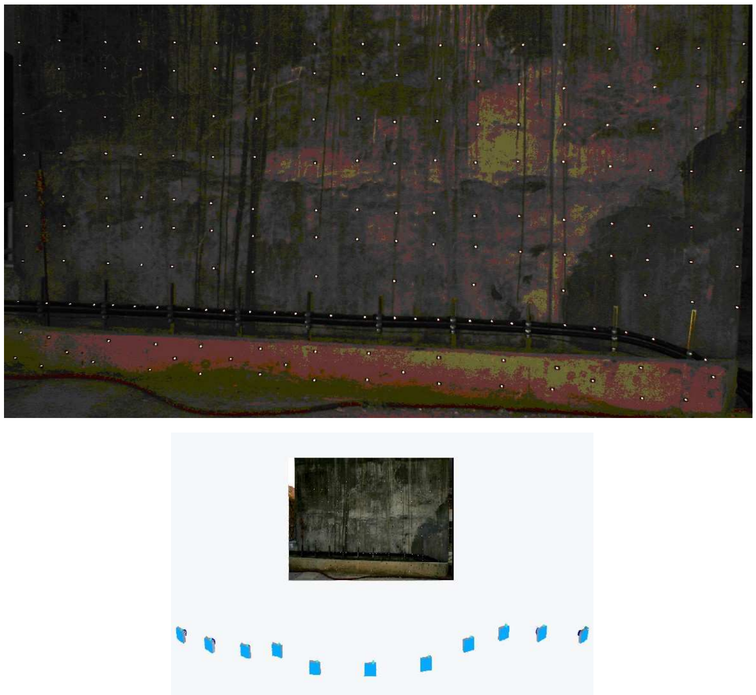

Figure 4: (above): Testfield view, (below): Network design used for pre-calibration imagery)

To reduce any correlation between calibration parameters in each station, imagery with 90-degree camera rotation about optical axis for all images have made. By solving co-linearity equations (4), which have formed for entire testfield points, calibration elements before/after imagery have computed (table 1).

Table 1: Calibration parameters before and after imagery

Calibration parameters (*mm*)	Before imagery (*mm*)	After imagery (*mm*)	difference (*mm*)
c	28.4419	28.4579	-0.016000000
Xp	0.0108	0.0681	-0.057300000
Yp	-0.0917	-0.0414	-0.050300000
K1	1.16E-04	1.15E-04	0.000001205
K2	-2.31E-22	-1.57E-22	0.000000000
K3	-4.38E-20	-2.73E-20	0.000000000
P1	-4.39E-27	-4.29E-27	0.000000000
P2	1.17E-05	8.43E-06	0.000003267
A1	4.42E-28	1.47E-28	0.000000000
A2	3.47E-04	4.18E-04	-0.000070793

Result shows that calibration parameters are so close in both procedures, which approve the stability of the camera. In next procedure (self-calibration), calibration parameters were assumed unknown and beside target point coordinates from spillover imagery, were computed simultaneously.
To evaluate optimum calibration method, by using interior elements of the camera in both pre-calibration and self-calibration, entire target coordinates were computed, *RMSE* of target points are shown in table(2):

Table 2: *RMSE* of target points in pre-calibration and self-calibration

Precision from Adjustment (mm)	σ_x	σ_y	σ_z	*Total (67%)*	*Total (95%)*
Pre-Calibration	0.5908	0.6772	0.2885	0.9438	1.8877
Self-Calibration	0.6283	0.6938	0.3033	0.9839	1.9679

As have seen, *RMSE* in pre-calibration is better than self-calibration, because accuracy of self-calibration based on network geometry, and in this research due to environmental and working limitations, the stability of the network were weak. To test assurance of result in the following procedures, calculated coordinates and measured coordinates were reviewed (table 3).

Table 3: *RMSE* of checkpoints in pre-calibration and self-calibration

Point No	**ΔX (*mm*) (Xphoto –Xground)**		**ΔY (*mm*) (Yphoto –Yground)**		**ΔZ (*mm*) (Zphoto –Zground)**	
	Pre-calibration	**Self-calibration**	**Pre-calibration**	**Self-calibration**	**Pre-calibration**	**Self-calibration**
1	0.189	-0.144	0.357	0.265	-0.003	0.016
4	2.801	2.595	0.803	1.472	0.664	0.648
5	1.413	1.530	1.250	1.146	0.328	0.328
8	0.677	1.375	0.351	1.807	-0.627	-0.961
16	-0.576	-0.052	-0.147	-0.021	0.013	-0.055
17	2.255	5.019	0.345	2.709	0.395	-0.190
23	-3.055	-1.749	-3.017	-2.711	1.453	1.218
25	0.432	0.289	-1.133	-1.612	-0.202	-0.176
27	-0.766	-0.192	0.115	-1.056	-0.591	-0.853
28	-0.463	0.316	1.088	-0.154	-0.208	-0.519
31	0.661	1.017	2.946	1.285	-0.012	-0.022
36	-0.297	-0.167	-1.728	-1.969	0.995	0.992
37	0.115	0.132	-0.916	-0.994	0.040	0.045
39	-1.633	-1.011	1.275	1.676	0.881	0.723
40	-0.106	-0.093	0.571	0.607	0.315	0.306
41	-1.551	-1.276	2.681	2.967	0.231	0.177
42	0.824	0.170	0.168	0.118	-0.004	0.009
RMSE of Checkpoints (pre-calibration) : ***2.3786 (mm)***						
RMSE of Checkpoints' (self-calibration) : ***2.9849 (mm)***						

Result shows that total mean *RMSE* of checkpoints in pre-calibration is 2.3786 mm and this value in self-calibration is 2.9849 mm. Due to table(4), maximum difference between calculated and measured coordinates in pre- calibration in *X,Y,Z* directions are 3.055 mm, 2.80 mm and 1.453 mm and in self-calibrations these values in *X,Y,Z* directions are 5.019 mm, 2.967 mm and 1.218 mm. Therefore, we understand that both accuracy and *RMSE* of checkpoints is better in pre-calibration method.

6. Conclusions

As mentioned before, practically main aim of the research was evaluation the capability of photogranmmetry in 3D measurements of dams due to monitor any deformation caused on it. By noticing, the advantages such as direct measurement of non-contact points on spillover due to safety problems and total time (time of targeting and imagery 4 hour and time of processing about 3 days), besides all environmental and instrumental limitation, this method is good. In this project, we obtain total precision of 1.88 mm, therefore this method can be use to monitor any deformation above this range and it is acceptable due to standard 3D Dam measurement in Iran (2-3 mm). Similarly, in optimum method maximum difference between computed and measured points in X,Y,Z direction are 3.055, 2.80 and 1.453 mm.

Dam construction is one of the most important parameter effects on using this method. On embankment dams because of their characteristics and their surfaces this method cannot be involve. For further studies on embankment dams, this must be mention and design of special targets recommend.

As seen in the project by considering camera to object distance (80-100m), target diameter is so important. By looking in images, it is easy to find out that in edges of the entire images respect to far distance to camera, targets diameter are small and it is better to use targets with diameter 2 times larger than the one computed in network design. The other effective parameter is the instrumental limitation, for example in order to improve the network geometry, by using platforms in front of the spillover, better result can achieve.

Advisedly by comparison two methods involve in the project (pre-calibration & self-calibration) and considering all the difficulties and limitations mentioned above, it is recommend to use pre-calibration beside bundle adjustment in dam 3D measurements in the similar projects.

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Contact Author	:	alireza shirkhani
Email	:	alireza.shirkhani@yahoo.com
Designation	:	Mr
Affilation / Organisation	:	K.N.Toosi University Of Technology
Address	:	Mirdamad Cross,Valiasr St
City	:	Tehran
Country	:	Iran
Zip	:	19967-1543
Telephone	:	+98 21 8878 6212
Fax	:	+98 21 8878 6213
Co-Authors1	:	Alireza Shirkhani[Mr][Department of photogrammetry & Remote sensing, K.N Toosi Unoversity of Technology][alireza.shirkhani@yahoo.com]
Co-Authors2	:	Masoud Varshosaz[Dr][Department of photogrammetry & Remote sensing, K.N Toosi Unoversity of Technology][varshosazm@kntu.ac.ir]
Co-Authors3	:	Mohammad Saadat seresht[Dr][Center of Ecellence for Geomatics Engineeing and Disaster Management, Tehran University][msaadat@ut.ac.ir]