Assessment of the Three-Dimensional Model Produced by Photogrammetric and Geodetic Surveying Techniques

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Abstract. A combination of close-range photogrammetry techniques and geodetic surveying techniques are used to produce the three-dimensional model, which is one of the major tasks in the field of surveying at present because it is used in many engineering applications, industrial, medical and in cultural heritage objects which requires regular monitoring because of the high accuracy and reliability needed to conduct the measurements. The study area was in the university of Baghdad, specifically for the building of the university tower this research has been produced the three dimensional model of the tower depending on the overlapping ground images captured by a digital camera and the total station instrument used to measure the coordinates of ground points distributed on the university of Baghdad tower. The mathematical model used in this study is the direct linear transformation method to intensify ground points which are used to produce the three-dimensional model of the university tower. Also, a photogrammetric program is used to compute the object space coordinates from the point cloud three-dimensional modeling.

Keywords: Close range photogrammetry; geodetic surveying; DLT; MATLAB; Agisoft program-3D.

1. Introduction
Digital close-range photogrammetry is a branch of photogrammetry which has been widely used for non-topographic applications in industrial and engineering areas with the digital technology and corresponding algorithms [1]. The term of close-range photogrammetry is defined as the art, science, and technology of extracting information of an object’s geometry and position from photographic images, this information may be used to recreate an accurate representation of an object in three-dimensional space, alternatively, it may be used to measure the change of an object position or shape [2]. This technique is used when an object to camera distance is not more than 300 meters as a maximum and a fraction of millimeters as a minimum. these limitations are assumed to distinguish between terrestrial, and close-range photogrammetry [3].

The close-range photogrammetry has a wide range of use and its applications are in many disciplines, such applications are different in terms of its importance some need high measurement accuracy and others don’t, the accuracy of these applications is a function of the elements of the photogrammetric system. these elements are the camera used, the accuracy achieved by any camera is a function of the principal distance, the format size, the error of image points, and the resolution of the image, the layout of the two camera stations, the layout of the two camera stations relative to the object is a function of the external orientation parameters. These parameters determine the distribution, transformation, and magnification of the image error to the corresponding object points [4]. The techniques of three-dimensional (3D) modeling have been advancing over the past few years. One of the main tasks of photogrammetry is to find the precise 3D coordinates of an object, these coordinates must be obtained...
from a stereo pair images. Features in the image can be observed and 3D coordinates are determined in a given coordinates system, under a mathematical model Direct Linear Transformation (DLT) [5].

2. Digital Close Range
Close range Photogrammetry is one of the most important subjects in geomantic engineering, according to the development in 3D modeling from a digital image, for engineering applications, which needs high resolution, many programmers have appeared which process the digital images [6].

3. Mathematical Models
The used mathematical model is the direct linear transformation (DLT) model which rely on means direct transformation from comparator coordinates of image points to object space coordinate [7]. This concept is particularly useful for imaging with non-metric cameras that have one in x image coordinate and the other in y image coordinate. The standard (DLT) equations are:

\[
\begin{align*}
x &= \frac{L_1X + L_2Y + L_3Z + L_4}{L_9X + L_{10}Y + L_{11}Z + 1} \\
y &= \frac{L_5X + L_6Y + L_7Z + L_8}{L_9X + L_{10}Y + L_{11}Z + 1}
\end{align*}
\]

Where \(x\) and \(y\) are the measured coordinates of an image point. Fiducial marks in the focal length to define the axes of the photo coordinate system.[8]. The minimum number of points required to solve these equations using the least-squares method is six points. Each point provides two equations \(X, Y, Z\):

In matrix form

\[
\begin{bmatrix}
X_1 \\
Y_1 \\
Z_1 \\
0 \\
0 \\
X_2 \\
Y_2 \\
Z_2 \\
0 \\
0
\end{bmatrix}
= \begin{bmatrix}
-x_1X_1 \\
-x_1Y_1 \\
-x_1Z_1 \\
-x_1Y_1 \\
-x_1Z_1 \\
-x_1Z_1 \\
X_1 \\
Y_1 \\
Z_1 \\
0 \\
0
\end{bmatrix}
\begin{bmatrix}
L_1 \\
L_2 \\
\vdots \\
L_11
\end{bmatrix}
\]

\[
B.X = f
\]

Where \(X\) is the vector of (DLT) parameters. (DLT) parameters can be obtained by using the principle of least squares method, we should consider solving the normal equation that can be derived from the observation, which can be expressed as [9]. The normal equation of the previous observation equation can be written as follows:

\[
(BB^T)X = (B^T)f
\]

By multiplying both sides of Eq. (7) by by \((B^T)\) and reducing we obtain:

\[
X = (BB^T)^{-1}B^Tf
\]

After computing the DLT coefficients for all images, the ground coordinate of any object point is computed. The formulas for computing object space coordinate from (DLT) coefficients is as follows [10]:

\[
(L_1 - xL_9)X + (L_2 - xL_{10})Y + (L_3 - xL_{11})Z = x - L_4
\]

\[
(L_5 - yL_9)X + (L_6 - yL_{10})Y + (L_7 - yL_{11})Z = y - L_8
\]

If the solution is done by using Matrix (which mean measuring the ground coordinates for one point in two photos) the equations will be as the following:
\[
\begin{bmatrix}
L_1^{(1)} - xL_9^{(1)} & L_2^{(1)} - xL_{10}^{(1)} & L_3^{(1)} - xL_{11}^{(1)} \\
L_5^{(1)} - yL_9^{(1)} & L_6^{(1)} - yL_{10}^{(1)} & L_7^{(1)} - yL_{11}^{(1)} \\
L_1^{(2)} - xL_9^{(2)} & L_2^{(2)} - xL_{10}^{(2)} & L_3^{(2)} - xL_{11}^{(2)} \\
L_5^{(2)} - yL_9^{(2)} & L_6^{(2)} - yL_{10}^{(2)} & L_7^{(2)} - yL_{11}^{(2)}
\end{bmatrix}
= \begin{bmatrix}
x^{(1)} - L_4^{(1)} \\
y^{(1)} - L_8^{(1)} \\
x^{(2)} - L_4^{(2)} \\
y^{(2)} - L_8^{(2)}
\end{bmatrix}
\]  

(11)

4. The Agisoft Program

Agisoft PhotoScan is a stand-alone software product that performs photogrammetric processing of digital images and generates 3D spatial data [6]. After opening the digital photos in (Agisoft) control points are selected and their ground coordinate are interred, then the processes of creating the 3D model is extracted, the processing of aligning photos are done to calculate exposure stations.

5. Experimental work

This research aims to compute the 3D coordinates the are used to produce three models according to the following steps:

1) Selecting a baseline with a length of 10 m.
2) Measuring the local 3D coordinates of 178 control points and checkpoints on the University of Baghdad tower, total station instruments are used to fix the coordinates of the control points and baselines with millimeter accuracy in a predesigned network [11].
3) Using Nikon D5200 camera to take a stereo pair for the tower with an overlap equal to 100%.
4) Measuring the digital photo coordinates to compute DLT parameters.
5) Using DLT program (MATLAB language) to intensify points, 250 points have been intensified points that are inaccessible.
6) The property of symmetric in the shape of Baghdad university tower has been used to compute the coordinates of the other side and then get a 3D drawing of the tower.
7) The 3D design has been produced by using AutoCAD, QT Modeler programs, and Agisoft program.
8) The control points were precisely measured by using Topcon total station ES 105. A baseline of ten meters has been chosen with two end stations A and B. The 3D coordinates of station A assumed locally to be (5000, 5000, 40) meter, then the total station has been mounted on A and backsight on B, the 3D coordinates of the control points have been measured directly by the total station. The control points and checkpoints have been distributed on the tower same of these points are shown in Fig. 1.
To establish the DLT, at least six control points are required. If more than six points are used, so that and improved solution can be arrived at by using least square. In this research 23 points are used to compute DLT parameter the measured ground coordinates of these points are listed in Table 1.

Table 1. The measured object coordinates of the control points

| Point | Northing | Easting | Elevation | Point | Northing | Easting | Elevation |
|-------|----------|---------|-----------|-------|----------|---------|-----------|
| Occ   | 500.0000 | 500.0000| 40.0000   | 127   | 513.6983 | 598.8347| 35.1839   |
| B.S   | 508.6860 | 499.9978| 39.9550   | 131   | 512.9127 | 598.5543| 35.1790   |
| 63    | 538.4229 | 595.4597| 35.1676   | 60    | 512.5939 | 599.2462| 35.1811   |
| 67    | 537.6394 | 595.1849| 35.1799   | 72    | 511.5658 | 604.4550| 35.1982   |
| 68    | 537.3381 | 595.9473| 35.1938   | 84    | 510.7608 | 604.1059| 35.1823   |
| 69    | 532.2048 | 593.0862| 35.1875   | 96    | 510.4714 | 604.9048| 35.1902   |
| 73    | 531.4138 | 592.7802| 35.1900   | 108   | 509.4389 | 610.0368 | 35.1944   |
| 74    | 531.1309 | 593.6083| 35.2160   | 103   | 508.6574 | 609.7711| 35.1878   |
| 75    | 524.2462 | 590.0477| 35.1813   | 63    | 508.3522 | 610.5832| 35.1718   |
| 51    | 523.4825 | 589.7672| 35.1773   | 67    | 538.3408 | 595.3009| 43.0456   |
| 52    | 523.1548 | 590.5008| 35.1870   | 68    | 537.6541 | 595.2289| 43.0604   |
| 57    | 517.9772 | 587.6124| 35.1812   | 69    | 537.3600 | 596.0064| 43.0612   |
| 58    | 517.1893 | 587.3590| 35.1902   | 73    | 532.1634 | 593.0882| 43.0527   |
| 147   | 516.8882 | 58.1155 | 35.1881   | 74    | 531.4112 | 592.8137| 43.0620   |
| 175   | 515.8454 | 593.2299| 35.1866   | 75    | 531.1327 | 593.5400| 43.0467   |
| 93    | 515.0512 | 592.9373| 35.1752   | 51    | 524.2568 | 590.1744| 43.0721   |
| 117   | 514.7514 | 593.7130| 35.1773   | 51    | 524.2568 | 590.1744| 43.0721   |

23 control points distributed on the University of Baghdad tower are chosen for computing the (11 DLT) parameters. The photo coordinates were measured in the stereopair which is illustrated in figure (1). The results of image measurements have been listed in Table (2).
Table 2. The measured photo coordinates of the control points.

| Point No. | Left image | Right image |
|-----------|------------|-------------|
|           | $x_1$ (mm) | $y_1$ (mm)  | $x_2$ (mm) | $y_2$ (mm) |
| 63        | 166        | 321.9       | 167.3      | 328.7      |
| 67        | 112.6      | 310.5       | 118.2      | 318.7      |
| 68        | 135.5      | 309.2       | 139.1      | 316.8      |
| 69        | 166.3      | 307.3       | 167.4      | 314.2      |
| 73        | 113.4      | 297.1       | 118.7      | 305.6      |
| 74        | 136.1      | 295.4       | 139.4      | 303.1      |
| 75        | 166.6      | 292.8       | 167.6      | 299.8      |
| 51        | 165.3      | 352.3       | 167.1      | 358.8      |
| 52        | 193.1      | 352.3       | 193.1      | 358.2      |
| 57        | 165.6      | 337         | 167.2      | 343.5      |
| 58        | 193.2      | 336.3       | 192.9      | 342.3      |
| 147       | 170.3      | 131.7       | 168.7      | 140.9      |
| 175       | 143.6      | 104.4       | 143.8      | 115.8      |
| 93        | 167.6      | 242.2       | 167.7      | 249.7      |
| 117       | 168.9      | 190.4       | 168.2      | 198.8      |
| 127       | 120.4      | 178.9       | 123.6      | 189.9      |
| 131       | 200.7      | 160.2       | 197.8      | 167.2      |
| 60        | 242.9      | 342.8       | 251.5      | 347.6      |
| 72        | 242.3      | 318.1       | 250.3      | 322.7      |
| 84        | 241.7      | 294         | 249.1      | 298.5      |
| 96        | 241        | 263.3       | 247.7      | 267.5      |
| 108       | 240.3      | 240.8       | 246.5      | 244.9      |
| 163       | 238.3      | 150.2       | 242.7      | 154.4      |

The DLT Eqs. (1) and (2) were applied to compute the 11 DLT parameters and this process has been done by preparing a program in Matlab language as in Fig. 2. Matlab can be used for math computations, modeling and simulations, data analysis and processing, visualization and graphics, and algorithms development [12]. The results of the Matlab program are listed in Table 3.

Table 3. DLT parameters of the left and right photos.

| Par. | Left photo | Right photo | Par. | Left photo | Right photo |
|------|------------|-------------|------|------------|-------------|
| $L_1$ | -0.40018   | -0.43797    | $L_7$ | 0.55700    | 0.51761     |
| $L_2$ | 0.65625    | 0.58083     | $L_8$ | 328.66370  | 341.26267   |
| $L_3$ | -0.09993   | -0.08759    | $L_9$ | -0.00168   | -0.0015     |
| $L_4$ | -129.80528 | -67.63666   | $L_{10}$ | -0.00026 | -0.00039 |
| $L_5$ | -0.61599   | -0.57830    | $L_{11}$ | -0.00050 | -0.00049 |
| $L_6$ | -0.08596   | -0.14603    |      |            |             |
The three-dimensional coordinates of any point appear in overlapped photos can be computed by using equation (11) after computing the 11 DLT parameters of and the photo coordinates in a stereopair. 23 checkpoints were selected to validate the resulted accuracy of the 3D coordinates by determining the Root Mean Square Error (RMSE) which was found to be about RMSE = 2.2 cm as shown in Table 4.

Table 4. The coordinates of checkpoints and their RMSE.

| Point No. | X (m)   | Y (m)   | Z (m)   | ΔX (m) | ΔY (m) | ΔZ (m) |
|-----------|---------|---------|---------|--------|--------|--------|
| 63        | 588.620 | 524.357 | 50.328  | 0.091  | -0.027 | 0.025  |
| 67        | 594.238 | 538.601 | 53.646  | -0.955 | -0.050 | -0.012 |
| 68        | 591.872 | 532.284 | 53.625  | -0.119 | 0.032  | 0.009  |
| 69        | 588.683 | 524.374 | 53.585  | 0.034  | -0.046 | 0.050  |
| 73        | 594.076 | 538.551 | 56.897  | 0.076  | -0.010 | 0.025  |
| 74        | 591.701 | 532.551 | 56.883  | 0.055  | 0.070  | 0.034  |
| 75        | 588.955 | 524.431 | 56.934  | -0.271 | -0.104 | -0.011 |
| 51        | 588.685 | 524.374 | 43.787  | 0.017  | -0.040 | -0.057 |
| 52        | 586.383 | 518.041 | 43.801  | -0.075 | 0.040  | -0.054 |
| 57        | 588.773 | 524.398 | 47.068  | -0.068 | 0.055  | -0.017 |
| 58        | 586.252 | 518.017 | 47.079  | 0.055  | 0.069  | -0.021 |
| 147       | 588.786 | 524.365 | 98.723  | -0.031 | -0.037 | -0.073 |
| 175       | 591.989 | 532.573 | 110.016 | -0.075 | 0.082  | 0.026  |
| 93        | 588.712 | 524.414 | 68.945  | 0.011  | -0.066 | 0.007  |
| 117       | 588.721 | 524.378 | 82.232  | 0.016  | -0.038 | -0.068 |

Figure 2. Flow chart of the computation of DLT parameter.
After applying the DLT equations, the 3D coordinates of the intensified points are computed and then these coordinates could be used to produce the 3D model of the Baghdad University tower this model is produced in this research by using two programs Auto CAD and QT modeler this drawing could be illustrated in Fig. 3.

| 127   | 594.206 | 538.624 | 88.837 | -0.039 | -0.101 | -0.074 |
|-------|---------|---------|--------|--------|--------|--------|
| 131   | 586.688 | 516.367 | 88.870 | -0.056 | -0.022 | -0.108 |
| 60    | 610.747 | 507.304 | 47.109 | -0.163 | -0.098 | -0.062 |
| 72    | 610.634 | 507.259 | 53.611 | -0.054 | -0.044 | 0.0005 |
| 84    | 610.458 | 507.219 | 60.145 | 0.101  | -0.001 | 0.050  |
| 96    | 610.464 | 507.143 | 68.858 | 0.090  | 0.055  | 0.071  |
| 108   | 610.505 | 507.138 | 75.5002| 0.053  | 0.055  | 0.038  |
| 163   | 610.410 | 506.855 | 105.077| -0.035 | 0.033  | -0.064 |

RMSE ±0.025 ±0.024 ±0.019

Total RMSE ±0.022

After aligning the camera photos point cloud is built to calculate 3D coordinates of the model university of Baghdad tower, then points cloud mesh will create the 3D structure of the model and filtering is required to remove all unneeded noise for university of Baghdad tower, finally, the texture is made as shown in Figs. 4a and 4b.

Figure 3. (a) 3D model for the University tower by using (QT Modeler) (b) 3D Model by using (Auto CAD).

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6. Conclusion

From the results obtained in this research, we concluded that the presented technique of DLT gives good accuracy which is suitable for many engineering applications, like architectural engineering and industrial engineering. The DLT could be used to recreate the 3D model of an object which is one of the important applications in close-range photogrammetry especially when the objects are inaccessible. The presented technique in this research can save time and effort because of the use of DLT equation which was easier than the other mathematical model in programming, the use of laser total station (without reflector), and digital camera. The other adopted techniques are represented by computing the 3D coordinates obtained from the Agisoft program is gave a centimetric accuracy of the point cloud in the 3D modeling of the tower but this photogrammetric technique is needed a high specification computer because there are millions of points of the point cloud in the 3D modeling.

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