Analysis of Object Depth Effects on Accuracy of Dimensional Shape in X and Y Directions Using Single Non-metric Image

Tarek M.A. ZHU Qing

Abstract In general, to reconstruct the accurate shape of buildings, we need at least one stereomodel (two photographs) for each building. In most cases, however, only a single non-metric photograph is available, which is usually obtained either by an amateur, such as a tourist, or from a newspaper or a post card. To evaluate the validity of 3D reconstruction from a single non-metric image, this study analyzes the effects of object depth on the accuracy of dimensional shape in X and Y directions using a single non-metric image by means of simulation technique, as this was considered to be, in most cases, a main source of data acquisition in recording and documenting buildings.

Keywords single; non-metric image; reconstruction; object depth; accuracy; dimensional shape

CLC number P237.4; TP753

Introduction

Surveying is taking measurements to determine the relative positions of various points on the surface of the Earth. It is the art of measuring slopes and horizontal and vertical distances between objects as well as measuring angles between lines, determining the directions of lines, and establishing point locations by performed angular and linear measurements. Distances, direction, locations, elevations, and volumes are thus determined from the data of the survey. Also, much of the information of the survey is portrayed graphically, either by the construction of maps, profiles, and diagrams on map sheets or by viewing a video screen using digitized data stored in electronic computer. The development of these sophisticated data acquisition and processing systems, the duties of surveyor, have expanded beyond the traditional fieldwork tasks of taking the measurements and the office work of computing and drawing.

The discipline of photogrammetry involves obtaining information about an object indirectly, i.e., by measuring photos taken of the object. Unlike surveying procedures, the measurements are usually made directly on the object in the field. In photogrammetry the object is first recorded on an intermediate medium, such as photographs and images, and the measurements are carried out later in the office. Photogrammetry is a generally accepted technique for the collection of the three-dimensional (3D) representations of the environment. For this reason, this technique has also been extensively used to produce high quality 3D models of different building for documentation.

Received on September 11, 2007.

Tarek M.A., State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan 430079, China; Faculty of Engineering, Al-Azhar University, Cairo, Egypt.
Nowadays 3D scanners are also becoming a standard source for input data in many applications and 3D modeling of an object can be seen as the complete process that starts from data acquisition and ends with a 3D virtual model that is visually interactive on a computer.

But in some cases, what can we do if there is a damage in the construction and only a single non-metric photograph is available, which is usually obtained either from an amateur photographer (such as a tourist) or from a newspaper or a post card. The validity of the 3D reconstruction from single non-metric image should therefore be validated. This study analyses effects of the object depth effects on the accuracy of the dimensional shape in $x$ and $y$ directions using a single non-metric image by means of simulation technique.

## 1 Experiment design

A simulation technique was used where the object coordinates of a model were assumed (see Fig.1). Forty-eight targets of dimensions ($5 \times 5$ cm) were fixed at the points of the intersection of eight horizontal rows ($A$ to $H$) and six columns (1 to 6) which were perpendicular to the rows. The inclined space distance between each row was chosen to be 6 cm and between each column was 10 cm.

Three control points were chosen C.P.1, C.P.2 and C.P.3 as shown in Fig.1 where point C.P.2 was chosen as the origin of the coordinate system. The $X$-axis passed through point (C.P.1) and it was parallel to the rows of the model. The $Y$-axis passed through point (C.P.3) and it was perpendicular to the $X$-axis (i.e. $Y$-axis was precisely vertical). The $Z$-axis is perpendicular to the plane containing $X$ and $Y$-axes. The model was set on a plane table, but was adjusted at the same to be accurately horizontal.

The spatial coordinates of the origin of the simulation model (point C.P.2) was assumed to be (10, 20, 30 m) in the directions $X$, $Y$ and $Z$. Accordingly, the spatial coordinates of the forty-eight targets were calculated and tabulated in Table 1.

### 2 Experimental data acquisition

Ten single non-metric photographs were taken from the same exposure station by using a non-metric camera Yashka (EZS-70). The best five photographs were chosen and used in our study. The Kodak film’s speed is 100 A.S.A. (American Standard Association); film speed describes a film’s sensitivity threshold to light. The focal length ($f$) is 50 mm and the image format of the roll film is $24 \times 36$ mm. The only available way of getting a digital image is by using a personal computer and a good scanner using a resolution of
Table 1  The computed space coordinates of the targets obtained from simulation technique

|          | X /mm | Y /mm | Z /mm |
|----------|-------|-------|-------|
| C.P.2    | 10 000| 20 000| 30 000|
| C.P.1    | 8 905 | 20 000| 30 000|
| C.P.3    | 10 000| 19 532| 30 000|
| A1       | 9 205 | 19 948| 29 970|
| B1       | 9 205 | 19 896| 29 940|
| C1       | 9 205 | 19 844| 29 910|
| D1       | 9 205 | 19 792| 29 880|
| E1       | 9 205 | 19 740| 29 850|
| F1       | 9 205 | 19 688| 29 820|
| G1       | 9 205 | 19 636| 29 790|
| H1       | 9 205 | 19 584| 29 760|
| A2       | 9 305 | 19 948| 29 970|
| B2       | 9 305 | 19 896| 29 940|
| C2       | 9 305 | 19 844| 29 910|
| D2       | 9 305 | 19 792| 29 880|
| E2       | 9 305 | 19 740| 29 850|
| F2       | 9 305 | 19 688| 29 820|
| G2       | 9 305 | 19 636| 29 790|
| H2       | 9 305 | 19 584| 29 760|
| A3       | 9 405 | 19 948| 29 970|
| B3       | 9 405 | 19 896| 29 940|
| C3       | 9 405 | 19 844| 29 910|
| D3       | 9 405 | 19 792| 29 880|
| E3       | 9 405 | 19 740| 29 850|
| F3       | 9 405 | 19 688| 29 820|
| G3       | 9 405 | 19 636| 29 790|
| H3       | 9 405 | 19 584| 29 760|
| A4       | 9 505 | 19 948| 29 970|
| B4       | 9 505 | 19 896| 29 940|
| C4       | 9 505 | 19 844| 29 910|
| D4       | 9 505 | 19 792| 29 880|
| E4       | 9 505 | 19 740| 29 850|
| F4       | 9 505 | 19 688| 29 820|
| G4       | 9 505 | 19 636| 29 790|
| H4       | 9 505 | 19 584| 29 760|
| A5       | 9 605 | 19 948| 29 970|
| B5       | 9 605 | 19 896| 29 940|
| C5       | 9 605 | 19 844| 29 910|
| D5       | 9 605 | 19 792| 29 880|
| E5       | 9 605 | 19 740| 29 850|
| F5       | 9 605 | 19 688| 29 820|
| G5       | 9 605 | 19 636| 29 790|
| H5       | 9 605 | 19 584| 29 760|
| A6       | 9 705 | 19 948| 29 970|
| B6       | 9 705 | 19 896| 29 940|
| C6       | 9 705 | 19 844| 29 910|
| D6       | 9 705 | 19 792| 29 880|
| E6       | 9 705 | 19 740| 29 850|
| F6       | 9 705 | 19 688| 29 820|
| G6       | 9 705 | 19 636| 29 790|
| H6       | 9 705 | 19 584| 29 760|

1 000 dpi while the size of storage area used in the hard disk for one photograph is about 70 MB. The basic function of a scanner is to convert a hardcopy photograph to digital format (i.e., softcopy format).

Scanners are employed to digitize the photograph for further computing. The photographs were converted to digital format by using a Genius advanced scanner color page-HR6X. This scanner has true optical resolution up to 600 dpi with an interpolation of up to 19 200 dpi.

The best five photographs were chosen and then used in our study. Although the photo coordinates that should be used should be measured from the principal point of the metric camera, in our study, because we used a non-metric camera, we measured the photo coordinates from the center of each photograph by using an AutoCAD software.

This method is based on the collinearity condition. It represents a non-linear mathematical relationship which is linearized using Taylor’s theorem.

### 3 Mathematical model

Problems in photogrammetry can be solved mainly by pure mathematical modeling based on the precise measurements of the x and y coordinates of the image points. As in any field, a number of mathematical models can be adapted to cover the same physical situation. The collinearity, the coplanarity and the direct linear transformations are mathematical methods in the photogrammetric technique\[1\].

To calculate the space coordinates from a single non-metric photograph, a computer software was designed using SQL language (Excel program). The collinearity condition equations were used to compute the ground coordinates as follows:

\[
x = -f \left[ M_{11}(X_p - X_i) + M_{12}(Y_p - Y_i) - M_{13}(Z_p - Z_i) \right]
\]

\[
y = -f \left[ M_{21}(X_p - X_i) + M_{22}(Y_p - Y_i) + M_{23}(Z_p - Z_i) \right]
\]

where \( M \) is the element of rotation matrix \( \mathbf{M} \) and

\[
\begin{bmatrix}
    M_{11} & M_{12} & M_{13} \\
    M_{21} & M_{22} & M_{23} \\
    M_{31} & M_{32} & M_{33}
\end{bmatrix}
\]

\[
\begin{bmatrix}
    \cos \phi \cos \kappa \cos \omega \sin \kappa + \sin \omega \sin \phi \cos \kappa - \sin \omega \sin \kappa - \cos \omega \sin \phi \cos \kappa \\
    -\cos \phi \sin \kappa \cos \omega \sin \kappa - \sin \omega \sin \phi \cos \kappa + \sin \omega \cos \phi \sin \kappa \\
    \sin \phi \cos \omega \sin \kappa - \sin \omega \cos \phi \sin \kappa
\end{bmatrix}
\]

(3)

\[
\begin{bmatrix}
    \cos \omega \cos \kappa \\
    \sin \omega \cos \kappa
\end{bmatrix}
\]
where $\omega, \phi, \kappa$ are the rotations of the camera relative to the object space.

Knowing the space coordinates $(X_p, Y_p, Z_p)$ and image coordinates $(x, y)$ for the three control points, as well as the focal length $f$ of the non-metric camera we can determine the six unknown exterior values of a single photograph $[X_L, Y_L, Z_L, \omega, \phi, \kappa]$. We assumed the initial values for the six unknowns and, by solving the six equations having the six unknowns, we can derive the primary values of the image coordinates of the control points. Applying Eq.(4) and Eq.(5) we can get the values of $\delta x$, $\delta y$, $\delta z$, $\delta \omega$, $\delta \phi$ and $\delta \kappa$.

Then we can use the values obtained from Eq.(6) as new values in the second iteration. Using many iterations, we can obtain the most probable values (correct values for $[X_L, Y_L, Z_L, \omega, \phi, \kappa]$) and that occurs when

$$[dX_L, dY_L, dZ_L, d\omega, d\phi, d\kappa] = 0$$

By assuming that:

$$q = M_{31}(X_p - X_L) + M_{32}(Y_p - Y_L) + M_{33}(Z_p - Z_L)$$

$$\Delta X = (X_p - X_L), \Delta Y = (Y_p - Y_L), \Delta Z = (Z_p - Z_L)$$

We can get the following equations:

$$\frac{\delta x}{\delta X_L} = \frac{X}{q} M_{31} + \frac{f}{q} M_{11},$$

$$\frac{\delta x}{\delta Y_L} = \frac{X}{q} M_{32} + \frac{f}{q} M_{12},$$

$$\frac{\delta x}{\delta Z_L} = \frac{X}{q} M_{33} + \frac{f}{q} M_{13},$$

$$\frac{\delta x}{\delta \omega} = \left[ \frac{X}{q} \right] (-M_{31} \times \Delta Y) + (M_{32} \times \Delta Z) + \left[ \frac{f}{q} \right] (-M_{11} \times \Delta Y) + (-M_{12} \times \Delta Z)$$

$$\frac{\delta x}{\delta \phi} = \left[ \frac{X}{q} \right] ((\cos \phi \times \Delta X) + (\sin \omega \sin \phi \times \Delta Y) - (\cos \omega \sin \phi \times \Delta Z)) + \left[ \frac{f}{q} \right] [(-\sin \phi \cos \kappa \times \Delta X) + (\cos \omega \cos \phi \cos \kappa \times \Delta Z)]$$

Similarly:

$$\frac{\delta y}{\delta X_L} = \left( \frac{Y}{q} \right) M_{31} + \left( \frac{f}{q} \right) M_{11},$$

$$\frac{\delta y}{\delta Y_L} = \left( \frac{Y}{q} \right) M_{32} + \left( \frac{f}{q} \right) M_{12},$$

$$\frac{\delta y}{\delta Z_L} = \left( \frac{Y}{q} \right) M_{33} + \left( \frac{f}{q} \right) M_{13},$$

$$\frac{\delta y}{\delta \omega} = \left[ \frac{Y}{q} \right] \left( (-M_{31} \times \Delta Y) + (M_{32} \times \Delta Z) \right) + \left[ \frac{f}{q} \right] \left( (-M_{11} \times \Delta Y) + (M_{12} \times \Delta Z) \right)$$

$$\frac{\delta y}{\delta \phi} = \left[ \frac{Y}{q} \right] [\cos \phi \times \Delta X] + (\sin \omega \sin \phi \times \Delta Y) - (\cos \omega \sin \phi \times \Delta Z) \right] + \left[ \frac{f}{q} \right] \left[ \sin \phi \sin \kappa \times \Delta X \right] - \left[ \frac{f}{q} \right] \left[ \cos \omega \cos \phi \sin \kappa \times \Delta Z \right]$$

$$\frac{\delta y}{\delta \kappa} = \left[ \frac{Y}{q} \right] \left( \cos \phi \times \Delta X \right) + \left( \sin \omega \sin \phi \times \Delta Y \right) - \left( \cos \omega \sin \phi \times \Delta Z \right) \right]$$

Form Reference [2]:

$$\begin{align*}
(x - x_o) &= \left( \frac{\delta x}{\delta \omega} \right) d\omega + \left( \frac{\delta x}{\delta \phi} \right) d\phi + \left( \frac{\delta x}{\delta \kappa} \right) d\kappa - \\
\frac{\delta x}{\delta X_L} dX_L - \frac{\delta x}{\delta Y_L} dY_L - \frac{\delta x}{\delta Z_L} dZ_L = 0 \quad (4)
\end{align*}$$

$$\begin{align*}
(y - y_o) &= \left( \frac{\delta y}{\delta \omega} \right) d\omega + \left( \frac{\delta y}{\delta \phi} \right) d\phi + \left( \frac{\delta y}{\delta \kappa} \right) d\kappa - \\
\frac{\delta y}{\delta X_L} dX_L - \frac{\delta y}{\delta Y_L} dY_L - \frac{\delta y}{\delta Z_L} dZ_L = 0 \quad (5)
\end{align*}$$

We can get the solution for the unknowns as follows:

$$A_6 \times X_{6,1} = B_{6,1}$$

$$X_{6,1} = A_6^{-1} \times B_{6,1}$$

$$A_6 = \begin{bmatrix}
-\frac{\delta x}{\delta X_L} & -\frac{\delta x}{\delta Y_L} & \frac{\delta x}{\delta Z_L} & -\frac{\delta x}{\delta \omega} & \frac{\delta x}{\delta \phi} & \frac{\delta x}{\delta \kappa} \\
-\frac{\delta y}{\delta X_L} & -\frac{\delta y}{\delta Y_L} & \frac{\delta y}{\delta Z_L} & -\frac{\delta y}{\delta \omega} & \frac{\delta y}{\delta \phi} & \frac{\delta y}{\delta \kappa} \\
-\frac{\delta z}{\delta X_L} & -\frac{\delta z}{\delta Y_L} & \frac{\delta z}{\delta Z_L} & -\frac{\delta z}{\delta \omega} & \frac{\delta z}{\delta \phi} & \frac{\delta z}{\delta \kappa} \\
-\frac{\delta \omega}{\delta \omega} & -\frac{\delta \omega}{\delta \phi} & \frac{\delta \omega}{\delta \kappa} \\
-\frac{\delta \phi}{\delta \omega} & -\frac{\delta \phi}{\delta \phi} & \frac{\delta \phi}{\delta \kappa} \\
-\frac{\delta \kappa}{\delta \omega} & -\frac{\delta \kappa}{\delta \phi} & \frac{\delta \kappa}{\delta \kappa}
\end{bmatrix}$$
By using the five non-metric photographs, which were chosen for our study, we can get five spatial coordinates for every target. Then we calculate the most probable value ($\bar{X}$ and $\bar{Y}$) using Eq.(7) for each target and their mean square error ($\sigma_x$ and $\sigma_y$) using Eq.(8). All results were calculated and tabulated in Table 2.

$$B_{6,1} = \begin{bmatrix} X_1^n - X_1^o \\ Y_1^n - Y_1^o \\ X_2^n - X_2^o \\ Y_2^n - Y_2^o \\ X_3^n - X_3^o \\ Y_3^n - Y_3^o \end{bmatrix} \quad \text{and} \quad X_{6,1} = \begin{bmatrix} \Delta X^n_L \\ \Delta Y^n_L \\ \Delta Z^n_L \\ \Delta \phi^o \\ \Delta \kappa^o \end{bmatrix}$$

$$B_{6,1} = \begin{bmatrix} X_1^n = X_1^o + \Delta X^n_L \\ Y_1^n = Y_1^o + \Delta Y^n_L \\ Z_1^n = Z_1^o + \Delta Z^n_L \\ \phi_1^n = \phi^o + \Delta \phi^o \\ \kappa_1^n = \kappa^o + \Delta \kappa^o \end{bmatrix}$$

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n} \quad \text{(7)}$$

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n} \sigma_i^2}{n(n-1)}} \quad \text{(8)}$$

### 4 Experimental analysis results

A comparison between the calculated grounds coordinates from the simulation technique ($X_s, Y_s, Z_s$) and the spatial coordinates obtained from the non-metric photographs ($X_{ph}, Y_{ph}$) were tabulated in Table 2. For more details on how the non-metric spatial coordinates were computed, see Reference [3]. Figs.2-5 indicate the direct proportion between the tolerance in object depth ($\Delta Z$) and the average difference in $X$-direction ($\Delta X$), the average for m.s.e. in $X$-direction ($\sigma_x$), the average difference in $Y$-direction ($\Delta Y$), the average for m.s.e in $Y$-direction ($\sigma_y$), respectively.

![Fig.2](image1.png)  
**Fig.2** Relationship between the tolerance in object depth ($\Delta Z$) and the average differences in $X$-direction ($\Delta X$)

![Fig.3](image2.png)  
**Fig.3** Relationship between the tolerance in object depth ($\Delta Z$) and the average of $\sigma_x$

![Fig.4](image3.png)  
**Fig.4** Relationship between the tolerance in object depth ($\Delta Z$) and the average differences in $Y$-direction ($\Delta Y$)

![Fig.5](image4.png)  
**Fig.5** Relationship between the tolerance in object depth ($\Delta Z$) and the average of $\sigma_y$
Table 2  Comparison between the calculated space coordinates from the simulation coordinates and the space coordinates obtained from non-metric coordinates

| The calculated spatial coordinates | The computed non-metric spatial coordinates | The final differences in coordinates | σ  |
|-----------------------------------|---------------------------------------------|--------------------------------------|----|
|                                   | \( X_i / \text{mm} \)                        | \( Y_i / \text{mm} \)                  | \( \Delta X / \text{mm} \) | \( \Delta Y / \text{mm} \) | \( \sigma_x / \text{mm} \) | \( \sigma_y / \text{mm} \) |
| A1                                | 9 205                                      | 19 948                               | 13.66                  | 2.96                     | 0.549                       | 0.800                       |
| B1                                | 9 205                                      | 19 896                               | 18.00                  | 3.92                     | 1.030                       | 0.870                       |
| C1                                | 9 205                                      | 19 844                               | 17.00                  | 2.88                     | 0.630                       | 0.650                       |
| D1                                | 9 205                                      | 19 792                               | 21.00                  | 4.15                     | 1.190                       | 0.500                       |
| E1                                | 9 205                                      | 19 740                               | 26.00                  | 8.19                     | 1.580                       | 1.110                       |
| F1                                | 9 205                                      | 19 688                               | 24.00                  | 11.23                    | 2.240                       | 0.980                       |
| G1                                | 9 205                                      | 19 636                               | 27.00                  | 15.27                    | 2.060                       | 1.330                       |
| H1                                | 9 205                                      | 19 584                               | 32.00                  | 21.31                    | 2.240                       | 1.340                       |
| A2                                | 9 305                                      | 19 948                               | 17.00                  | -5.04                    | 0.480                       | 0.850                       |
| B2                                | 9 305                                      | 19 896                               | 22.00                  | -0.08                    | 0.710                       | 0.820                       |
| C2                                | 9 305                                      | 19 844                               | 23.00                  | 0.88                     | 1.830                       | 1.030                       |
| D2                                | 9 305                                      | 19 792                               | 26.00                  | 6.15                     | 1.450                       | 1.170                       |
| E2                                | 9 305                                      | 19 740                               | 28.00                  | 6.19                     | 2.580                       | 0.910                       |
| F2                                | 9 305                                      | 19 688                               | 32.00                  | 10.23                    | 2.160                       | 0.910                       |
| G2                                | 9 305                                      | 19 636                               | 36.00                  | 15.27                    | 1.860                       | 0.930                       |
| H2                                | 9 305                                      | 19 584                               | 39.00                  | 18.31                    | 2.020                       | 1.220                       |
| A3                                | 9 405                                      | 19 948                               | 19.00                  | 3.96                     | 0.810                       | 0.940                       |
| B3                                | 9 405                                      | 19 896                               | 23.00                  | 2.92                     | 0.750                       | 1.240                       |
| C3                                | 9 405                                      | 19 844                               | 25.00                  | 4.88                     | 0.950                       | 1.500                       |
| D3                                | 9 405                                      | 19 792                               | 26.00                  | 5.15                     | 1.860                       | 1.500                       |
| E3                                | 9 405                                      | 19 740                               | 28.00                  | 9.19                     | 1.600                       | 1.210                       |
| F3                                | 9 405                                      | 19 688                               | 32.00                  | 8.23                     | 1.470                       | 0.948                       |
| G3                                | 9 405                                      | 19 636                               | 36.00                  | 14.27                    | 2.150                       | 0.850                       |
| H3                                | 9 405                                      | 19 584                               | 39.00                  | 18.31                    | 2.020                       | 1.220                       |
| A4                                | 9 505                                      | 19 948                               | 19.00                  | 1.96                     | 0.710                       | 0.410                       |
| B4                                | 9 505                                      | 19 896                               | 23.00                  | 0.92                     | 1.290                       | 0.710                       |
| C4                                | 9 505                                      | 19 844                               | 25.00                  | 5.15                     | 1.860                       | 1.500                       |
| D4                                | 9 505                                      | 19 792                               | 26.00                  | 5.15                     | 1.860                       | 1.500                       |
| E4                                | 9 505                                      | 19 740                               | 28.00                  | 9.19                     | 1.600                       | 1.210                       |
| F4                                | 9 505                                      | 19 688                               | 32.00                  | 8.23                     | 1.470                       | 0.948                       |
| G4                                | 9 505                                      | 19 636                               | 36.00                  | 14.27                    | 2.150                       | 0.850                       |
| H4                                | 9 505                                      | 19 584                               | 39.00                  | 18.31                    | 2.020                       | 1.220                       |
| A5                                | 9 605                                      | 19 948                               | 19.00                  | 1.96                     | 0.710                       | 0.410                       |
| B5                                | 9 605                                      | 19 896                               | 23.00                  | 0.92                     | 1.290                       | 0.710                       |
| C5                                | 9 605                                      | 19 844                               | 25.00                  | 5.15                     | 1.860                       | 1.500                       |
| D5                                | 9 605                                      | 19 792                               | 26.00                  | 5.15                     | 1.860                       | 1.500                       |
| E5                                | 9 605                                      | 19 740                               | 28.00                  | 9.19                     | 1.600                       | 1.210                       |
| F5                                | 9 605                                      | 19 688                               | 32.00                  | 8.23                     | 1.470                       | 0.948                       |
| G5                                | 9 605                                      | 19 636                               | 36.00                  | 14.27                    | 2.150                       | 0.850                       |
| H5                                | 9 605                                      | 19 584                               | 39.00                  | 18.31                    | 2.020                       | 1.220                       |
| A6                                | 9 705                                      | 19 948                               | 19.00                  | 1.96                     | 0.710                       | 0.410                       |
| B6                                | 9 705                                      | 19 896                               | 23.00                  | 0.92                     | 1.290                       | 0.710                       |
| C6                                | 9 705                                      | 19 844                               | 25.00                  | 5.15                     | 1.860                       | 1.500                       |
| D6                                | 9 705                                      | 19 792                               | 26.00                  | 5.15                     | 1.860                       | 1.500                       |
| E6                                | 9 705                                      | 19 740                               | 28.00                  | 9.19                     | 1.600                       | 1.210                       |
| F6                                | 9 705                                      | 19 688                               | 32.00                  | 8.23                     | 1.470                       | 0.948                       |
| G6                                | 9 705                                      | 19 636                               | 36.00                  | 14.27                    | 2.150                       | 0.850                       |
| H6                                | 9 705                                      | 19 584                               | 39.00                  | 18.31                    | 2.020                       | 1.220                       |
From the previous Tables and Figures we can determine the relationship between the ratio of the tolerance in object depth ($\Delta Z$) and the object distance ($D$) against the accuracy of re-establishing the dimensional shape of the objects in $X$ and $Y$ directions. These were summarized and tabulated in Table 3.

### Table 3  Ratio of the tolerance ($\Delta Z$) and the object distance ($D$)

| Rows | $\Delta Z$ / cm | $D$/cm | $\Delta Z / D$ ratio/\% | $\Delta X$ / cm | $\Delta Y$ / cm | $\sigma_x$ / mm | $\sigma_y$ / mm |
|------|-----------------|--------|-------------------------|-----------------|-----------------|----------------|----------------|
| A    | 3               | 140    | 2.14                    | 1.76            | 0.14            | 0.73           | 0.79           |
| B    | 6               | 140    | 4.29                    | 2.18            | 0.28            | 0.77           | 0.89           |
| C    | 9               | 140    | 6.43                    | 2.42            | 0.43            | 0.89           | 0.92           |
| D    | 12              | 140    | 8.57                    | 2.88            | 0.55            | 1.29           | 0.86           |
| E    | 15              | 140    | 10.71                   | 3.28            | 0.69            | 1.41           | 0.97           |
| F    | 18              | 140    | 12.86                   | 3.65            | 0.89            | 1.61           | 1.00           |
| G    | 21              | 140    | 15.00                   | 4.15            | 1.23            | 1.67           | 1.03           |
| H    | 24              | 140    | 17.14                   | 4.61            | 1.65            | 1.85           | 1.05           |

From this table, we can conclude that when the minimum ratio ($\Delta Z / D$) is 2 %, the calculated mean square error in the $X$-direction is 0.73 mm and the calculated mean square error in the $Y$-direction is 0.79 mm. While the maximum value of ($\Delta Z / D$) is 17 %, the calculated mean square error in the $X$-direction is 1.85 mm and the calculated mean square error in the $Y$-direction is 1.05 mm.

## 5 Conclusions and recommendations

1) From the simulation model, we can derive the relationship between the ratio of the tolerance in object depth ($\Delta Z$) over the object distance ($D$) \([(\Delta Z / D)]\) against the accuracy of re-establishing the dimensional shape of the object in $X$ and $Y$ directions.

2) It can be concluded that when the minimum ratio ($\Delta Z / D$) is 2 %, the computed mean square error are $X$-direction $= \pm 0.73$ mm and in the $Y$-direction $= \pm 0.79$ mm.

3) When the maximum value of ($\Delta Z / D$) is 17 %, the calculated mean square error are $X$-direction $= \pm 1.85$ mm and in the $Y$-direction $= \pm 1.05$ mm.

4) It is recommended that further studies should be conducted on the effects of making scanned images using a negative film instead of a print photograph on the accuracy of the achieved ground coordinates.

## References

[1] Mikhail E M, Mulawa D C (1985) Geometric form fitting in industrial metrology using computer-assisted theodolites [C]. ASP/ACSM Fall Meeting, Arkansas

[2] Mofitt F H, Mikhail E M (1980) Photogrammetry (second edition) [M]. New York: Harper & Row, Inc. Publisher

[3] Tarek M A (2005) Application of some surveying techniques for documenting buildings[D]. Cairo, Egypt: AL-Azhar University

[4] Nutto M, Ringle K (2001) Photogrammetric documentation of the Castle of Heidelberg from data capture to information systems[OL]. http://www.gik.uni-karlsruhe.de/674.htmlpdf-datei/cipa2001.pdf

[5] Abd-Elhafeez A (2000) Studying some factors affecting the accuracy of digital photogrammetric applications[D]. Egypt: Assuit University

[6] Esmat A (1989) The applications close-range photogrammetry in restoration of architectural features[D]. Egypt: Zagazig University

[7] Wolf P R (1983) Elements of photogrammetry (second edition)[M]. New York: Mc-Graw Hill International Book Company

[8] Fawaz E M (1981) Evaluation of leveling-nets on the basis of the theory of stochastic processes[D]. Hannover: Hannover University

[9] Spiegel M R (1980) Theory and problems of probability and statistics, schaum’s outline series, SI (metric) (10th edition) [M]. New York: Mc-Graw Hill, Inc.

[10] Karara H M, Faig W (1980) An expose on photographic data acquisition system in close-range photogrammetry[J]. International Archives of Photogrammetry, 23:402-418

[11] Abdel-Aziz Y I, Karara H M (1971) Photogrammetric potential of non-metric cameras[R]. Civil Engineering Studies, Photogrammetric Series, University of Illinois, Urbana, USA