Assessment of Structure with Analytical Digital Close Range Photogrammetry

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ABSTRACT

Photogrammetry is an approach that can determine the size and the shape of objects through analyzing images recorded by a photographic or video camera. This paper studies measuring and evaluating the structure by using analytical close range photogrammetry method since it is characterized by; high precision, low effort and cost, as well as the possibility of measuring and / or assessing inaccessible places. The objective of the present study is to assess the distortion that occur during projects execution in compare with charts and designs and detect the problem by using (DCRP) with high precision to make a decision to keep or stop working. Several methods can be applied in data processing to determine 3D coordinates of object points for two or more images. To evaluate data processing using four commercial software (LPS, PhotoModeler, Photogrammetric MATLAB and AutoCAD Civil 3D). Also to overcome the difficulty of obtaining Ground Control Points (GCPs) that covers the photogrammetric object, a Portable Control System (PCS) had been established. Using a single camera Canon EOS 500D with image size is (4752 x 3168) pixels to capturing images. Two approaches used for 3D assessment of structure (single model and all models). This study depended structure of directorate of engineering projects at the university of technology this structures represented the study area. The results of analysis processes (3D model) will help the researcher to detect the distortion and suggest the proper solution for dissolve and develop it. The precision obtained from this results show high precision. The results are very promising ranges between (0.18 – 1.77) mm.

Key Words: Close range Photogrammetry, Sequential method, Bundle Adjustment, Relative Orientation, Absolute Orientation**,** Ground Control Points

INTRODUCTION

Photogrammetry is an approach that can determine the size and the shape of objects images through analyzing two Dimensional (2D) images, remotly by applying the measuring process directly on. The Photogrammetric approach must be used with a precaution since good results can only be produced from suitable images, so that, some skills are necessary to be taken.

Search includes the use of modern methods for measuring and evaluating the construction works, including analytical close range photogrammetry method since it is characterized by several advantages. First, it is possibility of measuring and /or assessing building elements inaccessible or located in hazardous areas. Second, photogrammetry provides a flexible framework in collecting the necessary data to perform the mapping (the speed of the construction works) can be achieved almost immediately. Third, low effort and cost of

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Photogrammetry in contrast to conventional surveying as well as it used digital cameras to collect the data which does not interfere with the continuous construction operations in field. Finally, Photogrammetry provides several types of digital products such as maps, digital elevation models (DEM), and orthoimages.

Generally, there are four basic steps in the photogrammetric process: (1) calibration of cameras; (2) images capturing; (3) images processing and (4) analysis of results [1].

Process of 3D reconstruction has been applied in several scientific and engineering applications. These applications can be classified as following: Architecture and heritage preservation, Forensics and accident reconstruction, Industrial applications, Medical applications engineering applications. With respect to engineering applications, photogrammetry has been applied in the monitoring and assessment of deformation on structures and facilities. Photogrammetry being applied and explored in several applications of construction engineering including use photogrammetry for more accurate measurement of structure surfaces for shape analysis.

Structural assessment is one of the potentially most interesting new applications of this technique in civil engineering problems. The main purpose of assessment is to ensure that a structure or part of the structure may have incorrect distances, location or deviation comparing with original designs. Assessment of structures is a very important process for getting structures with high quality and also for sustains these structures for longer time, besides that, the assessment used with heritage structures that have historical value. The major subject of this study is imaging 3D reconstruction (photo-textures) on building model using DCRP approach and determining the accuracy assessment of the structural building model based on coordinate evaluation.

Methodology

Figure (1) below represent a flowchart of the methodology used in this research for structure assessment

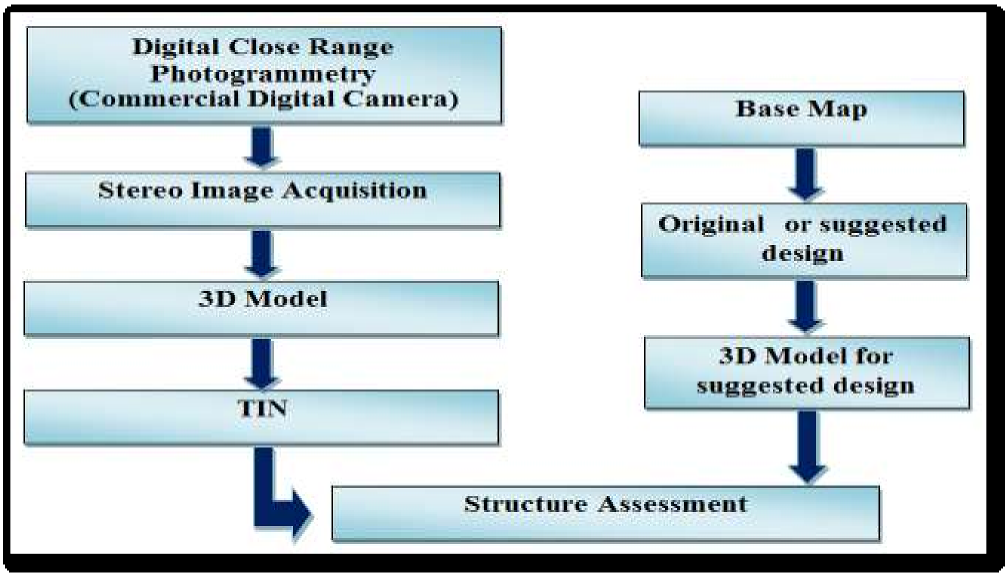

Figure (1): Methodology – Flow Chart

Case Study

Directorate of engineering projects structure is located at the University of Technology, it is executed. These structures represented the study area and were evaluated in regarding to dimensions and deviations. Part of that structure was chose for this study as shown in figure (2). That part was chose in order to provide an adequate area for image capturing. The essential schemes and designs were used for assessment. About 4 image (two models) was captured for this structure, and represented by (354) point with (50mm) focal length. The assessment of that structure will be display in two approach.

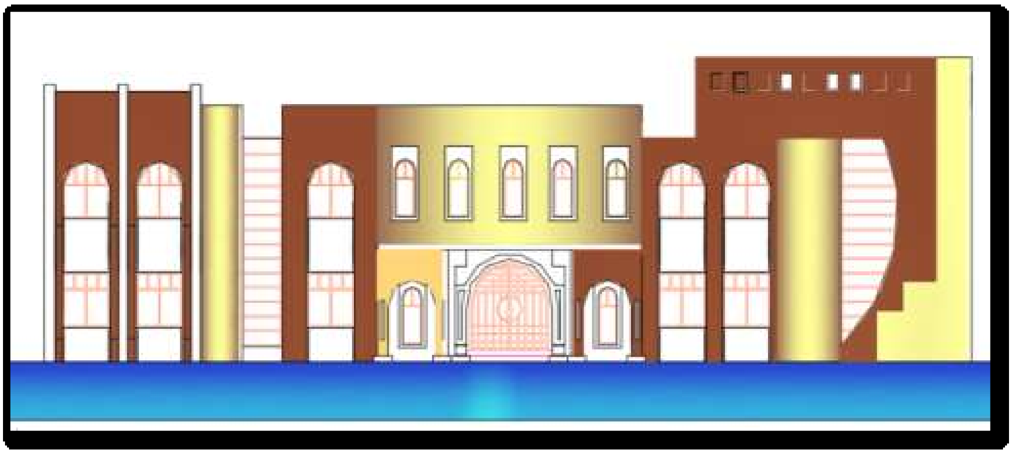

Figure (2): Directorate of Engineering Projects

Portable Control System (PCS)

Establishing a Portable Control System (PCS) to overcome the difficulties of having Ground Control Points in the captured images. By using **(PCS)** which contain ten control points distributed on three axis (X,Y,Z) high accuracy for all calculated variables can get which include (IOPs), (EOPs) and (X,Y,Z). The completed Portable Control System **(PCS)** as shown in figure (3).

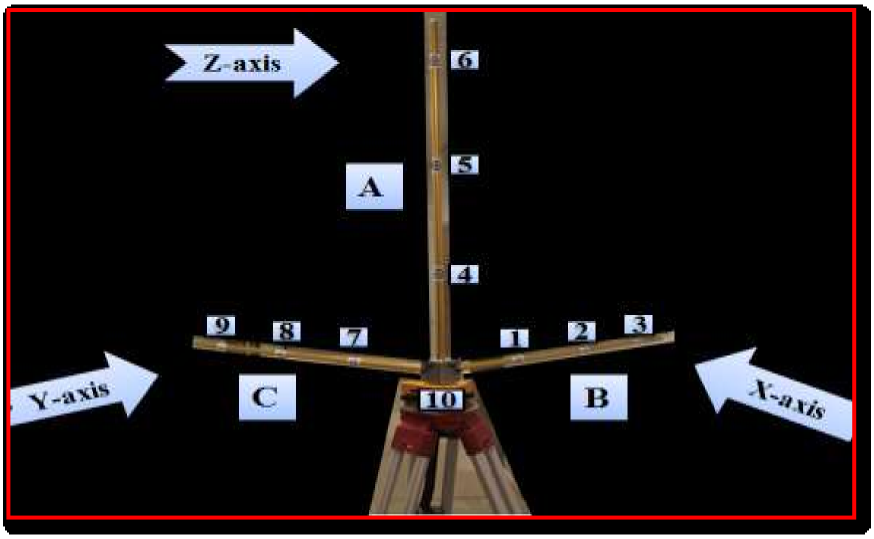

Figure (3): Portable Control System

Assessment of Data Processing (Precision Assessment)

Couple images of the case study structure were used and processing by different software. Different results were obtained as shown in figure (4).

Figure (4) represents the differences between distances measured by different software and reference distance measured by steel tape.

As a result the (PhotoModelar + Photogrammetric Matlab (Resection-Intersection)) Software method was used for getting a results with higher precision.

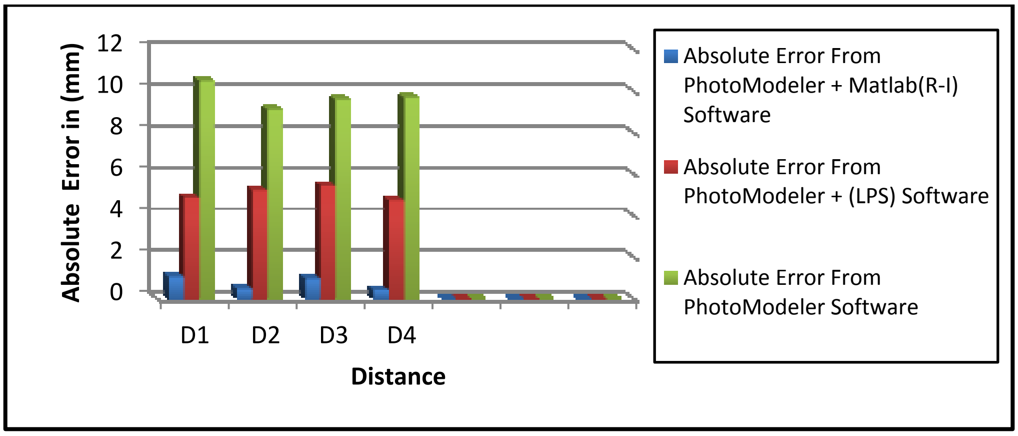

Figure (4): Assessment of Data Processing (Precision Assessment)

3D Photogrammetric Coordinates of the Structure

3D coordinate points for any structure can be get by capturing two or more images. The first step is determining of referencing points (matching process) which can be defined as the process of telling the software that two points marked on two different photographs represent the same physical point in space. The second step is calculation of the exterior orientation parameters (EOPs), and then recalculate all the 3D coordinates of the measurement points. Moreover, the proposed accuracy of photogrammetry can be detected by assessment the three dimensions for the located points.

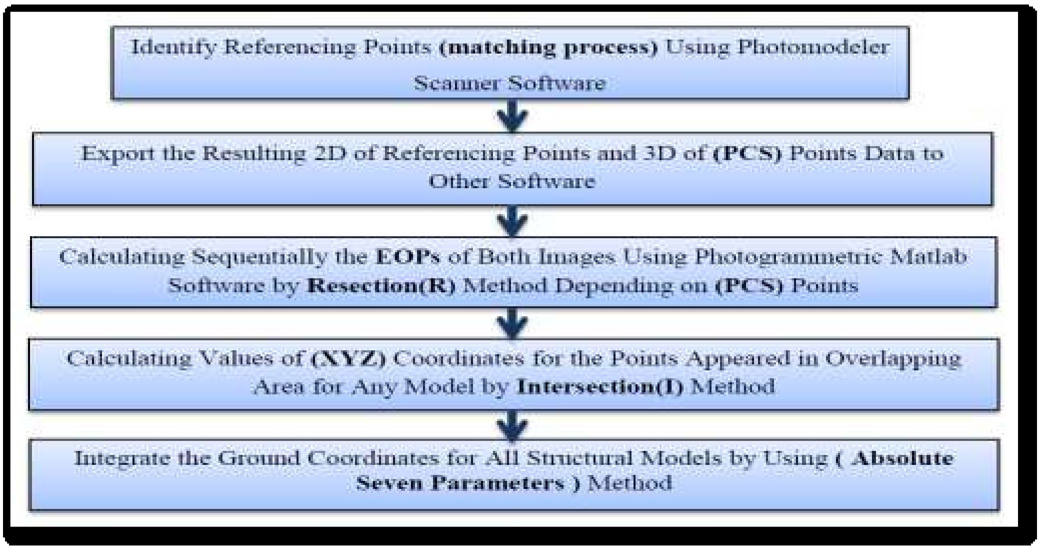

Figure (5): 3D Coordinates of the Structure – Flow Chart

Result Precision

The precision of the result was examined based on the computed distances of the selected shapes according to the following equation by using the 3D coordinates of the object points resulted from the photogrammetric software.

$$D = \sqrt{(\Delta X)^2 + (\Delta Y)^2 + (\Delta Z)^2} \quad \text{..... (1)}$$

Where:

D: is the distance in meter between two points.

ΔX: is the difference in X coordinate between two points.

ΔY: is the difference in Y coordinate between two points.

ΔZ: is the difference in Z coordinate between two points.

The Associated Data

The basic unit of the image coordinates is pixels, and thus a conversion between image pixels and metric units is possible as follows. The transformation from pixel to metric coordinate system is done by using pixel size as illustrated below:

$$x = -\left(x_{image} - x_c\right)s_x \quad \text{........(2)}$$

$$y = -\left(y_{image} - y_c\right)s_y \quad \text{........(3)}$$

Where:-

(x, y) : are the image coordinate expressed in metric units.

(x_{image}, y_{image}) : are an arbitrary image point in pixel units.

(x_c, y_c) : are the principal points in pixel units.

(s_x, s_y) : are the effective pixel size in the horizontal and vertical directions respectively (typically expressed in millimeters).

Mathematical Models

1. **Collinearity Condition**The collinearity condition expresses the basic relationship in which the perspective center (o), the image point (a), and the object point (A), lies on a straight line as illustrated in figure (6).

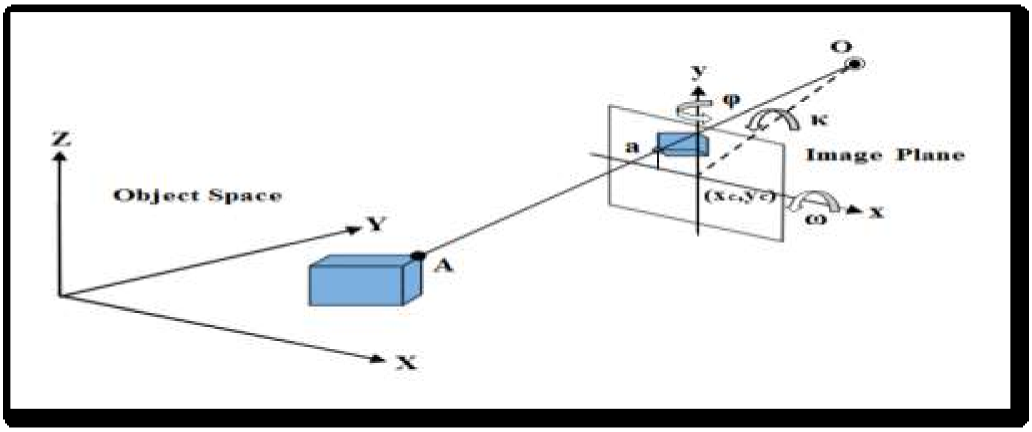

Figure (6): Collinearity Condition [2]

This collinearity equation contains the coordinates of the object**(X,Y,Z)** point furthermore the exterior orientation parameters **(EOPs)** and the interior orientation parameters**(IOPs)**. As noted by Ghosh [3] and Wolf DeWitt and Wilkinson [4] the mathematical model of the collinearity condition is illustrated as below:

$$x - x_c = -f\,\frac{[m_{11}(X-X_O)+m_{12}(Y-Y_O)+m_{13}(Z-Z_O)]}{[m_{31}(X-X_O)+m_{32}(Y-Y_O)+m_{33}(Z-Z_O)]} = -f\,\frac{r}{q}$$

$$y - y_c = -f\,\frac{[m_{21}(X-X_O)+m_{22}(Y-Y_O)+m_{23}(Z-Z_O)]}{[m_{31}(X-X_O)+m_{32}(Y-Y_O)+m_{33}(Z-Z_O)]} = -f\,\frac{s}{q} \quad \ldots (4)$$

Where:

x, y is the image point coordinates.

X, Y, Z is the object point coordinates.

X_O, Y_O, Z_O the coordinates of the exposure station O in the object space system.

f is the camera principle distance.

m is the elements of rotation matrix.

x_c, y_c is the coordinates of the principal points.

2. **Coplanarity Condition**

The camer's interior orientation parameters (IOPs) and exterior orientation parameters (EOPs) at each station should be known before collinearity equation (Eq.11) can be used to compute the ground coordinate points. The interior orientation parameters (IOPs) can be found by camera calibrations. To determine the six exterior orientation parameters (EOPs), for calculating the positional displacement and relative orientation angles between the two camera stations an analytical camera orientation method is proposed. figure (7), computing the orientation and position of the camera station II on right hand side relative to the camera station I on the left hand side [2].

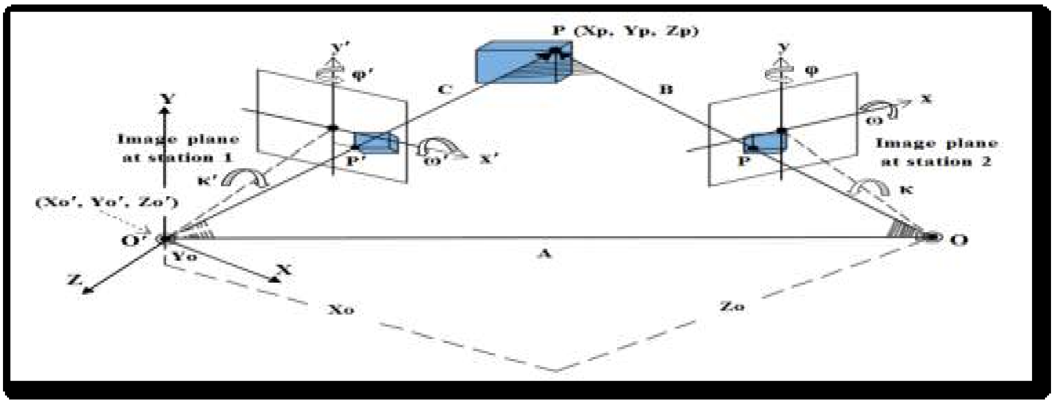

Figure (7): Coplanarity Condition [2]

Mathematically can represented coplanarity equations as follow (Eq. 5) [2].

$$A\,.(B \times C) = \begin{bmatrix} X_o - X_{o\prime} & Y_o - Y_{o\prime} & Z_o - Z_{o\prime} \\ X_p - X_o & Y_p - Y_o & Z_p - Z_o \\ X_p - X_{o\prime} & Y_p - Y_{o\prime} & Z_p - Z_{o\prime} \end{bmatrix} \quad \ldots (5)$$

Assessment Approaches

There are different approaches used for 3D assessment of structure. These approaches are:

1. Single model

This approach can be done by using couple of overlapping images each time, and compute the 3D coordinates for each model independently as showed in figure (8). This approach depending on (PCS) points and Resection-Intersection(R-I) method.

- Using photomodeler software scale input have been applied on portable control system **(PCS)** using any distance between two points (control dimension are known), then the coordinates **(X,Y,Z)** calculated for each point of portable control system (PCS) assumed that the control is accurate then the methods Resection-Intersection(R-I) and the Bundle(BA) used to compute the 3D coordinates of overlapping area. These steps repeated for all models.
- This approach have been applied on this structure as shown in figures (9 and 10).The accuracy that obtained shown in tables from (1 and 2). With (50 mm) focal length.

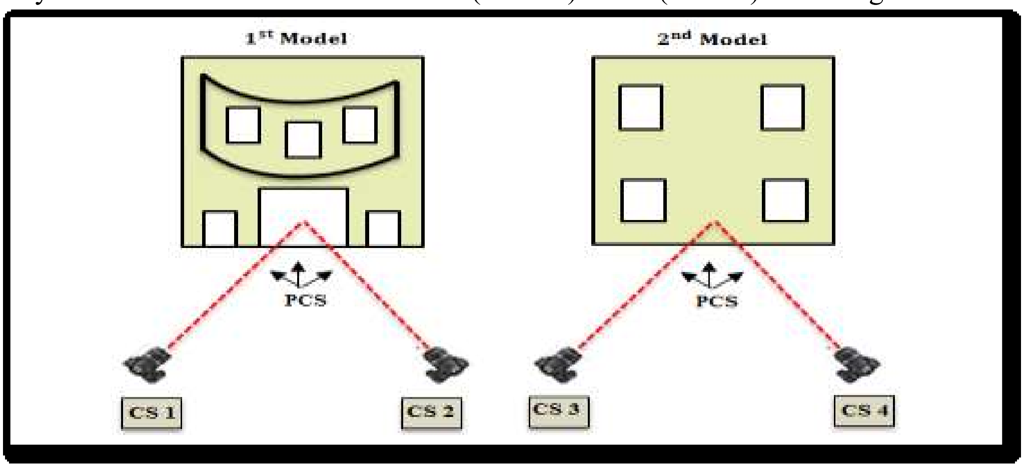

Figure (8): Single Model Plane for Directorate of Engineering Projects

First Model

Left Photo **Right Photo**

Figure (9): The 3D Model (Photo Texture) for First Model

Second Model

Left Photo **Right Photo**

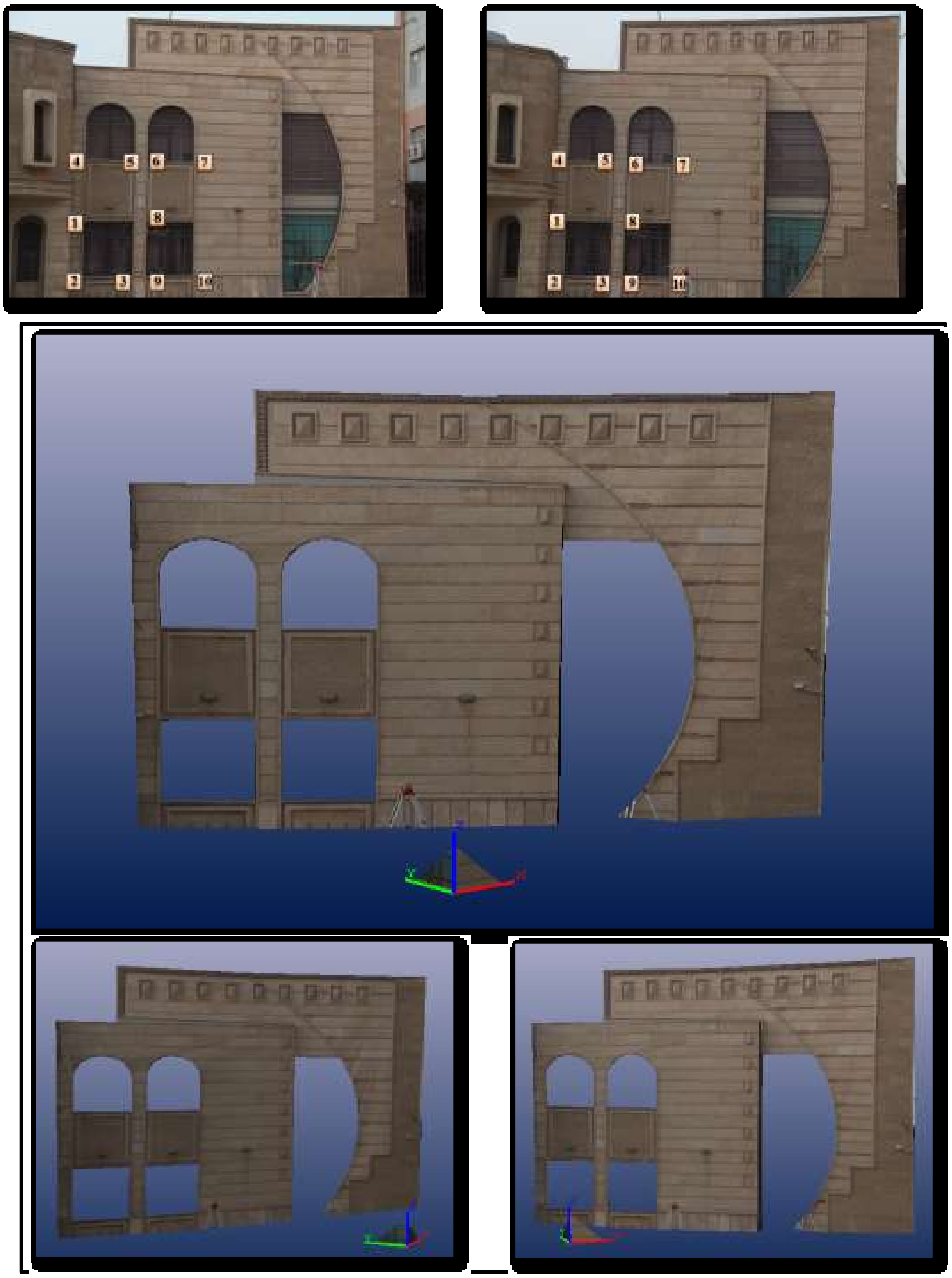

Figure (10): The 3D Model (Photo Texture) for Second Model

2. Structure as a whole (all models)

This approach can be done by using all overlapping images of, and compute the 3D coordinates for all models as a whole as showed in figure (11). This approach depending on (PCS) points, Resection-Intersection(R-I) and (Cop-RA) method.

- Using photomodeler software scale input have been applied on portable control system **(PCS)** using any distance between two points (control dimension are known), then the coordinates **(X,Y,Z)** calculated for each point of portable control system(PCS) assumed that the control is accurate then the methods Resection-Intersection(R-I) and the Bundle(BA) used to compute the 3D coordinates of overlapping area. These steps repeated for all models.
- After calculation of ground coordinates for all structural models, the structural coordinates system will be consolidated as a three model by depending on the following:

1. Choosing one model of all structure models as a reference model. This model located in the middle of all models. And depending on 3D coordinates of the overlapping area with other models, the absolute seven transformation parameters were calculated, depending in which the final ground coordinates **(X,Y,Z)** were computed.
2. scale value that computed from absolute seven parameters method will be adopted for correcting of systematic errors that resulted due to transformation of model points coordinates, because of the fact that the transformation including only rotation and the scale must remain constant because the aim is transforming of the coordinates system of model points coordinates from one system to another which must remain a constant scale. as a result, this goal can be achieved by using the following equations:

$$X = \frac{X}{S} \quad , \quad Y = \frac{Y}{S} \quad , \quad Z = \frac{Z}{S}$$

Which have been evaluated by comparing between distances that computed by sequential **(R-I)** method with distances that computed from calculated 3D coordinated by transformation in both old and new system.

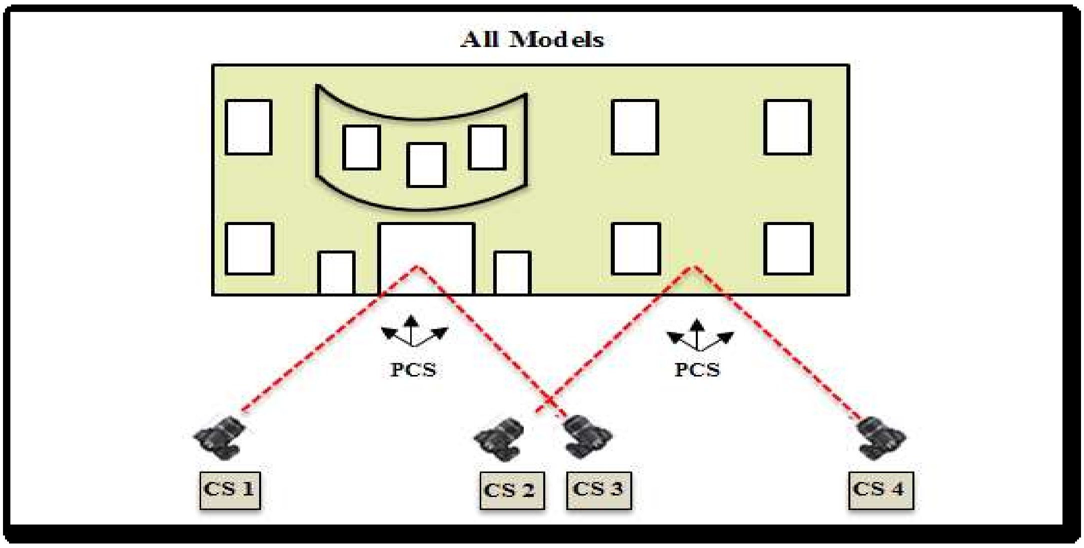

Figure (11): All Models Plane for Directorate of Projects Geometric

All Models (using all photos of Structure)

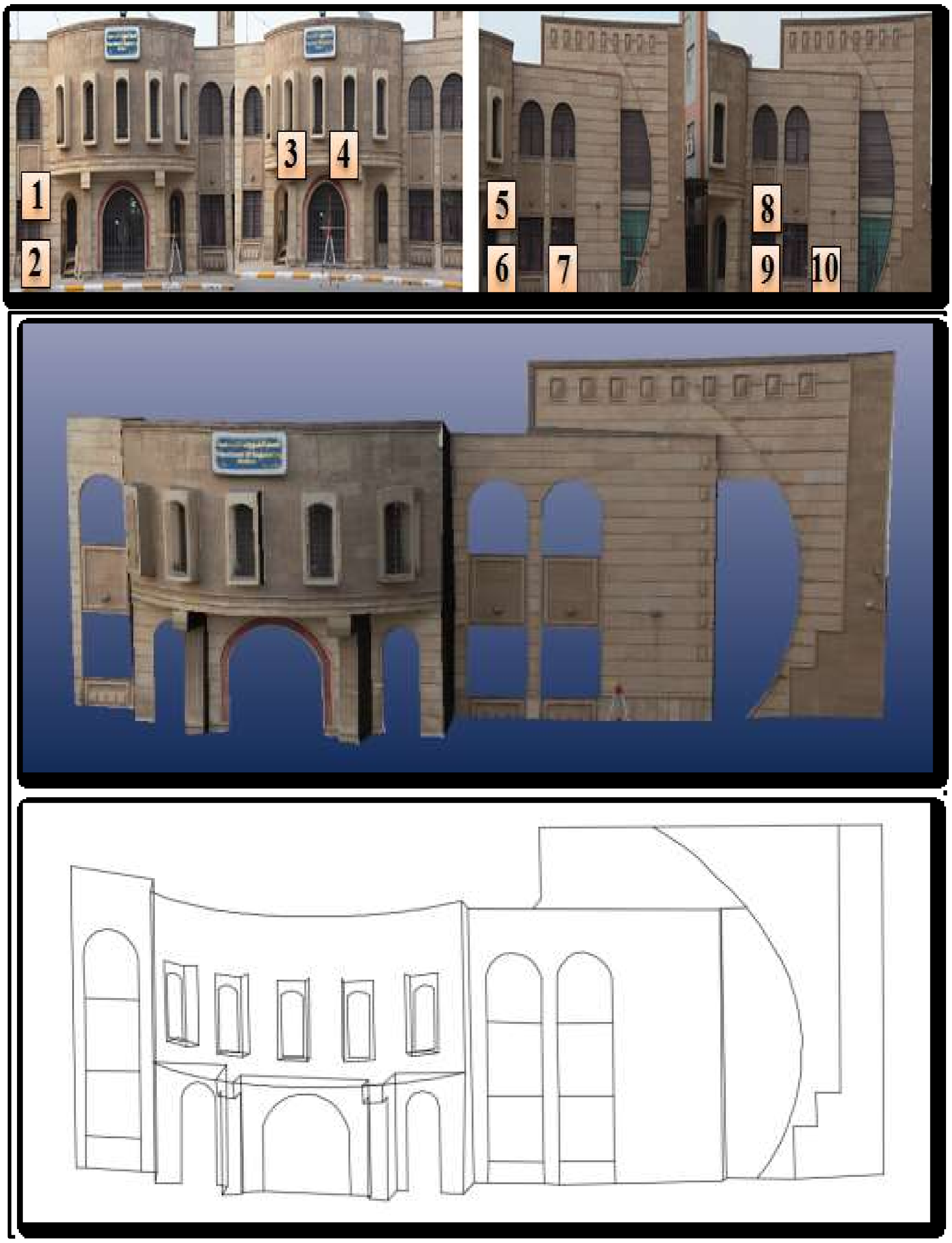

Figure (12): The 3D Model (Photo Texture) for All Models

Results Analysis

This section will focus on processing the previous pair of images by sequential (Resection-Intersection) method, relative and absolute orientation method. The three coordinates of the overlapping area points computed by photogrammetric software with their dimension and absolute error are shown in tables below.

Table (1): 3D Coordinates and Assessment for First Model

Point	Coordinates			Line		Dimension By Steel Tape	Dimension By Photogrammetry	Photogrammetric Absolute Error
	X (m)	Y (m)	Z (m)	From	To	(mm)	(mm)	(mm)
1	101.3062	112.7376	101.2199	1	2	1700	1698.62	1.38
2	101.2630	112.7347	99.5218					
3	102.1091	111.4163	99.5297	2	3	1565	1566.62	1.62
4	102.2024	105.3913	102.6159	4	5	797	797.18	0.18
5	102.7413	104.8039	102.6102					
6	108.1521	103.9650	101.1454	6	7	1701	1699.23	1.77
7	108.0993	103.9050	99.4481					
8	109.1276	102.8175	99.4358	7	8	1497	1496.77	0.23
Root Mean Square Error (mm)								
RMSE X=0.3802				RMSE Y=0.8118			RMSE Z=0.4105	
Total RMSE=0.9860								

Table (2):3D Coordinates and Assessment for Second Model

Point	Coordinates			Line		Dimension By Steel Tape	Dimension By Photogrammetry	Photogrammetric Absolute Error
	X (m)	Y (m)	Z (m)	From	To	(mm)	(mm)	(mm)
1	101.6654	109.5727	101.1559	1	2	1701	1700.16	0.84
2	101.6082	109.5411	99.4569					
3	102.7535	108.5763	99.4601	2	3	1497	1497.48	0.48
4	101.7291	109.5976	103.0985					
5	102.8477	108.5957	103.0707	4	5	1501	1501.97	0.97
6	103.1922	108.3610	103.0629	6	7	1505	1504.74	0.26
7	104.4122	107.4802	103.0455					
8	103.1699	108.3636	101.1592	8	9	1702	1701.08	0.92
9	103.1329	108.3453	99.4586					
10	104.3301	107.4446	99.4499	9	10	1498	1498.27	0.27
Root Mean Square Error (mm)								
RMSE X=0.3749				RMSE Y=0.8023			RMSE Z=0.4000	
Total RMSE=0.9718								

Table (3): 3D Coordinates and Assessment for All Models

Point	Coordinates			Line		Dimension By Steel Tape	Dimension By Photogrammetry	Photogrammetric Absolute Error
	X (m)	Y (m)	Z (m)	From	To	(mm)	(mm)	(mm)
1	101.3062	112.7376	101.2199	1	2	1700	1698.62	1.38
2	101.2630	112.7347	99.5218					
3	102.2024	105.3913	102.6159	3	4	797	797.18	0.18
4	102.7413	104.8039	102.6102					
5	108.4171	104.0747	101.1605	5	6	1701	1700.16	0.84
6	108.3680	104.0409	99.4614					
7	109.3977	102.9538	99.4769	6	7	1497	1497.48	0.48
8	109.7764	102.7044	101.1798	8	9	1702	1701.08	0.92
9	109.7488	102.6817	99.4791					
10	110.8374	101.6522	99.4829	9	10	1498	1498.27	0.27
Root Mean Square Error (mm)								
RMSE X=0.4168				RMSE Y=0.7759			RMSE Z=0.7520	
Total RMSE=1.1582								

From the 3D coordinates resulted from the photogrammetric MATLAB Software the distances of selected shapes have been computed. After computing the distance between the points by using (Eq. 1) compare with the distance measured by steel tape, the accuracy obtained from this results are ranges between (0.18 – 1.77) mm as shown in tables (1,2 and 3), the required accuracy depending on single model and all models also obtained.

Discussions and Conclusions

1. Test results show that a portable control system (PCS) can be used for photogrammetric measurement, and its measurement precision is high enough support the need of close-range photogrammetry.

2. Concerning data processing with (Photomodelar and Photogrammetric Matlab (R-I)) software with the (PCS) are the best in regarding to precision.

3. The chosen camera (cannon EOS 500D) has a high resolution (15 mega pixel) with the zoom (18-200) mm. it is an effective camera in close range photogrammetry.

4. Two approaches used for 3D assessment of structure. These approaches are (single model and all models), and the required precision depending on these approaches is obtained.

5. The results of analysis processes (3D model) will help the researcher to detect the problem and suggest the proper solution for dissolve and develop it.

6. High accuracy obtained from this study (using 3D coordinates resulted from the normal close range photogrammetry and photogrammetry software), this accuracy is very promising ranging from (0.18 – 1.77) mm.

REFRENCES

[1].MUSTAFFAR, M. et al. (2012) The Measurement Of Full Scale Structural Beam-Column Connection Deformation Using Digital Close Range Photogrammetry Technique. Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Malaysia.

[2].DAI, F. (2009) Applied Photogrammetry for 3D Modeling, Quantity Surveying and Augmented Reality in Construction. PhD. thesis. Hung Hom, Kowloon, Hong Kong: The Hong Kong Polytechnic University. [Online] Available from: http://www.lib.polyu.edu.hk.

[3].AL-HASOON, A. S. F. (2015) “Accuracy Assessment Of Data Processing In Analytical Digital Photogrammetry Using Relative & Absolute Orientation Mathematical Mode”. M.Sc. thesis. Geomatics Engineering, Building and Construction Engineering Department, University Of Technology, Iraq.

[4].ERDAS, Inc. (2009). ERDAS IMAGINE Version ٢٠١٣ Leica Photogrammetry Suite Project Manager. User’s Guide, USA.

[5].GHOSH, K. S. (2005) Fundamentals of Computational Photogrammetry. [online] New Delhi India: Ashok Kumar Mittal. Available from: http://books.google.iq/books.

[6].PHOTOMODELER. (20١٣) PhotoModeler Quick Start Guide. Available from: http:// www.photomodeler.com.

[7].WOLF, R. P., DEWITT, **A.** B. AND **WILKINSON, E. B.** (2000) Elements of Photogrammetry. McGraw- Hill, New York, 3rd edition