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Evaluation of GPS Data in Point Feature and 3D Building Modeling

Prof. Dr. Essam M. Fawaz, Prof. Dr. Said A. El-Maghraby, Dr. Mostafa H. Mohamed and Eng. Mohamed A. El-Shewy

Al Azhar University, Faculty of Engineering, Cairo, Egypt.

E-mail: shewe51@yahoo.com

Abstract— Recent years have seen significant improvements in the performance of the Global Positioning system (GPS) in different applications with different accuracy level. 3D building modeling has made a rapid development parallel to the technology, especially with the using of these models becomes more frequent than it was before. Hence, the present paper investigates the quality of the GPS observations in point feature (with different session duration) and 3D building modeling comparing with total station observations using Root Mean Square Error (RMSE) and quality indices. The quality indices are the detection rate (ρd), the quality rate (ρq), the branch factor (ρb), the miss factor (ρm) and the false alarm rate (ρf). These factors depend on the relations between the intersection or union areas for the reference (total station) and tested (GPS) data. The results supported by statistical analysis showed that, for point feature the discrepancy between fast static GPS coordinates and total station coordinates show about 13 mm as position mean value, while the maximum position error 40 mm. The errors decrease with the increase in session duration until five minutes, while after that the errors decrease with no significant effect. For 3D building modeling, the RMSE for the differences between total station and GPS observations for the top points is 0.143 m but it becomes 0.006 m when the observations of points beside obstacles are removed. The RMSE for the differences between total station and GPS observations for the bottom points is 0.061m. The values of two quality indices (ρd and ρq) are close to one and the other three quality indices are close to zero. This means that the characteristic of planes extracted from both datasets are closed with a good quality.

Key Words— 3D building modeling, Fast Static, GPS Accuracy, Quality Indices, RMSE, Session Duration.

1 Introduction

GPS plays a fundamental role in many applications, Owing to the ability for provide worldwide, three dimensional, all weather position, velocity and time synchronization. GPS provides continuous positioning and timing information, anywhere in the world under any weather conditions. The two fundamental GPS measurements for position determination are pseudorange and Carrier phase observation. The level of carrier phase measurement noise (at the mm level) is much lower than the level of pseudorange measurement noise (typically at the meter level) [9]. There are two methods by which a station position can be derived; Single Point Positioning (SPP) or Relative Positioning (RP). Single Point Positioning, When GPS observations made at only one particular station are used to independently derive the position coordinates of the point with respect to the reference frame WGS-84, the positioning technique is referred to as single point positioning. This technique can be further divided into two classes depending on the measurements used, namely pseudorange-based point positioning and carrier phase-based point positioning.

Carrier phase-based differential positioning can be classified, depending on the status of the rover receiver and the period of observation as static, fast static, kinematic or real-time kinematic. Static GPS surveying with the carrier-phase measurements is the most accurate positioning technique. This is mainly due to the significant change in satellite geometry over the long observation time span.

Fast, or rapid, static surveying is a carrier-phase based relative positioning technique similar to static GPS surveying. The rover receiver remains stationary over the unknown point for a short period of time only, and then moves to another point whose coordinates are unknown. This method is suitable when the survey involves a number of unknown points located in the vicinity of a known point. After collecting and downloading the field data from both receivers, the PC software is used for data processing. Depending on whether enough common data was collected, the software may output a fixed solution, which indicates that the ambiguity parameters were fixed at integer values. Otherwise, a float solution is obtained, which means that the software was unable to fix ambiguity parameters at integer values. A fixed solution means that the positioning accuracy is at the centimeter level while the float solution means that the positioning accuracy is at the decimeter or sub meter level [5].

Accurate 3D building models for a city are useful for a variety of applications such as simulation for 3D planning, GIS applications and fly through rendering. These different of information for 3D building models are computed or obtained from different data sources. For example, information such as the roof boundary or height can be obtained by using aerial images or LIDAR (LIght Detection And Ranging) data or GPS data.

2 Literature Review

Many researches have been carried out on accuracy assessment for GPS data. Some of these researches have been evaluated the accuracy of static GPS technique with duration; the

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proposed time can be reduced with increasing the number of tracking satellites using differential static technique [7]. The duration of observation is the critical factor in the determination of the baseline length [3]. The session duration, as a guide rule, should be about 10 minutes + 1 min/km for single frequency receivers [4]. As the time window increase as the error in baseline decrease, there are no effective differences in coordinates result from short time window in case of small baselines [1].

In addition, some of these researches have been evaluated the accuracy of static GPS technique with traditional surveying; static results show that on a typical day when single frequency data is processed with broadcast orbit and clock data, the RMS of the changes in the position errors over a 50-second interval is about 5.6 cm in northing, 3.9 in easting and 10.2 cm in height. When using precise orbits and clocks, in addition to dual frequency data, these values improve by 46-54% to 2.6 cm in northing, 2.1 cm in easting, and 4.7 cm in height [10]. Static GPS campaigns with 10-hour duration, the mean differences in coordinates components were following: 1.6 mm in North and 1.2 mm in East [6]. The discrepancy between static GPS coordinates and total station coordinates shows about 9mm as horizontal mean value and the RMSE is about 2cm, while the maximum horizontal error is about 4cm [1]. The horizontal positional discrepancy P2d between the single and dual frequency data has a mean value of 11.5mm with 3.5mm standard deviation, while the spatial positional discrepancy P3d has a mean value of 14.2mm with standard deviation 4.2mm [2].

3 Aim and Objectives

Our research aims to evaluate the accuracy of GPS data in two cases by comparing the observed data from GPS technique (fast static) using dual frequency receivers with traditional surveying techniques (total station). In the first case, the GPS data is evaluated in Point feature (with different session duration). In the second case, the GPS data is evaluated using 3D building modeling (two models extract from GPS and total station data). The evaluation has done using two methods (computing RMSE and calculating a set of indices).

4 Methodology

4.1 Evaluation of GPS Data in Point Feature

The methodology of our investigation will base on the statistical analysis of the discrepancies behavior in the position for point's observations from GPS and total station by computing RMSE. This is done by measuring six control points (two known and four unknown) using total station and fast static GPS technique. For fast static GPS surveying, the points were occupied by the receivers with different session duration (1, 5, 10, 15, 30 minutes). Precise ephemeris was used for the processing. The coordinates from GPS observation with different duration were compared with total station coordinates.

4.2 Evaluation of GPS Data in 3D Building Modeling

The used method to evaluate the accuracy of the GPS data in 3D building modeling will based on the comparison between two models for building. The two models were extracted from total station and GPS observations.

4.2.1 3D Building Modeling

In order to modeling the building, the geometry of objects (roofs, walls, and footprints) is extracted from total station and GPS data. The flowchart of the semi-automatic approach is depicted in Fig. 1. The first step of building reconstruction is finding the coordinates of the roof corners surfaces. Then, the mean plane of the ground surface is created by observing points on the ground and fitting their surface. After that, the projection of the roof corners points onto the ground is done in order to obtain footprints and thus to create the walls. Finally, planes of faces and footprints are created. The reconstruction approach is based on the assumption that: (a) every solid object can be described by a decomposition of its boundaries; (b) the walls are vertical and reach either the ground or another surface of the constructed model. The wall surfaces can be constructed using the projection of outlines of the roofs onto the ground surface as shown in Fig. 1.

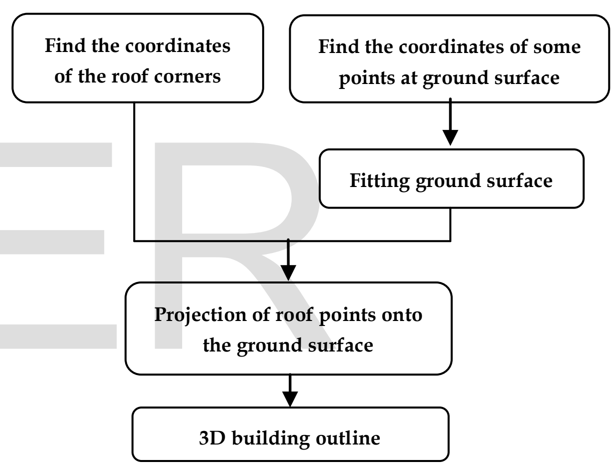

Fig. 1. Flowchart of 3D building modeling.

4.2.2 Building Modeling Evaluation

The used method to evaluate the accuracy of the GPS data in 3D building modeling is based on the comparison between two models for building which are extracted from total station and GPS observation by two methods. The first method, computed the mean value and the RMSE for the difference between GPS and total station coordinates for the building's corners (top and bottom). The second method, comparison of 3D planes of two building models (reference “total station” and test “GPS”) by calculating a set of indices. These indices could be summarized in these equations:-

The detection rate (ρd) is the ratio between the intersection area between two planes and the reference plane. If the rate is close to one, then the data will be of good quality.

$$\rho d = (Ar \cap At) / Ar \qquad \rho d = \in [0:1]$$

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The branch factor (ρb) is the ratio between the area of the reference plane not included in the plane intersection and intersection area between two planes. The factor is always positive and if the factor is close to zero, then the data will be of good quality.

$$\rho b = (At \setminus Ar) / (Ar \cap At) \qquad \rho b \geq 0$$

The miss factor (ρm) is the ratio between the area of the tested plane that is not included in plane intersection and intersection area between two planes. The factor always positive and if the factor is close to zero then the data will be of good quality.

$$\rho m = (Ar \setminus At) / (Ar \cap At) \qquad \rho m \geq 0$$

The quality rate (ρq) is the ratio between the intersection area between two planes and the union of two planes. If the rate is close to one then the data will be of good quality.

$$\rho q = (Ar \cap At) / (Ar \cup At) \qquad \rho q = \in [0:1]$$

The false alarm rate (ρf) is the ratio between the area of the reference plane not included in the plane intersection and the reference plane. The factor is always positive and if the factor is close to zero then the data will be of good quality.

$$\rho f = (At \setminus Ar) / Ar \qquad \rho f \geq 0$$

The principle idea of these quality indices is based on the relation between the reference surface area "Ar" (total station data) and the tested surface area "At" (GPS data) [8], see Fig. 2. As the increase of the intersection area between the reference surface area and the tested surface area as datasets are closed with a good quality.

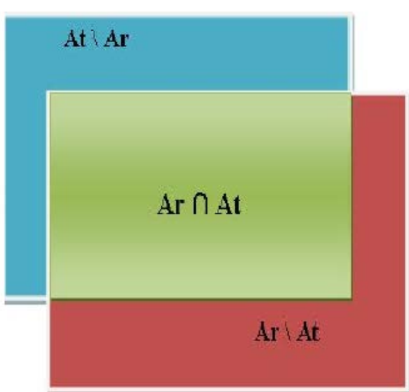

Fig. 2. Relationship between reference and tested models in 2D.

5 Experimental Works and Results

5.1 The Study Site and the Data Used

The field test is located at Al-Azhar University, Cairo, Egypt, (N30°03'22" and E31°18'54"). The civil engineering building is used for 3D building modeling see Fig. 3. Trimble R4 GPS system (dual frequency) is used to collect GPS observations. Trimble Business Center 2.2 software is used to process all GPS observations. A total station TOPCON (GTS-723) is used for collecting classical surveying observations.

Fig. 3. The civil engineering building at Al-Azhar University.

5.2 Point Feature Fieldwork

To evaluate the accuracy of the GPS surveying, primary, it has been established a six control points, two known points (M1 and M2) and four unknown points (M3, M4, M5 and M6) with distances between 60 m to 250 m as shown in Fig. 4. It has been made the line M1 M2 as a base line for total station observations. The coordinates of points (M3, M4, M5 and M6) were measured by total station and GPS (fast static) technique. During the collecting observation process using fast static technique the reference receiver stationary on point M1 where the unknown points were occupied by the second receiver with session duration (1, 5, 10, 15, 30 min.). The logging interval is 5 Sec, the elevation mask is 15º and PDOP between 2 to 5. Precise ephemeris was used for post processing.

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Fig. 4. The study area for GPS data evaluation with session duration.

Total station observations were done for these points (M3, M4, M5 and M6). The point M2 was occupied by total station and point M1 as back sight point while the points M3, M4, M5 and M6 were observed. To find out the accuracy of GPS positioning, the differences between total station coordinates and the coordinates obtained by GPS were calculated using equation 1 and the results are given in Table 1.

Difference (error) = Total Station coordinates – GPS coordinates. (1)

$$\text{Error Vector} = \sqrt{\delta E^2 + \delta N^2 + \delta h^2}$$

TABLE 1

DIFFERENCE BETWEEN TOTAL STATION AND GPS COORDINATES WITH SESSION DURATION.

Points	Session Duration	Difference in Coordinates			Error Vector
		δE(m)	δN(m)	δh(m)	
M3	1 Min.	0.007	-0.003	0.011	0.013
	5 Min.	0.009	-0.003	0.012	0.015
	10 Min.	0.007	-0.001	0.007	0.010
	15 Min.	0.006	-0.002	0.010	0.012
	30 Min.	0.004	-0.004	0.014	0.015
M4	1 Min.	0.002	-0.003	0.005	0.006
	5 Min.	0.001	0.001	0.007	0.007
	10 Min.	0.012	-0.001	0.012	0.017
	15 Min.	0.022	-0.002	0.001	0.022
	30 Min.	0.010	0.000	0.008	0.013
M5	1 Min.	-0.011	-0.008	-0.004	0.014
	5 Min.	-0.010	-0.009	0.001	0.013
	10 Min.	-0.008	-0.004	0.000	0.009
	15 Min.	-0.006	-0.009	0.001	0.011
	30 Min.	-0.010	-0.004	0.001	0.011
M6	1 Min.	-0.010	-0.006	-0.037	0.039
	5 Min.	-0.007	0.001	-0.006	0.009
	10 Min.	-0.007	0.003	-0.004	0.009
	15 Min.	-0.007	0.002	-0.007	0.010
	30 Min.	-0.006	0.002	-0.008	0.010

As a measure of accuracy, the mean and the RMSE for the differences between total station and GPS observations were determined. Fig. 5 shows the relation between session duration and mean error. Fig. 6 shows the relation between session duration and RMSE.

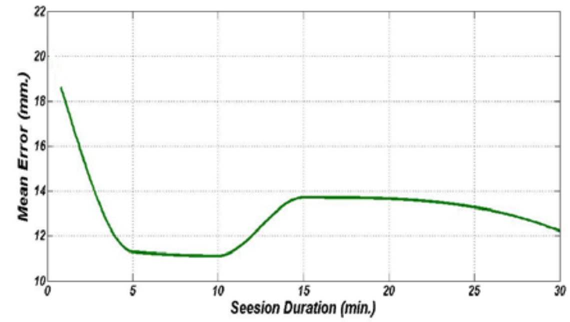

Fig. 5. Relation between GPS session duration and the mean for differences between total station and GPS observations.

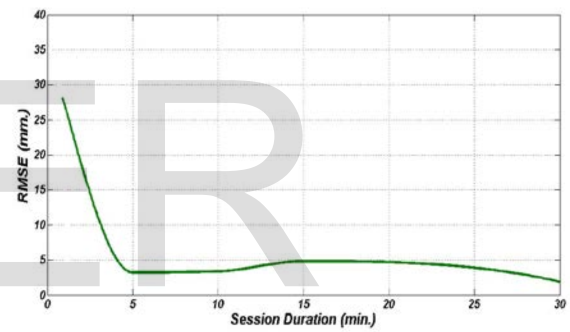

Fig. 6. Relation between GPS session duration and the RMSE for differences between total station and GPS observations.

Table 1 and Figures 5, 6 show that, the discrepancy between fast static GPS coordinates and total station coordinates show about 13 mm as position mean value, while the RMSE for the position is about 8mm with maximum position error 40 mm. The GPS observations provide results close to the observations from total station. In case of small baselines, there is no effective discrepancy in the coordinates result from duration five minutes and duration thirty minutes. In addition, as the session duration increase, the accuracy level may not also be raised. The reason for that contradiction is due to the nature of the GPS satellites constellation statues relative to the rover location at the observation time. The suitable observation time with high satellite numbers and low GDOP (Geometric Dilution of Precision) can be defined at the GPS planning stages.

5.3 3D Building Modeling Fieldwork

To evaluate the accuracy of the GPS data in building modeling, a twelve point were fixed above the top corners of the building (a1, a2, a3, a4, a5, a6, a7, a8, a9, a10, a11 and a12) as

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shown in Fig. 4. Once the points were fixed, the next step was establishing a closed travers (M2, M6, A, B, C, D and E) around the building used to find the coordinates of the points by total station. For GPS observation, the reference receiver is sited on point M1 where the unknown points were occupied by the second receiver with session duration 10 min. The logging interval was 1 Sec with elevation mask 15º and PDOP between 2 to 5. Precise ephemeris was used for post processing.

In order to find the coordinates of the bottom corners of the building, same points around the building were measured by total station and GPS. For GPS observation, the reference receiver was sited on point M1 where the unknown points were occupied by the second receiver with session duration 1 min and the logging interval was 1 Sec. The next step was programmed the Matlab toolbox to extract the parameters of the mean plane for building´s footprint by these points. Fig. 7 and Fig. 8 show the mean plane for GPS and total station observation using Matlab functions respectively.

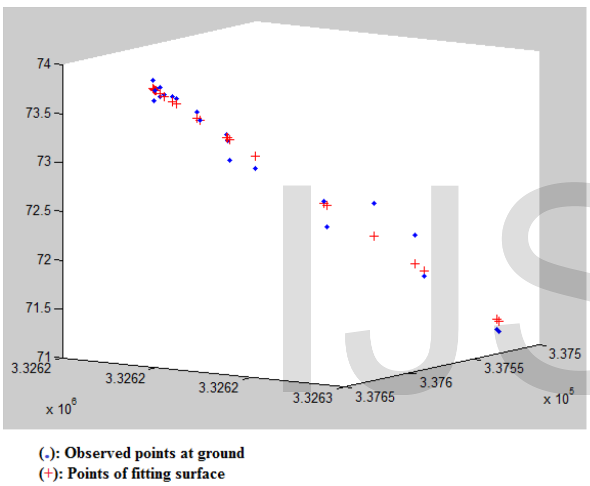

Fig. 7. The mean plane for building´s footprint using Matlab functions (GPS observations).

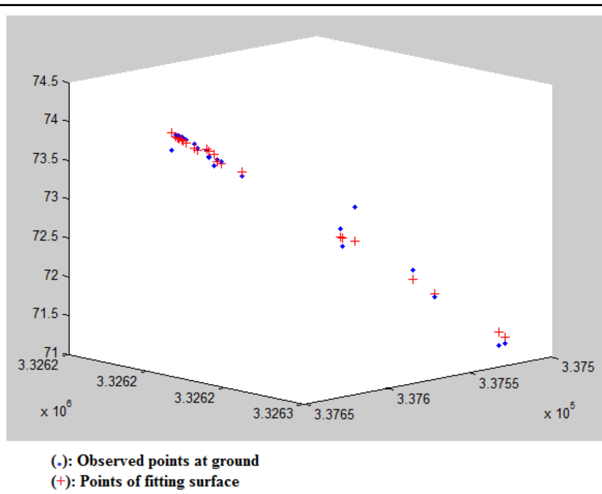

Fig. 8. The mean plane for building´s footprint using Matlab functions (total station observations).

To get the coordinates of the bottom corners for the building (d1, d2, d3, d4, d5, d6, d7, d8, d9, d10, d11 and d12), the top corners points were projected on the mean plane for building´s footprint. Now we have two models for the building (from total station and GPS observations) and twenty-four point represent the top and the bottom corners of the building as shown in Fig. 9. In addition, we have twelve surfaces for the building, four top surfaces and ten side surfaces.

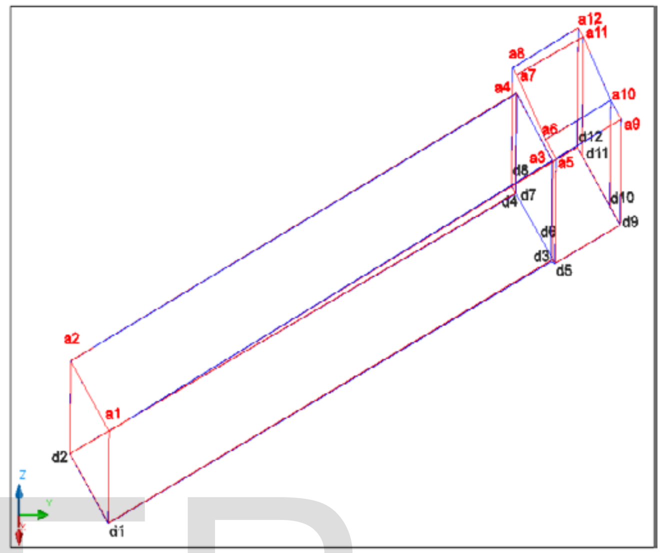

Fig. 9. 3D models for the building from total station and GPS observation.

The coordinates from GPS observation were compared with the coordinates from total station. The positional discrepancies were calculated and the position RMSE for the differences is determined and given in Table 2.

TABLE 2

STATISTICS FOR GPS RESULTS COMPARING WITH TOTAL STATION FOR THE TOP AND BOTTOM CORNERS OF THE BUILDING.

	Top Points with a3 and a4	Top Points without a3 and a4	Bottom Points
Mean (m)	0.078	0.022	0.199
Max. Dif. (m)	0.526	0.035	0.367
Min. Dif. (m)	0.013	0.013	0.132
RMSE (m)	0.143	0.006	0.061

Due to the presence of an obstacle (the upper part of the building) beside the two points a3 and a4 as shown in Fig. 3, this led to the observation of GPS for these points not good and the positional discrepancies at point a3 is 0.526m and at point a4 is 0.19m. The position RMSE for the differences to the top points with a3 and a4 is 0.143m but it become 0.006m when the observations for a3 and a4 were removed. The position RMSE for the differences to the bottom points is 0.061m.

For quality evaluation of the building surfaces, The Matlab toolbox was programmed to calculate the parameters of the mean planes for the twelve surfaces (from total station and GPS). After the mean planes for the building extracted, the Mean Distance (MD) between the surfaces (from total station and GPS observations) and the mean planes (from Matlab) are calculated. Table 3 shows the MD value.

TABLE 3

MEAN DISTANCE BETWEEN THE BUILDING'S SURFACES AND THE MEAN PLANES.

Plane no.	MD for Total Station (m)	MD for GPS (m)
1	0.062	0.062
2	0.016	0.007
3	0.048	0.040
4	0.005	0.010
5	0.004	0.004
6	0.041	0.041
7	0.041	0.041
8	0.033	0.032
9	0.001	0.001
10	0.002	0.002
11	0.002	0.002
12	0.037	0.036

The results of Table 3 show that, the MD values are very small and this means that, the formed mean planes for the building well done.

The quality indices were measured for the planes, Table 4 present the results of these quality indices, which were estimated from mean planes comparisons.

TABLE 4

QUALITY INDICES ESTIMATED FROM MEAN PLANES.

Plane	ρd	ρq	ρb	ρm	ρf
1	0.9929	0.9877	0.0072	0.0052	0.0071
2	0.9961	0.9930	0.0039	0.0031	0.0039
3	0.9988	0.9967	0.0012	0.0021	0.0012
4	0.9894	0.9827	0.0107	0.0068	0.0106
5	0.9946	0.9824	0.0054	0.0125	0.0054
6	0.9967	0.9750	0.0033	0.0223	0.0033
7	0.9998	0.9927	0.0002	0.0071	0.0002
8	0.9994	0.9890	0.0006	0.0105	0.0006
9	0.9859	0.9658	0.0143	0.0211	0.0141
10	0.9961	0.9830	0.0039	0.0134	0.0039
11	0.9668	0.9327	0.0343	0.0378	0.0332
12	0.9989	0.9949	0.0011	0.0040	0.0011

Table 4 shows that, the values of two indices (pd and pq) are close to one and the other three indices are close to zero. This means that the characteristic of planes extracted from both datasets are closed with a good quality.

6. CONCLUSIONS

In this paper, we have presented an evaluation for GPS data in point feature and 3D building modeling by comparing the observed data from GPS with the observed data from traditional surveying techniques (total station). In point feature, the points were observed by GPS (fast static) with different duration. The results show that, there are insignificant differences between GPS (fast static) technique observations and total station observations (about 13mm as position mean value). As the duration of GPS increases as the difference between GPS and total station decreases, because the geometry of the satellites improves and the number of available satellites increase. In case of small baselines, there is no effective discrepancy in the coordinates obtained from five minutes duration and thirty minutes duration. In 3D building modeling, the comparison between the GPS observations and the total station observations was by two methods. In the first method, the comparison between the observations for the building's corners was by using RMSE. In the second method, the comparison was between the building's surfaces by using quality indices. The two methods results show that, the observations from both total station and GPS closed with a good quality. The obstructions have a large effect on the GPS observations. Finally, our future researchers will concentrate in study the accuracy of using GNSS constellation for civil engineering applications, as it will provide solution that is more abundant. Study the effect of multipath on the GPS observations and how to minimize its effect.

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About The Authors

(1) Prof. Dr. Essam M. Fawaz,
Department of Civil Engineering,
Faculty of Engineering,
Al-Azhar University, Egypt.
E-mail: essamfawaz2001@gmail.com
Holds a PhD in Geodesy and Photogrammetry Engineering from
Hannover University, West Germany.

(2) Prof. Dr. Said A. El-Maghraby,
Department of Civil Engineering,
Faculty of Engineering,
Al-Azhar University, Egypt.
E-mail: saidmaghraby@yahoo.com
Holds a PhD in Geodesy and Photogrammetry Engineering from
Hannover University, West Germany.

(3) Dr. Mostafa H. Mohamed,
Department of Civil Engineering,
Faculty of Engineering,
Al-Azhar University, Egypt.
E-mail: mo_sattar762003@yahoo.com
Holds a PhD in Geodesy and Photogrammetry Engineering from
Strasbourg University, France.

(4) Eng. Mohamed A. El-Shewy,
M.SC at Department of Civil Engineering,
Faculty of Engineering,
Al-Azhar University, Egypt.
E-mail: shewe51@yahoo.com
Holds a B. Sc., in civil Engineering from
Al-Azhar University, Egypt