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The Accuracy of Determining the Volumes Using Close Range Photogrammetry

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Abstract: *Time and accuracy required are the two important factors that decide on the appropriateness of volume calculations for road project, mining enterprise, geological works and building applications. Geodetic surveying methods have been insufficient for the volume calculation of the objects need to calculation of volume in a short time or in a risk area. In this paper, digital close range photogrammetry is an alternative method to volume calculation. The main objective of this paper is investigated the use of close range photogrammetry to calculate the volume instead of traditional methods. This paper gives also the sequence of the field operations and computational steps for this task. A numerical example is included to reinforce the theoretical aspects.*
Keywords: *Close Range Photogrammetry, Accuracy, Volumes, Surfer Software.*

I. Introduction

The volume calculations are important requirement of the construction and mining industry. The accurate volume estimation is important in many applications, for example road project, mining enterprise, geological works and building applications. The traditional methods such as the trapezoidal method (rectangular or triangular prisms), traditional cross sectioning (trapezoidal, Simpson, and average formula), and improved methods (Simpson-based, cubic spline, and cubic Hermite formula) have been used in volume computing [1]. The main elements of these methods are to collect the points that appropriate distribution and density. These methods needs more mathematical processes and take more time. The difficulties have been overcome by developments in computer technologies. The corrections of volume is direct proportional with the presentations of land surface in a best representation of land surface in best form is depend on the number of certain X,Y,Z coordinate points. The total station instrument has been used to determine the certain coordinate for land surface.

In this research, digital close range photogrammetry is an alternative method to volume calculation. Digital close range photogrammetry is a method which has been used for three dimension surveying of objects for many years. By the development of digital techniques, digital close range photogrammetry used in many fields such as engineering surveying, topographic surveying, architectural surveying, archeological surveying, etc disciplines has become a productive, faster and an economical method. Due to the developments in digital photogrammetry and computer technology in past years, to constitute of three dimension models of objects included in current research topics [2]. In this study, performance in volume calculation of digital close range photogrammetry has been investigated.

The ground control points in photogrammetric method are used to calculate the position and orientation of each camera in a stereo pair of photographs. In many cases the placement cannot be made because of inaccessibility or safety restrictions. Even if access is not a problem it is often difficult to place the ground control points in positions that allow for good visibility or distribution. Poor distribution of ground control points can result in the calculated position and orientation of the camera to have a non unique solution or variations of true position in the order of 10s of meters. The use of ground control points to calculate position adds significantly to the time and skill required for image processing particularly in the documentation and identification [3]. Only ground control points have to be signalized and measured in terrain by traditional methods. However, it means just a few points in a comparison to an evaluation of all points or lines in a quarry or a mine. In this paper, volume calculation performance has been investigated using two methods (traditional and digital close range photogrammetry).

II. Traditional Methods For Determination The Volume

Current methods used for estimating volume assumes that the ground profile between the grid points is linear (based on the trapezoidal rule), or nonlinear (based on Simpson's 1/3 and 3/8 formulas). Generally speaking, the nonlinear profile formulas provide better accuracy than the linear profile formulas. However, all the methods mentioned above have a common drawback: The joints (grid points) of any two straight lines (the

trapezoidal rule), quadratic polynomials (Simpson's 1/3 formula), or cubic polynomials (Simpson's 3/8 formula) form sharp corners [3].
Simpson equations have been used in volume calculation with cross sections.

$$V = \left(\frac{A_1 + A_2}{2}\right) * \ l_1 + \left(\frac{A_2 + A_3}{2}\right) * \ l_2 + \ \ldots . + \left(\frac{A_{n-1} + A_n}{2}\right) * \ l_n$$

Where;
$A_{1 \ldots n}$ = cross section areas,
$l_{1 \ldots n}$ = distances between cross sections.
In surfer 10 software, grid surfaces of object have been generated from the X, Y, Z coordinates of object surface using linear interpolation methods. In this software, the volume under the f(x,y) function can be determined with double integral equations.

$$\mathrm{V} = \int_{\mathrm{X_{min}}}^{\mathrm{X_{max}}} \int_{\mathrm{Y_{min}}}^{\mathrm{Y_{max}}} \mathrm{f(x,y)dx\,dy}$$

In software, extended trapezoidal rules for volumes;

$$A_i = \frac{\Delta x}{2}\left[H_{i,1} + 2H_{i,2} + 2H_{i,3} + \cdots . + 2H_{i,n-1} + H_{i,n}\right]$$
$$V = \frac{\Delta y}{2}\left[A_1 + 2A_2 + 2A_3 + \cdots . + 2A_{n-1} + A_n\right]$$

Extended Simpson Rule;

$$A_i = \frac{\Delta x}{3}\left[H_{i,1} + 4H_{i,2} + 2H_{i,3} + 4H_{i,4} + \cdots . + 2H_{i,n-1} + H_{i,n}\right]$$
$$V = \frac{\Delta y}{3}\left[A_1 + 4A_2 + 2A_3 + 4A_4 + \cdots . + 2A_{n-1} + A_n\right]$$

Extended Simpson 3/8 Rule;

$$A_i = \frac{3\Delta x}{8}\left[H_{i,1} + 3H_{i,2} + 3H_{i,3} + 2H_{i,4} + \cdots . + 2H_{i,n-1} + H_{i,n}\right]$$
$$V = \frac{3\Delta y}{8}\left[A_1 + 3A_2 + 3A_3 + 2A_4 + \cdots . + 2A_{n-1} + A_n\right]$$

In traditional methods by means of set points on object surface and forming cross sections, excavation volume of soil has been calculated. Using surfer 10 software, object surface obtained from geodetic points and volume calculation could be accomplished. During this process the time spent and cost calculations have been also made [3].

III. Close Range Photogrammetry For Determination The Volume

Digital close range photogrammetry is a technique for accurately measuring objects directly from photographs or digital images captured with a camera at close range. Multiple overlapping images taken from different perspectives, produces measurements that can be used to create accurate three dimension models of objects. Knowing the position of camera is not necessary because the geometry of the object is established directly from the images. Photogrammetry techniques allow you to convert images of an object into a three dimension model. Using a digital camera with known characteristic (lens focal length, imager size and number of pixels), you need a minimum of two pictures of an object. If you can indicate the same three object points in the two images and you can indicate a known dimension, you can determine other three dimension points in the images [4]. The photogrammetric three dimension coordinate determination is based on the co-linearity equation which simply states that object point, camera projective centre and image point lie on a straight line. The determination of the three dimension coordinates from a definite point is achieved through the intersection of two or more straight lines or observed by electronic total station instrument.
Therefore, each point of interest should appear in at least two photographs then, coordinates are measured from three dimension model which is constituted by photogrammetric software [5].
Abdel Aziz and Karara proposed a simple method for close range photogrammetric data reduction with non-metric cameras; it establishes the direct linear transformation (DLT) between the two-dimensional coordinates, and the corresponding object- space coordinates [6].
The Direct Linear Transformation (DLT) between a point (X, Y, Z) in object space and its corresponding image space coordinates (x, y) can be established by the linear fractional equations:

$$\begin{aligned} f &= x + \Delta x - \frac{L_1 X + L_2 Y + L_3 Z + L_4}{L_9 X + L_{10} Y + L_{11} Z + 1} \\ g &= y + \Delta y - \frac{L_5 X + L_6 Y + L_7 Z + L_8}{L_9 X + L_{10} Y + L_{11} Z + 1} \end{aligned} \tag{1}$$

Where:
L_1, L_2 L_3…L_{11} are the transformation parameters
X, Y and Z are the object space coordinates

$$\Delta x = x^{-}(k_1 r^2 + k_2 r^4 + k_3 r^6) + p_1(r^2 + 2x^{-2}) + 2p_2\, x^{-} y^{-}$$
$$\Delta y = y^{-}(k_1 r^2 + k_2 r^4 + k_3 r^6) + 2p_1\, x^{-} y^{-} + 2p_2\,(r^2 + 2y^{-}) \qquad (2)$$

Where:

$x^{-} = x - x_o$ $\qquad$ $y^{-} = y - y_o$ $\qquad$ $r^2 = (x - x_o)^2 + (y - y_o)^2$ $\qquad$ (3)

x, y are image coordinates
p_1 and p_2 are two asymmetric parameters for de-centering distortion
k_1, k_2 and k_3 are three symmetric parameters for radial distortion
r is the radial distance from the principal point

Equation 1 results from the equation of the central perspective in a trivial manner; Δx, Δy are systematic deformations of the image, i.e. deviations from the central perspective. Equation 1 can be solved directly for the 11 transformation parameters (L_1, L_2 L_3 …L_{11}) if there are at least six points in the image whose object-space coordinates are known. Equation 1 is rewritten to serve in a least squares formulation relating known control points to image coordinate measurements:

$$v_x = L_1 X + L_2 Y + L_3 Z + L_4 - xX L_9 - xY L_{10} - xZ L_{11} - \Delta x \qquad (4)$$
$$v_y = L_5 X + L_6 Y + L_7 Z + L_8 - yX L_9 - yY L_{10} - y Z L_{11} - \Delta y$$

IV. Test Field

This test was carried out inside Kafr El-Sheikh University. A test field area has 361.5 m length, 234 m width and 3.25 m height (Figure 1). A test field consist of many stone heap has been used for volume calculation. Both traditional and photogrammetric methods have been applied for the volume calculation. Volume calculation results with traditional and photogrammetric methods are given in the next parts.

Figure 1: A test field area inside Kafr El-Sheikh University

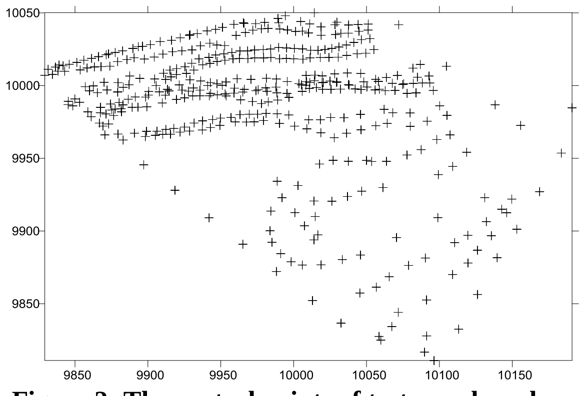

Figure 2: The control points of test area based on traditional methods

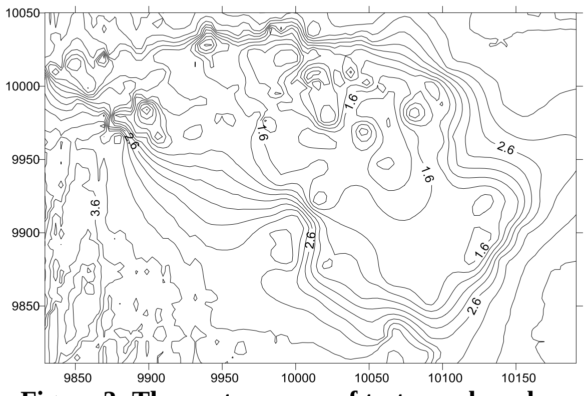

Figure 3: The contour map of test area based on traditional methods

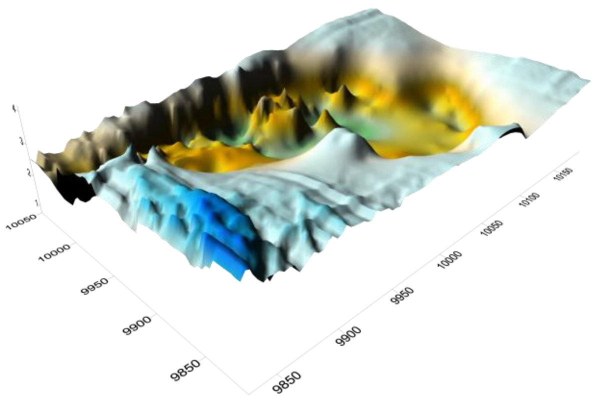

Figure 4: Three dimension map of test area based on traditional methods

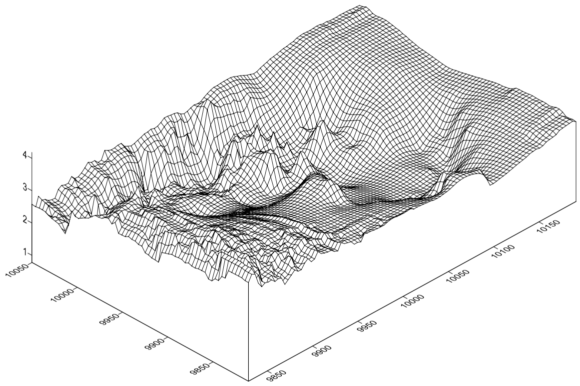

Figure 5: Three dimension map of test area based on traditional methods

Volume Computing By Traditional Methods

Cross sections have been obtained with the points placed on the test field area. The 425 points coordinates were measured using SOKKIA SET330RK electronic total station instrument. The horizontal distribution of the points is seen in Figure 2. The accuracy of the SOKKIA SET330RK total station is 5 mm ± 2 mm/km and angle accuracy 3" [7] & [8]. Figure 3 is shown the contour map of test area based on the elevation of 425 points. The same points have been transferred to Surfer 10 software and from Trapezoidal Rule; volume of the test field has been calculated as 221475.14356249 m^3. According to Simpson's Rule, volume of the test field has been calculated as 221424.52105452 m^3. From Simpson's 3/8 Rule, the volume of test field has been calculated as 221484.05385912 m3. The three dimension map of test area based on traditional methods is shown in figures 4 and 5.

Volume Computing By Photogrammetic Methods

To carry out photogrammetric evaluation, 42 control points (20cm*20cm) in white and black have been used to make it easy to see. The coordinates of the control points have been measured with SOKKIA SET330RK electronic total station instrument. The horizontal distribution of the points is seen in Figure 6.

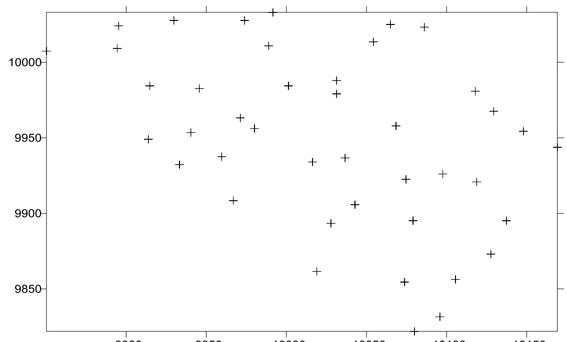

Figure 6: The control points of test area based on photogrammetric method

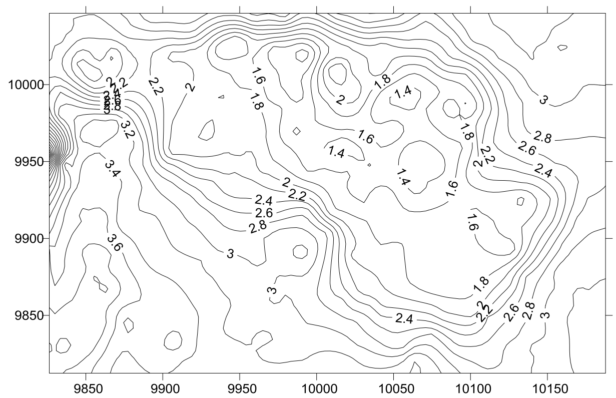

Figure 7: The contour map of test area based on photogrammetric methods

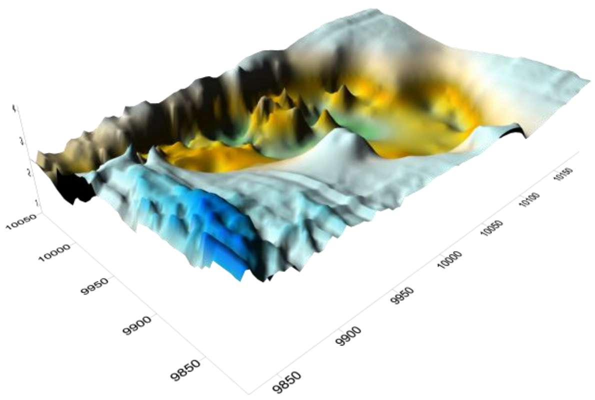

Figure 8: three dimension map of test area based on photogrammetric methods

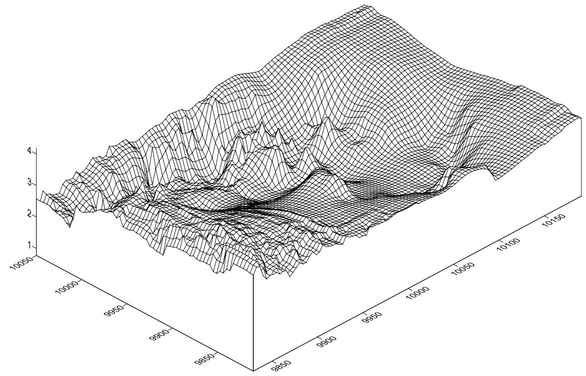

Figure 9: three dimension map of test area based on photogrammetric methods

Taking photographs has been done with the Nikon D 3100 digital camera (Figure 10) in 14.2 mega pixel resolution. Camera calibration procedures have been completed for mathematical calculations. Photographs have been transferred to Photomodeler software, photogrammetric evaluation has been accomplished 574 coordinate points have been obtained. PhotoModeler is a software application that performs image based modeling and close range photogrammetry producing three dimension models and measurements from photography. PhotoModeler, first publicly released in 1993, was the first commercial all digital close range photogrammetry and image based modeling system

Figure 10: The Nikon D 3100 digital camera

PhotoModeler creates accurate three dimension models (consisting of Points, Lines, Curves, Edges, Cylinders, Surfaces and Shapes), and accurate three dimension measurements from photographs taken with most standard cameras (either digital or film). Three dimension models can be created and exported with photographic textures extracted from the original photographs [9].

The 574 control points obtained have been transferred to Surfer software and Figure 7 shown the contour map of test area based on photogrammetric methods. The volume of test field has been calculated. From Trapezoidal Rule; volume of the test field has been calculated as 215310.5960983 m^3. According to Simpson's Rule, volume of the test field has been calculated as 215300.43158866 m^3. From Simpson's 3/8 Rule, the volume of test field has been calculated as 215304.11889089 m^3. The three dimension model of test area based on photogrammetric methods is seen in Figures 8 & 9. Tables 1 summarize the obtained volume in previous cases. Table 1 summarizes the obtained volumes result by the traditional and photogrammetric methods and percentage of accuracy for photogrammetric method.

Table 1: The volume calculation according to traditional and photogrammetric methods.

Methods	Traditional Method		Photogrammetric Method			Difference (m3)	Accuracy (%)
	No. of Control Points	Volume (m3)	No. of Control Points	No. of Generated Points	Volume (m3)		
Trapezoidal Rule	425	221475.1436	42	574	215310.5961	6164.5475	97.2166
Simpson's Rule		221424.5211			215300.4316	6124.0895	97.23423
Simpson's 3/8 Rule		221484.0539			215304.1189	6179.935	97.20976

V. Conclusions

The photogrammetric method has been used and the obtained accuracy is discussed and presented. When experimental results examined photogrammetric method could approach 97.21% ratio to the traditional method value. Based on the experimental results, the following conclusions can be drawn:

- The photogrammetric method is efficient to determination the volumes;
- The photogrammetric method has proved to be fast and useful to estimate the volume with compared by traditional method;
- The accuracy of photogrammetric method to determine the volume can be given good results 97.21% in comparison with traditional method.
- The 10% of ground control points using to determine the volume was saved by photogrammetric method with compared by traditional method which determine the same accuracy.

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