# GPS ENABLED DIGITAL PHOTOGRAMMETRY FOR 3D EARTH MODELING

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**Commission -----, Working Group ------**

**KEY WORDS:** Volume Computation, Landslides, GPS, Digital Close Range Photogrammetry, Constrained Bundle Adjustment

**ABSTRACT**

Many engineering land projects need an efficient volume computation technique with high accuracy and short time in both theoretical and practical aspects. In most cases, classical geodetic surveying methods for capturing sufficient field data are not adequate and/or impossible to be applied in risk or inaccessible areas as the case of unstable areas and landslides. By the rapid development in digital close range photogrammetry, including both image acquisition and processing modules, this demand has become productive, faster, and safer along with being an economical approach. This paper presents a practical investigation for testing the reliability of this approach in volume computation of a certain hill. In this terminology, a GPS-enabled digital camera (RICOH Capilo 500SE) captured the required images and the Leica Photogrammetric Suite (LPS) software is used for bundle adjustment solution considering the great privilege for automatic tie points' generation. In addition, the ability of fixing the base distance between exposure stations as a constrained bundle solution has demonstrated an increase in the accuracy of the 3D shape reconstruction to be compared with the traditional terrestrial geodetic methods. This will be done while taking into account the excessive amount of time required, in addition to consumed effort and higher cost in terms of required instruments and manpower.

## 1. INTRODUCTION

Earth and excavation works are among the most common and important activities in civil engineering field. For these demands, accurate 3D shape reconstruction and volume computations, which have always been a challenge to be captured precisely, safely and rapidly, should be available to be used in many applications such as erosion studies, mining activity monitoring and terrain assessment for construction (e.g. Yilmaz, 2010). However, landslides and ground movement is considered one of the most challenging cases, in opposition to regular ground surveying techniques, especially regarding safety of manpower near critical cliffs and hills. In this context, heights information are used to produce accurate mathematical ground models which in turn can be used to produce sectional information and cut/fill volumes which can greatly assist design engineers.

The accuracy of computed volumes depends mainly on the correct modeling of the Earth surface, which is usually represented by certain number of specific 3D coordinate points with good distribution, and the used interpolation methods (Yakar et al., 2010). Of course, these requirements need more observed points, which in turn, increase the required time and cost. Also in most cases, as mentioned earlier, obtaining these geodetic points is impossible to be acquired using classical ground surveying approaches in risky and/or inaccessible areas. These drawbacks are considered the basic motivation behind the current study.

Various methods have been proved as efficient tools to be used in the field of earthworks volume computations. Among these, the approaches of making non-contact and rapid spatial measurements are most preferably, such as close range phorogrammetry and laser scanning with improvements of their hardware and software products (e.g. Kiat, 2007; Yakar et al., 2008). This is due to the enhancement of the flexibility to execute volume computations at any time regardless of weather and on-going activities at site, besides the less complexity in their applications. However, its main drawbacks is that terrestrial laser scanner is a high cost technique (at least compared with the cost of a complete photographic equipment: camera body and several lenses) with an intensive and cumbersome post-processing (Cardenal et al., 2008). Also and in this terminology, photogrammetry or laser scanner only, is not capable of generating sufficient information on particular objects or object features directly in exact global orientation. To obtain global geographic coordinates, GPS is introduced for use (Du and Teng, 2007).

Accordingly, the main purpose of the current study is to test the efficiency of a combined digital close range photogrammetric system (digital camera equipped with GPS) as an auxiliary measurement tool and powerful digital phorogrammetric software, for 3D modeling of a certain hill. This combined approach of GPS and close range photogrammetry proved to be noteworthy, especially from decreasing number of required ground control points and manpower (Ragab and Ragheb, 2010). To achieve this purpose, the description of the used instruments as well as the photographed area along with the main characteristics of the used combined digital system is outlined first. This mainly includes the acquisition and processing of digital images. Then, the criteria of assessment for evaluating the obtained results is presented and analyzed. Finally, the output main conclusions along with some appropriate recommendations will be given.

## 2. INSTRUMENTS AND DATA SETS AQUISITION

Again, the main aim of this study is to prove the benefit of the use of GPS enabled photogrammetric camera against classical photogrammetry and terrestrial total station technique, used to calculate the volume of Earthworks, mainly from the practical point of view. Accordingly, a natural hill was chosen as a test volume in Shorouk city, Cairo, Egypt, in order to perform such research upon. The reason for choosing such area is its

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accessibility, uniformity as much as possible and most importantly stability. The tested hill measures approximately 28.10m in length, 26.65m in width, and 3m in height difference. Figure 1 shows the chosen test module along with its proximity and some distributed ground control points.

Figure 1 Chosen test volume in Shorouk city, Cairo, Egypt

Four exposure stations were chosen in each direction surrounding the test volume (North, East, South and West) in which images were captured from the exposure stations (one image for each exposure station). In addition, four points are chosen in different places of the test volume with variety of elevations, to be used during photogrammetric data processing. These control points will appear in as many captured images from exposure stations as possible, in order to utilize them as ground control points. Figure 2 shows a schematic plan of the test area along with both chosen exposure stations and ground control points.

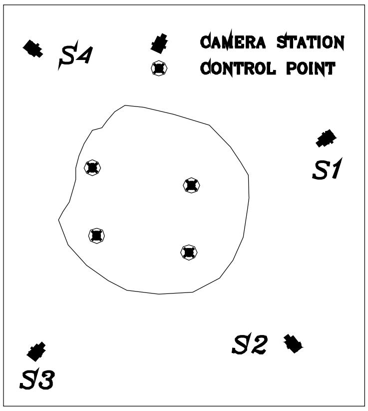


Figure 2 Plan of chosen test area and surroundings along with exposure and control points

Hence, three kinds of data sets will be compared here, the first using classical photogrammetry utilizing different available control points in order to obtain the required interior and exterior unknown orientation parameters. The second data set will be utilized by decreasing the number of available essential control points due to the availability of tilt parameter and coordinates of each exposure station, available due to the usage of a GPS digital camera. The Camera used here is digital camera equipped with a GPS receiver, called RICOH Capilo 500SE GPS camera shown in Figure 3. This 8.0 Megapixels camera is available with an integrated GPS receiver and a digital compass, which consequently have the ability of providing the coordinates of the exposure station and one of the tilt angles of the exterior orientation parameters. The third data set was collected using a Topcon GTS-712 total station and a well calibrated reflector prism, through normal grid leveling technique by the determination of 3D position values of grid node points on the test volume for the formation of contour lines and calculation of the volume.

During ground surveying of the test volume, the position of the four exposure stations as well as the four chosen control points were observed by the total station, to determine their coordinates relative to a local coordinate system. Processing of photogrammetric data sets in both cases whether classical or GPS enabled photogrammetry will be performed through the Leica photogrammetric suite LPS 9.2 embedded within Imagine ERDAS software 9.2. On the other hand, the determination of the volume of earthworks through the usage of all data sets will be calculated using the Surfer software 8.0.


Figure 3 RICOH Capilo 500SE GPS digital camera
http://www.korecgroup.com/images/images_img-229.jpg

## 3. METHODOLOGY

Evaluation of this combined methodology using GPS enabled digital camera will be executed first by considering the time required to obtain the volume of Earthworks using the GPS enabled technique versus the corresponding time required to obtain the same volume using classical ground surveying techniques. Secondly, the results of the GPS enabled technique will be compared to the technique using classical photogrammetry from two different aspects. The first could be through the accuracy of obtained coordinates of specified discrete check points on the chosen case study volume of earthworks, and/or the accuracy of computed volume. The second will be from the practical point of view, based on decreasing number of ground control points used in the processing of the LPS software, which is considered a pivotal issue here in, regarding the cost and time required to determine the volume of such earthwork. In addition, another approach is undertaken using constrained network bundle adjustment through the fixation of distances between exposure stations, applying different cases of fixation. Yet it is worth mentioning here that, in the normal case of engineering application of such research approach, where as no total station is available, the baseline length can be also determined by differencing the GPS coordinates of exposure stations determined from the Ricoh GPS Camera, which can be considered accurate enough due to differencing of coordinates, by removing most of embedded GPS errors to be as the same value measured by total station. Nevertheless, both photogrammetric techniques, whether using classical or GPS enabled photogrammetric processing, will be compared to terrestrial total station technique, which is considered the most accurate among them, used to determine the coordinates and elevations of points within the specified volume as well as being the commonly used in daily Earth volume computations by many surveyors, without even the need to fix control points within the required volume to be calculated.

However, this terrestrial technique requires the availability of at least two control points within the premises of the required earthwork, in order to calculate such volume as well as at least one surveyor (or in some cases even more than that) holding a reflecting prism. This in our case here, is considered a major drawback of this technique, as in some cases such control points are not available, in addition to the urgent need of skilled manpower with grid leveling procedure experience. Beside all this, the usage of terrestrial total station technique is very critical and dangerous near unstable areas where landslides exist within the perimeter of the volume required to be determined, from the safety of the surveyor and assisting crew point of view.

## 4. PHOTOGRAMMETRIC DATA PROCESSING

Bundle adjustment is the most appropriate method used in digital photogrammetery since it depends on analytical principals as well as being an effective numerical technique. The 3D reconstruction process based on digital close range photogrammetry can be divided mainly to orientation, measurements and modeling. Thus, automatic reconstruction depends on the automation of these parameters, which can be easily achieved through the use of the Leica Photogrammetric Suite (LPS) version 9.2, as the conventional digital photogrammetric workstation (DPW). Additionally, this particular software has the ability to generate automatically common tie points after orienting the captured images internally and externally to the ground plan, as typically shown in Figure 4, which motivates the purpose of the current study. The following subsections illustrate briefly the different concepts and formulations of all investigated photogrammetric data sets, whose precisions will be assessed relative to the accurate total station grid leveling technique for volume computations.

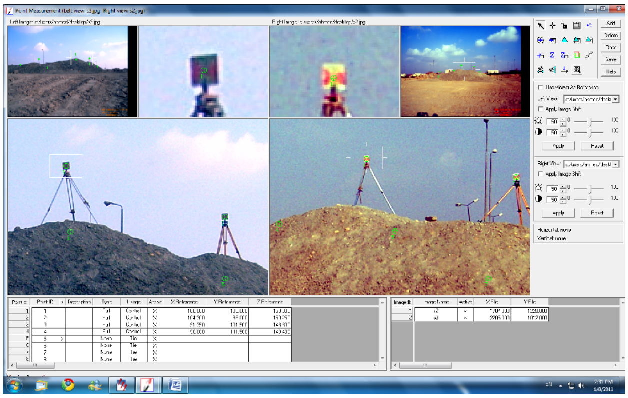

Figure 4 LPS software interface with tie points generation

### 4.1 Classical and GPS Enabled Photogrammetric Data Processing

As stated before concerning the different data sets to be investigated, the used camera is tested twice. In other words, the digital bundle solution by LPS software is performed through two main study cases according to the way of treatment of the extrinsic orientation parameters (exposure station coordinates and rotation angles) of the captured images. The former case treats those parameters as unknown values to be typically classical photogrammetric data processing which can be termed as stand-alone digital camera, whereas the latter considers those parameters are known as fixed values taken directly from the embedded GPS receiver and attached digital compass respectively. This second case can be termed as GPS-enabled digital camera, in which no ground control points are needed. Hence, great benefits are gained from the strength of this technology to be applied in applications where safety may be an issue, such as providing accurate measurements on landslides or debris flow area.

Also, other alternative bundle solutions are tested as a median merge between the above-mentioned two main study cases. These solutions aim to reduce the number of required control points along with its influence on the accuracy of the final computed Earthworks volumes. This means that, the extrinsic orientation parameters of some exposure stations are considered unknowns while the corresponding parameters of the remaining exposure stations are taken as fixed values. In other words, the four captured images will be processed while considering a) one ground control point, thus considering fixation of three of the four exposure stations, b) two ground control (fixation of coordinates of two exposure stations, and finally c) using three ground control (fixing only one of the exposure station coordinates). Accordingly, the required number of control points is specified related to the number of associated unknown parameters in the bundle solution besides the availability of these control points to be visible in some or all taken images.

### 4.2 Constrained Bundle Adjustment

Finally and for the sake of reaching at the best improvement in the precision of the computed Earthworks volumes, another bundle solution is introduced as constrained bundle adjustment. According to the used camera, the baseline distances among exposure stations are added as external constraints into the least squares bundle estimation process via sequential adjustment. On the one hand, these constraints can stabilize weak image configurations, strengthens the solution with appropriate weights and, last but not least, support the adjustment process (Lerma et al., 2010). On the other hand, if the additional constrained observations are weighted with unrealistic values, the solution can adversely affect the final results. Keeping mind that, the third case under which all used number of ground control points will be performed through unconstrained (classical) and constrained bundle adjustment as mentioned earlier.

In the context, a certain MATLAB program has been written for the solution of this particular constrained bundle adjustment. The used mathematical models are the well-known collinearity condition equations. It should be noted that, the correctness and reliability of the developed program was tested first by comparing its results in the classical bundle solution with the corresponding ones output from the LPS software, since nearly identical 3D ground coordinates were obtained for the generated tie points. In addition, the output values of both intrinsic and extrinsic orientation parameters, in addition to the 3D coordinates of all exposure stations, were taken as starting data for constrained bundle adjustment.

Shortly and in a matrix form, the linearization of the collinearity condition equations can be expressed and extended, as follows:

$$B.V + A1.\Delta 1 + A2.\Delta 2 + W1 = 0, \quad (1)$$

in which, ( $B$ ) is the coefficient matrix of the vector of residuals of the observations for the observed image coordinates of all involved object points, in all images, and the 3D ground coordinates of control points; ( $A1$ ) and ( $A2$ ) are the coefficient matrix of the first and second set of unknown parameters ($X1$)

and $(X2)$, which are all orientation parameters and 3D coordinates of tie points respectively; $(\Delta 1)$ and $(\Delta 2)$ are the solution vectors or corrections to be added to the approximate values of both sets of unknowns; and $(W1)$ is the misclosure vector of the linearized collinearity condition equations. In addition, baseline distance constraints are used to strengthen the photogrammetric solution. The inclusion of a distance constraint between any two points requires the linearization of the following equation:

$$D_{ij} = \left[ (\overline{X}_i - \overline{X}_j)^2 + (\overline{Y}_i - \overline{Y}_j)^2 + (\overline{Z}_i - \overline{Z}_j)^2 \right]^{1/2}, \qquad (2)$$

where $\overline{X}_i, \overline{Y}_i, \overline{Z}_i, \overline{X}_j, \overline{Y}_j, \overline{Z}_j$ are the coordinates of the corresponding 3D perspective centers and ($D_{ij}$) is the estimated value of the distance between them. Thus, linearization yields:

$$A3\Delta 1 + W2 = 0, \qquad (3)$$

in which, ($A3$) is the coefficient matrix of the unknown solution vector ($\Delta 1$); and ($W2$) is the misclosure vector of the linearized constraint condition equations.

The main effect of the inclusion of one baseline distance through Equation (3) into Equation (1) is to constrain the two perspective centre positions. The final solution of both sets of unknowns besides their corresponding accuracy can be found in Ragab, 2003. It is worthwhile to be mentioned that, as the perspective centers are part of the bundle adjustment solution, they neither add any additional unknowns to the system nor need additional image observations. The baseline distance constraints only add additional rows to the design matrix.

## 5. COMPUTATIONAL RESULTS

This section is devoted to the manipulation and analysis of the results obtained from both geodetic and photogrammetric approaches in the field of volume computation of a certain hill.

### 5.1 Volume Computation by Geodetic Technique

At first the total station grid leveling data was downloaded from the instrument and exported to the surfer software to form the contour lines of the test volume as well as the calculation of the accurate volume of chosen Earthwork. Such volume was computed and found to be 749.96 $m^3$. As mentioned earlier, this computed volume using classical and widely common ground surveying technique is considered the most accurate technique for determination of the test volume and will be considered the true value of this volume to which other processing techniques and search cases will be compared to.

### 5.2 Volume Computation by Photogrammetric Technique

To reach at the maximum accuracy of the used combined digital system, all available data sets, mentioned previously in section 4, are processed by bundle adjustment using commercial LPS software and/or the developed MATLAB program. In all solutions, the resulted volume is compared and assessed relative to the corresponding one associated with the geodetic technique, as it is considered the most precise one. Before digging into the assessment of each data set, a brief preliminary comparison between geodetic and classical photogrammetric techniques is presented in Table 1, in terms of time spent to accomplish both field data acquisition and processing.

Table 1: Comparison of data acquisition, preparation, processing and output time

| Technique | Tasks (minutes) | | | | |
|---|---|---|---|---|---|
| | Field Planning | Data Acquisition | Data Transfer | Data Processing and Volume Computation | Total |
| Geodetic | 10 | 80 | 5 | 35 | 130 |
| Photogrammetric | 25 | 30 | 5 | 30 | 90 |

Concerning the output computed volume, all the obtainable results are listed in Tables 2 and 3, associated with each data set absolutely and relatively to the corresponding geodetic one. Table 2 compares between both stand-alone photogrammetry (necessitating ground control points) and GPS-enabled photogrammetry (no ground control points), whereas Table 3 shows the influence of reducing the number of ground control points on the final accuracy of computed volume using both unconstrained and constrained bundle adjustment mathematical models, considering the privilege of GPS-enabled digital camera.

On the basis of the tabulated results in table 1, the close range photogrammetric technique, when compared to the classical geodetic technique, has nearly 30% advantage in terms of time saving for Earthwork volume computation of the tested hill. Aside of this time advantage is the cost of the main used equipment of GPS-enabled camera, which is around five times cheaper than the regular total station, not to mention the recent prices of more advanced total stations. This price comparison is considered, regardless the cost of tribrach, reflector prism(s) and used targets.

Table 2: Stand-alone and GPS-enabled photogrammetric results

| Data Set | No. of GCP | No. of Tie Points | Volume ($m^3$) | Accuracy (%) |
|---|---|---|---|---|
| Stand-alone | 4 | 117 | 721.46 | 96.2 |
| GPS-enabled | 0 | 82 | 684.71 | 91.3 |

Table 3: Effect of ground control points reduction

| No. of GCP | No. of Fixed Exposure Station | No. of Tie Points | Bundle Adjustment | | | |
|---|---|---|---|---|---|---|
| | | | Unconstrained | | Constrained | |
| | | | Volume ($m^3$) | Accuracy (%) | Volume ($m^3$) | Accuracy (%) |
| 1 | 3 | 86 | 688.46 | 91.8 | 692.21 | 92.3 |
| 2 | 2 | 94 | 699.71 | 93.3 | 711.71 | 94.9 |
| 3 | 1 | 110 | 715.46 | 95.4 | 724.46 | 96.6 |
| 4 | 0 | 117 | 721.46 | 96.2 | 731.21 | 97.5 |

From Table 2, one can clearly predict the great efficiency of the close range photogrammetry, when compared to geodetic method, since only about 3.8 % as an error in the final computed earthwork volume for the tested hill has occurred. This is, of course, insignificant discrepancy considering the time saving in data acquisition besides the less number of needed personnel to accomplish the mission, as well as the cost of the whole equipment. Moreover, even in the case of GPS-enabled digital camera with no ground control points, the obtained accuracy of computed volume can be acceptable in some cases especially in risk or landslide area in which the conventional geodetic terrestrial methods are impossible to be applied for gathering information.

In addition, revealing the results listed in Table 3 indicate the powerful of applying the constrained bundle adjustment in the processing of images acquired by the GPS-enabled digital camera. This is obviously noticeable according to the high achievable accuracy in case of using all available four ground control points, compared with its corresponding one by classical photogrammetry listed before in Table 2. The 97.5 % accuracy is nearly the same or better compared with the laser scanner results, gained previously by many researchers in the same field, taking into account the cost and time for data acquisition of laser scanners (e.g. Yakar et al., 2010). This finding is also verified in Table 3, since using two or three control points and constraining the distances among exposure stations yields nearly the same results by using four control points in classical photogrammetry, which is a remarkable benefit in Earthwork volume computation. Note that in Table 3, regarding changing the number of ground control points used, the results shown here are for the most accurate combination of control points after altering different combinations of control points, which still showed similar if not identical accuracy of computed volume, that is with very slight discrepancies.

## 6. ASSESSMENT AND EVALUATION

As a complementary study for testing the efficiency of close range photogrammetry in Earthworks volume computations, with its proposed methodology in data capture and data processing, some additional assessment criteria are to be illustrated graphically herein. Of course, this graphical assessment will be presented only for the output results of the distances constrained bundle adjustment for the captured images, which proved computationally to be practically applied in this field of interest rather than the conventional geodetic method. This will be done firstly by quick glance of the output contour lines and 3D representation of the tested hill as shown in Figures (5) and (6) respectively, which nearly give identical configurations for both geodetic and photogrammetry methods.

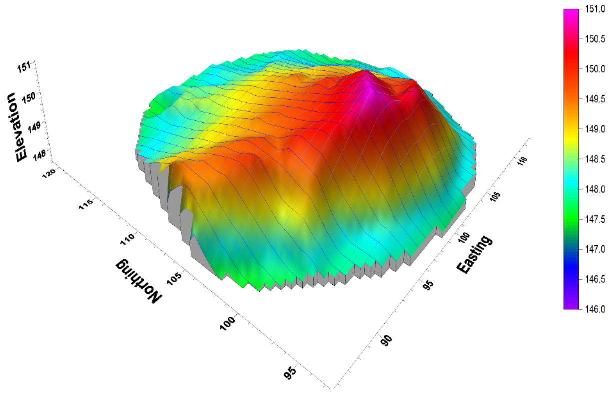


Figure 5 3D representation of the ground of the test area using total station

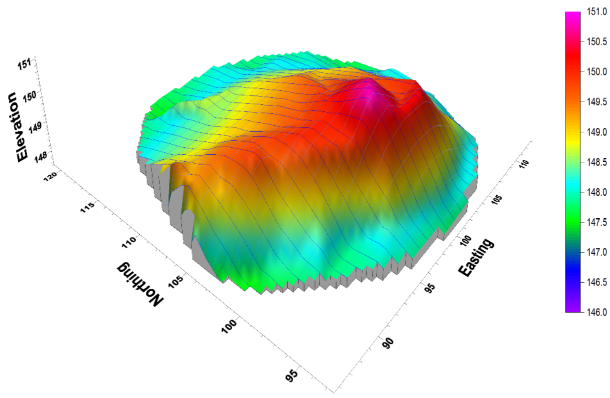


Figure 6 3D representation of the ground of the test area using constrained bundle adjustment

This can be visualized through the contour differences between both techniques shown in Figure 7, verifying the homogeneity of distribution of these differences among the whole area. In addition and to ensure the previous finding, Figure (8) illustrates a certain profile showing significant height variations taken along the middle of the test volume in North-South direction. From this figure, one can easily notice slight height discrepancies between both illustrated methods along the selected section, with a maximum value of nearly 0.2 m, which also assures the strength of this methodology. Moreover, great discrepancies occurred in case of using the GPS-enabled digital camera without ground control points, up to 1.97 m, which indicates its non-applicability to be used in case of longitudinal and/or cross sections in roads and highway engineering, although it is not illustrated here.

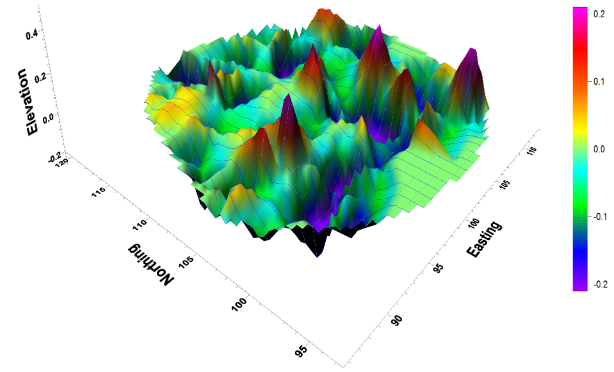


Figure 7 Discrepancies between the ground representation using total station and constrained bundle adjustment

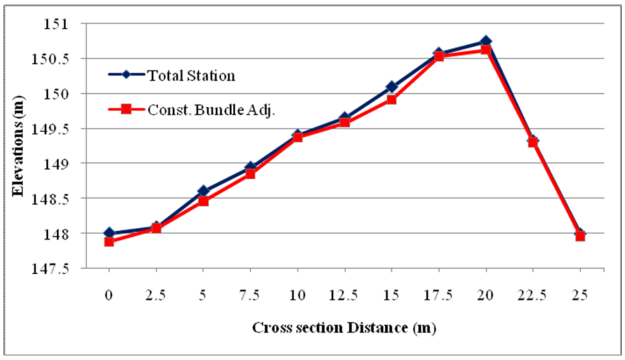


Figure 8 Profiling of total station and constrained bundle adjustment techniques used for volume computation of test area

## 7. CONCLUSIONS

Based on the shown results presented in Tables 1, 2 and 3, as well as illustrated in Figures 5, 6, 7 and 8, the use of GPS-enabled digital close range photogrammetry proved to be beneficial for computing and 3D modeling of Earthworks, through the determination of planimetric coordinates or even more importantly the height component. This is well illustrated from different aspects, starting with the time saving of the whole process when compared to terrestrial technique, and then throughout the high accuracy and reliability of the computed volume when compared to the accurate total station grid leveling technique. In addition to that, and most importantly the applicability of this technique in landslides and unstable areas, which on the contrary not the case for total station or any other terrestrial technique. In the latter technique, instruments, tools and manpower are necessary, working nearby these landslides, which is considered dangerous and unsafe. This of course, pays off very well in confining tragic situations and disaster management.

Moreover, constrained bundle adjustment produces extra strengthen to the whole process of bundle solution by increasing the accuracy and reliability in the computation of both the interior and the exterior orientation parameters, and hence the accuracy of the final computed Earthworks volume. However, this additional constraint forms extra programming and processing burden, but can be ignored considering its great privilege in decreasing the number of required ground control points which, in turn, save time, cost and disasters.

As further practical and computational works, regarding such useful GPS-enabled close range photogrammetry for Earthworks volume computation technique presented here, it could be studied and extended for its capability of extraction of profiles and cross section, which -if it proves successful- could boom the use of this technique. Also and similarly, other constant relative rotations between cameras might be considered as valid constraints to be investigated. This may yield to more mathematical effort and slightly more complicated formulation that would result from the inclusion of a higher number of additional equations, whereas the implementation of the baseline distance constraints is relatively straightforward.

## REFERENCES

- Cardenal, J.; E. Mata; J.L. Perez-Garcia; J. Delgado; M.A. Hernandez; A. Gonzalezb; and J.R. Diaz-de-Teran 2008. Close Range Photogrammetry Techniques Applied to Landslides Monitoring. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Beijing , China, Vol. XXXVII, Part B8.

- Du, J. and H. Teng 2007. 3D Laser Scanning and GPS Technology for Landslide Earthwork Volume Estimation. *Automation in Construction* 16, 657-663.

- Kiat, J. T. 2007. On-Bank Volume Estimation Using Close Range Photogrammetry for Quarry Production", *M.Sc Thesis*, Faculty of Civil Engineering, University of Teknologi, Malaysia.

- Lerma, J. L.; S. Navarro; M. Cabrelles and A. E. Segui 2010. Camera Calibration with Baseline Distance Constraints. *The Photogrammetric Record* 25(130):140-158.

- Ragab, A. F. 2003. An Advanced Analytical Technique for Data Processing and Improving the Results of Close Range Photogrammetry for Recording of Monuments. *Ph.D. Thesis*, Faculty of Engineering, Ain Shams University, Egypt.

- Ragab, A. F. and A. E. Ragheb 2010. Efficiency Evaluation of Processed Photogrammetric Data Captured by GPS Digital Camera. *World Applied Sciences Journal* 8 (4): 414-421, ISSN 1818-4952.

- Yakar, M.; H. M. Yilmaz and O. Mutluoglu 2008. Data Collecting to Volume Computing Using Digital Close Range Photogrammetry and Laser Techniques. *Integrating Generations, FIG Working Week*, Stockholm, Sweden.

- Yakar, M.; H. M. Yilmaz and O. Mutluoglu 2010. Close Range Photogrammetry and Robotic Total station in Volume Calculation. *International Journal of the Physical Sciences*, Vol. 5 (2), pp. 086-096.

- Yilmaz, H. M. 2010. Close Range Photogrammetry in Volume Computing. *Society for Experimental Mechanics*.