Polytechnic Journal
Polytechnic Journal

Volume 13 | Issue 1 Article 4

9-1-2023

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How to Cite This Article

Ahmed, Shamal Fatah Mr. (2023) "Impact of Crowded Sky on GNSS Positioning," *Polytechnic Journal*: Vol. 13: Iss. 1, Article 4.
DOI: https://doi.org/10.59341/2707-7799.1728

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Abstract

Presently, there is a huge number of Global Navigation Satellite System (GNSS) satellites in orbit, and it is possible for users to have a clear view with a high number of satellites at a single epoch. This large number of satellites results in a significant improvement in satellite geometry, visibility, Dilution of Precision (DOP), and simultaneously, reduction of occupation time and sufficient time to fix the integer ambiguity. The static method is the most accurate method to establish geodetic networks using satellites, but the length of time required for the survey and the post-processing of the data may restrict its applicability. This paper investigated the impact of increasing number of satellites, regardless the type of the system, on occupation time and evaluating accuracy in static method with a 13 km baseline length. The observations were assessed and compared to the accuracy obtained from different satellite numbers in different periods. The results indicate that by increasing satellite's number from 4 to 20, the occupation time reduces by 83% from 30 min. to 5 min., and position dilution of precision (PDOP) reduces from 5.30 to 1.4.

Keywords

GNSS, occupation time, PDOP, static method, accuracy.RESE A RCHART I C L E

Polytechnic Journal. 2023. 13(1)
ISSN: 2313-5727
http://journals.epu.edu.iq/index.php/polytechnic

POLYTECHNIC JOURNAL

RESEARCH ARTICLE

Impact of Crowded Sky on GNSS Positioning

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Received: 23February 2023
Accepted: 15 June 2023
Published: 20 September 2023

DOI: https://doi.org/10.59341/2707-7799.1728

ABSTRACT

Presently, there is a huge number of Global Navigation Satellite System (GNSS) satellites in orbit, and it is possible for users to have a clear view with a high number of satellites at a single epoch. This large number of satellites results in a significant improvement in satellite geometry, visibility, Dilution of Precision (DOP), and simultaneously, reduction of occupation time and sufficient time to fix the integer ambiguity. The static method is the most accurate method to establish geodetic networks using satellites, but the duration of time required for the survey and the post-processing of the data may restrict its applicability. This paper investigated the impact of increasing number of satellites, regardless the type of the system, on occupation time and evaluating accuracy in static method with a 13 km baseline length. The observations were assessed and compared to the accuracy obtained from different satellite numbers in different periods. The results indicate that by increasing number of satellites from 4 to 20, the occupation time reduces by 83% from 30 min. to 5 min., and position dilution of precision (PDOP) reduces from 5.30 to 1.4.

Key Words: GNSS, occupation time, PDOP, static method, accuracy.

1-INTRODUCTION

The Global Navigation Satellite System (GNSS) covers different kinds of applications and accuracies in navigation and positioning. Absolute positioning and differential positioning, also known as relative positioning, are the two methods typically offered by GNSS. When operating in absolute mode, the position is figured out with reference to the predicted orbits of the satellites. Surveying tasks cannot be performed with the required degree of accuracy using this method (Enge *et al.*, 1996; Hofmann-Wellenhof *et al.*, 2001). Differential positioning allows for the acquisition of highly accurate results. Differential GNSS (DGNSS) needs the use of at least two receivers, both of which must operate at the same time. This technique is based on spatial correlation of systematic errors between receivers to estimate or reduce their effects (Enge *et al.*, 1996; Hofmann-Wellenhof *et al.*, 2001; Seeber, 2008). Depending on the type of survey and the capabilities of the receiver, various field procedures have been developed. Currently, kinematic, pseudo kinematic, fast static, and static methods are employed in surveying. All these methods rely on carrier phase-shift measurements and use relative positioning techniques; that is, at least two receivers are set up at different stations and tracking the same satellites simultaneously. In theory, static GNSS surveying relies on concurrently collecting data from satellite signals at the base and other receivers for a certain period of time. The occupation time is defined by the number of satellites, baseline length, GDOP, and kind of equipment. Occupation time must be long enough to completely resolve the integer ambiguity in the baseline solution; hence, the greater number of satellites over the project area, the integer can be resolved more accurately and quickly (Army Corps of Engineer, 2011; Ashour *et al.*, 2022).

In this paper, the occupation time of static method was relatively short (about 60 minutes) and as reported by (Mageed, 2015; Ocalan *et al.*, 2016) a commercial software was sufficient to post process the raw data. This study's main aim is to evaluate the impact of increasing number of satellites on occupation time in static method. These evaluations might be utilized for a variety of practical purposes. In this paper, the researcher shortened the minimum time of observation to 5 minutes and analyzed the accuracy at points while the number of satellites increased from 4 to 20.

2- METHODOLOGY

2-1 Study Area

To study the accuracy evaluation of decreasing occupation time and increasing number of satellites, a 13 km length base line was chosen in Erbil city, Iraq as shown in Figure 1. Leica GS16 receivers were used for base and rover, the base was in the Tishk International University Campus (TIU) and the rover was on the Kerkuk road.

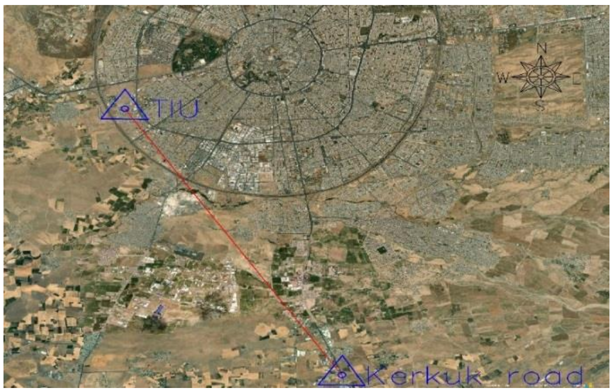

Fig. 1: Satellite Image of the Study Area

2-2 Static Method

Static GNSS surveying method is a carrier-phase relative positioning method (Teunissen and Montenbruck, 2017). This method is used when great accuracy over a great distance is required, such as in geodetic control surveys (Schofield and Breach, 2007). In this technique, two or more occupied receivers are tracking the same satellites simultaneously. The base receiver is being used by a station whose exact value is known. Another receiver is used up to a point whose values are unknown. The base receiver can work with any number of receivers (El-Rabbany, 2002). A baseline is the distance (range) between two receivers, and the ΔX, ΔY, and ΔZ coordinate differences of a baseline are derived based on the observations of those baseline's positions (Ghilani and Wolf, 2012). For GNSS observations, observing the same particular satellites simultaneously and calculating the differences between these observations can significantly reduce or eliminate the majority of errors, with the exception of some random errors such as multipath and receiver noise. This can be accomplished via GNSS double difference mode. This mode is defined as the simple subtraction of the two receivers single difference mode between satellites and receivers.

$$\Delta\Phi_{uj}^{s} = \lambda\Delta\emptyset_{uj}^{s} = \Delta\rho_{uj}^{s} + \lambda\Delta N_{uj}^{s} + c\left(\delta t_{u} - \delta t_{j}\right) + M_{\emptyset uj} + \epsilon_{\emptyset uj} \quad (1)$$

$$\Delta\Phi_{uj}^{k} = \lambda\Delta\emptyset_{uj}^{k} = \Delta\rho_{uj}^{k} + \lambda\Delta N_{uj}^{k} + c\left(\delta t_{u} - \delta t_{j}\right) + M_{\emptyset uj} + \epsilon_{\emptyset uj} \quad (2)$$

$$\nabla\Delta\Phi_{uj}^{sk} = \Delta\Phi_{uj}^{s} - \Delta\Phi_{uj}^{k} = \lambda\nabla\Delta\emptyset_{uj}^{sk} = \Delta\rho_{uj}^{sk} + \lambda\Delta N_{uj}^{sk} + M_{\emptyset uj} + \epsilon_{\emptyset uj} \quad (3)$$

$\Delta\Phi_{uj}^{s}$:is the single difference between receivers at points u and j to the satellite s.

$\Delta\Phi_{uj}^{k}$: is the single difference between receivers at points u and j to the satellite k.

$\nabla\Delta\Phi_{uj}^{sk}$: is the double difference between two points u and j and two satellites s and k.

Depending on the distance between the two receivers, errors of satellite orbital, satellite clock, receiver clock, and atmospheric are significantly reduced or eliminated (for the short baseline: all atmospheric errors will be eliminated (Ashour *et al.*, 2022; Gethin Wyn Roberts, 2019; Hofmann-Wellenhof *et al.*, 2001). Specifically, the static mode provides the highest levels of accuracy, even though the length of time required for the survey and the post-processing of the data may restrict its applicability (Hofmann-Wellenhof *et al.*, 2001; Leick *et al.*, 2015; Mader, 1992; Xu and Xu, 2016). After post-processing of the collected data, the unknown point's coordinates are determined (El-Rabbany, 2002). The occupation time using dual frequency equals (20 min + 2 min/km) according to (Ghilani and Wolf, 2012; Hofmann-Wellenhof *et al.*, 2001). On the other hand, (El-Rabbany, 2002) claims that the occupation time is 20 minutes to a few hours, and (Schofield and Breach, 2007) states that observation durations might range from 45 minutes to a few hours. A good guideline is five minutes per kilometer of baseline distance, with a minimum of fifteen minutes. In a static method, the epoch sampling rate should be the same for all receivers at the time of the observation. The relative accuracy of the static method is around (3 to 5 mm +1 ppm) (Ghilani and Wolf, 2012). Or 5 mm + 0.5 ppm for two dimensional positions and 10 mm + 0.5 ppm for the height (Uren and Price, 2018).

The accuracy of this method is the resolution of unknown cycle ambiguity in carrier-phase data into integers. Once this has been accomplished, the extremely exact carrier-phase data will function as extremely precise pseudorange navigation.

Starting with the observation equations for the pseudorange (code) and carrier-phase observables allow us to proceed with the formulation of the GNSS model for ambiguity resolution. If the j-frequency pseudorange and the carrier-phase are defined for the *r-s* receiver–satellite combination at epoch t as $P^s_{r.j}(t)$ and $\varphi^s_{r.j}(t)$, respectively, then their observation equations may be stated as follows:

$$P^s_{r.j}(t) = \rho^s_r(t) + T^s_r(t) + I^s_{r.j}(t) + cdt^s_{r.j}(t) + e^s_{r.j}(t) \quad (4)$$

$$\varphi^s_{r.j}(t) = \rho^s_r(t) + T^s_r(t) - I^s_{r.j}(t) + c\delta t^s_{r.j}(t) + \lambda_j N^s_{r.j} + \epsilon^s_{r.j}(t) \quad (5)$$

where ρ^s_r is the receiver–satellite range, $T^s_r(t)$ and I^s_r are the tropospheric and ionospheric path delays, $dt^s_{r.j}$ and $\delta t^s_{r.j}$ are the pseudorange and carrier-phase receiver–satellite clock biases, $N^s_{r.j}$ is the time-invariant integer carrier-phase ambiguity, c is the speed of light, λ_j is the j-frequency wavelength, and $e^s_{r.j}$, $\epsilon^s_{r.j}$ are the remaining error terms respectively (Teunissen and Montenbruck, 2017).

The solution is referred to as a float solution when the double differences are calculated as non-integer real values. The solution is fixed when ambiguities are rounded to integers and constrained. In general, the fixed integer solution yields the most accurate positional results (El-Rabbany, 2002).

The robustness of satellite geometry can, as is already well-known, eliminate or reduce some errors and biases; however, an increase in the number of recipient satellites is one thing that helps to obtain good satellite geometry. In most cases, improved satellite geometry is the result of receiving a greater number of satellite signals (Ashour et al., 2022; Qu et al., 2013; Steer, 2021). Generally, the GDOP parameter declines as the number of satellites in view rises, and the processing difference between all-in-view and a well-selected subset of satellites is normally negligible (Blanco-Delgado and Nunes, 2009). After checking for cycle slip and multipath, the increased number of satellites strengthens the orbit geometry, which leads to an increase in precision and accuracy, a reduction in initialization times, and an increase in the overall availability of the system. Furthermore, using a combination of multiple GNSS can lead to significant improvements in many applications (Ferrão, 2013).

2-3 Post-Processing

Processing GNSS data may be done using several different software programs that are available. These software packages have been created by academic institutions and government agencies that are actively engaged in research for the purpose of commercial daily processing of GNSS data for surveying activities all over the world, as well as for high precision scientific applications. The following are some examples of scientific products using GNSS: The Massachusetts Institute of Technology (MIT) is responsible for the development of GAMIT, GLOBK, and TRACK. The Jet Propulsion Laboratory (JPL) is responsible for the development of GIPSY-OASIS II. Applied Research Laboratories ARL at the University of Texas in Austin is responsible for the development of GPSTk. Bernese is developed by the Astronomical Institute of the University of Bern (AIUB). On the other hand, there are more GNSS commercial software packages that can be bought and are presently offered for sale and obtained by purchasing them (Enge et al., 1996). These products are utilized in the everyday GNSS job. There are several software programs including: LGO: Leica Geo Office and leica infinity softwares which are both developed by Leica Company. TBC: Trimble Business Center software developed by Trimble Company. Topcon MAGNET software developed by Topcon Company. The main differences between scientific software and commercial software are (Seeber, 2008): Scientific software is instrument-independent and accepts data in RINEX format, allowing for the modeling of errors' components (final ephemeris, tropospheric, ionospheric) (Mageed, 2015). Commercial software is generally developed to handle data from a certain GNSS sensor receiver type. Based on the outcomes of comparable testing (short baselines, 10–30 kilometers in length, observed for an hour), it has been revealed that commercial software packages perform better than scientific ones (Andritsanos et al., 2016; Mageed, 2015).

3-RESULT AND DISCUSION

The raw data was collected in open sky environments. The required occupation time for the base line according to the mentioned references was approximately one hour; therefore, the observation was recorded from 9:11 AM on 11 December 2021 to 10:11 AM on the same day. Leica Infinity 3.0.1 software was utilized to process the GNSS raw data, which was developed and released by Leica Geosystems. Leica Infinity is a package of geospatial office applications software that was built to handle, process, and analyze GNSS data as well as other observations gathered by topographic devices such as Digital Levels, Total Stations, and Unmanned Aerial Vehicles (UAVs). Concerning the processing of GNSS data, the software enables the processing of the four most important worldwide constellations, specifically GPS, GLONASS, Galileo, and BeiDou. The user has the option of combining data from many constellations into a single file or processing them separately (Poluzzi *et al.*, 2021).

Preliminarily, the coordinates of GNSS reference control were computed in WGS84 frame performing the static survey with dual frequency GNSS receivers Leica GS16, equipped with controller CS20. The occupation time was about 60 minutes. One-hour observation was chosen, since the distance from the base to the rover was about 13km, and according to the mentioned references this occupation time is sufficient at this distance. The gathered GNSS observations were processed using a variety of durations (5min., 10min., 15min., 20min, 25min., and 30min.), at same time with different number of satellites (4, 6, 8, 10, 12, 14, 16, 18, and 20). GNSS receivers were configured with a 1 second sample rate for multiple signals in static mode, 15 degrees mask angle and using precise ephemeris.

The distribution of the disparities between the estimated positions of the unknown points and their corresponding true positions is shown in the following figures from 2 to 10. All solution variants were grouped into nine groups of satellites starting from 4 satellites to 20. The figures presented maximum offsets from 20 satellites. It is clear that a very small number of satellites were accountable for the most significant deviations in different sessions where all observations were done under conditions of an open sky environment. Generally, processing 8 number of satellites or larger guarantees that the offsets will be less than 1cm. For 20 satellites with best measurement condition, even 5 minutes session duration was sufficient to keep the accuracy within millimeters range. In case, if the duration of the sessions was 30 minutes, 4 and 6 satellites do not guarantee differences of less than 5cm.

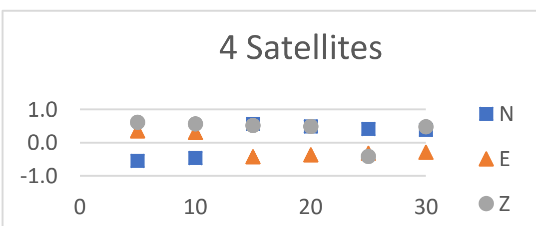

Fig. 2. Positional disparities between estimated and true positions by 4 satellites

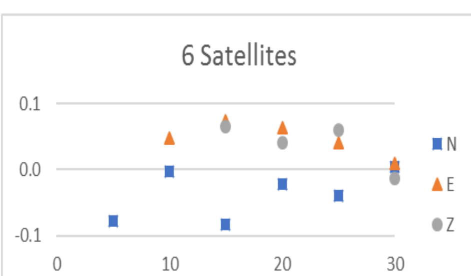

Fig. 3. Positional disparities between estimated and true positions by 6 satellites

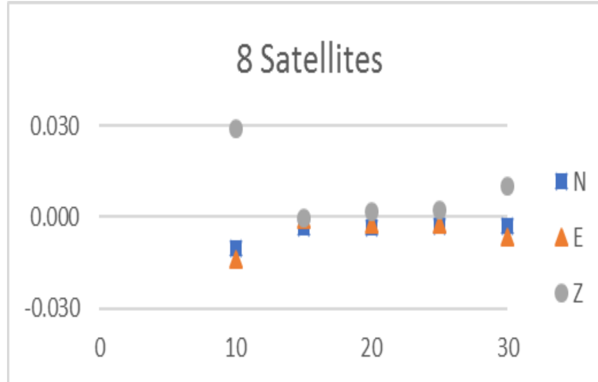

Fig. 4. Positional disparities between estimated and true positions by 8 satellites

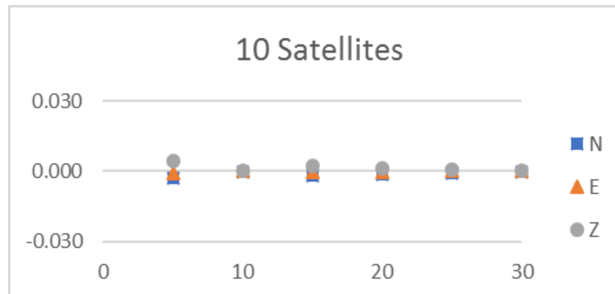

Fig. 5. Positional disparities between estimated and true positions by 10 satellites

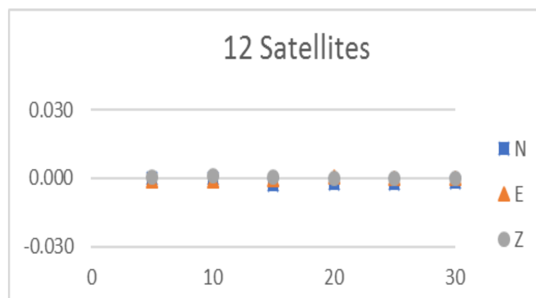

Fig. 6. Positional disparities between estimated and true positions by 12 satellites

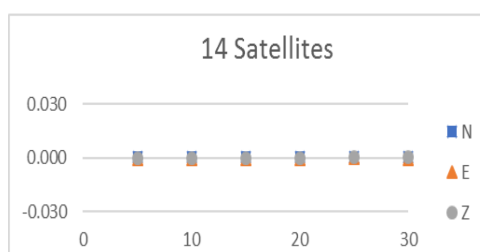

Fig. 7. Positional disparities between estimated and true positions by 14 satellites

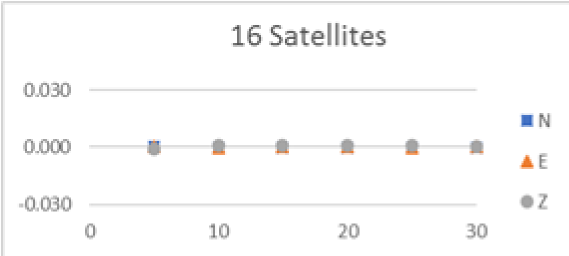

Fig. 8. Positional disparities between estimated and true positions by 16 satellites

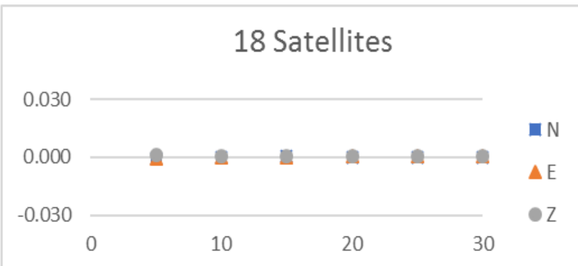

Fig. 9. Positional disparities between estimated and true positions by 18 satellites

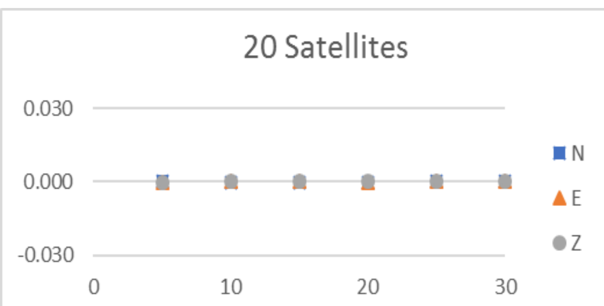

Fig. 10. Positional disparities between estimated and true positions by 20 satellites

Fig. 11. PDOP coefficients on different number of satellites

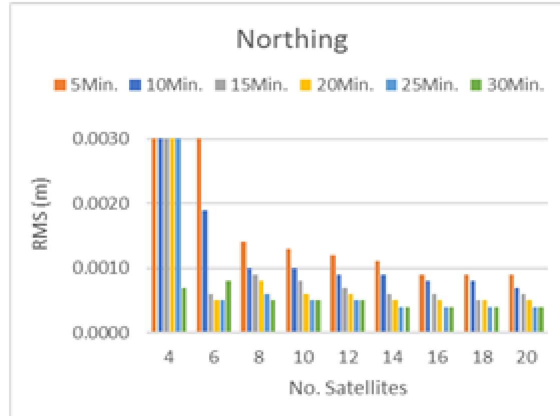

Fig. 12. RMS errors for northing according to time and the number of satellites

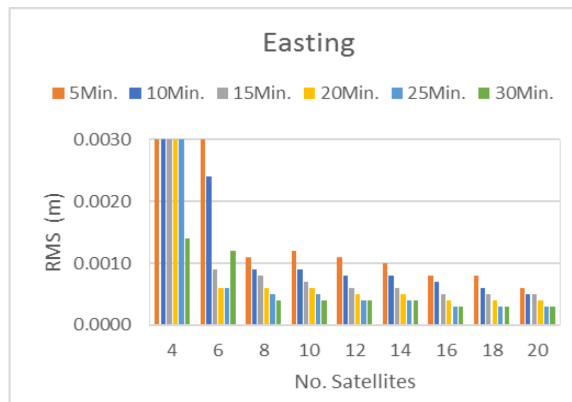

Fig. 13. RMS errors for easting according to time and the number of satellites

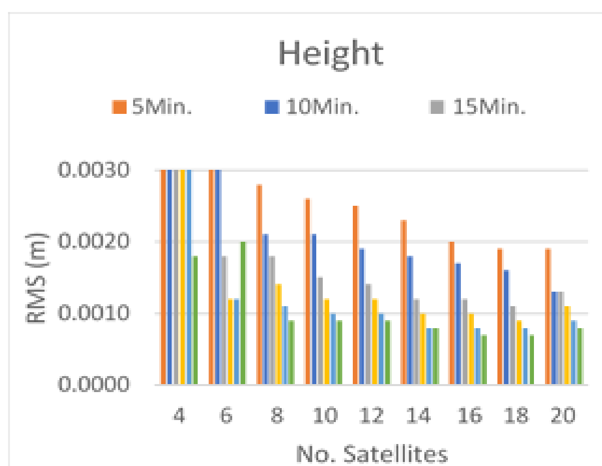

Fig. 14. RMS errors for height according to time and the number of satellites

In the static processing, the change of PDOP values and the number of satellites are changed proportionally. Whereas the number of satellites carrying out observations decreases, the PDOP value increases, which will result in a reduction in the accuracy of the three-dimensional position.

The number of tracked satellites as well as the values that were computed for the PDOP (Position Dilution of Precision) were presented in Figure 3 during the static test. In accordance with Figure 11, the number of satellites that were tracked increased from four to twenty. Calculated average PDOPs were 5.30 for four and six satellites, 2 for eight satellites, 1.85 for ten satellites, 1.75 for twelve satellites, 1.60 for fourteen satellites, 1.45 for sixteen and eighteen satellites, 1.40 for 20 satellites respectively. According to Figure 11, it is seen that every pair number of satellites added to the processing decreases the PDOP value.

Figures 12–14, summarize the results of the easting, northing and height of the point concerning both the increasing satellite numbers and observing session time span considered for the test. The positioning Root Mean Square (RMS) errors are calculated from the differences between the ‘true’ coordinates with the estimated values. The average position from each of (4, 6, 8, 10, 12, 14, 16, 18, and 20) satellites was adopted as the true position. In analyzing the results presented in figures 12-14, it is obvious that increasing the number of satellites significantly affect the position determination accuracy. Using four satellites is characterized by the largest RMS errors, especially when the occupation time is less and even if session duration is 25 minutes for the baseline with 13 km. Whereas the number of satellites is increased, RMS differences were clearly reduced. Using 4 and 6 satellites in 5 minutes, ambiguity solution cannot be fixed, the resolution was code and the errors in meter. Using 4 satellites in session lengths (10, 15, 20 and 25 minutes) the ambiguity still was not fixed and was float and the error in a range from decimeter to centimeter. The ambiguity was fixed using 8 or more satellites at different times and the accuracies were varies from centimeters to millimeters.

4- Conclusion

Application of static method needs sufficient occupation time to resolve the integer ambiguity. There are many factors that affect the session length or occupation time and obtained accuracy. One of the most important factors is the number of satellites at the epoch time. Increasing number of satellites results in a great improvement in GDOP, PDOP and occupation time to fix the ambiguity, and the achieved accuracy. In this paper, it was analyzed that the effect of increasing satellites’ number on reducing occupation time by taking a baseline with 13 km length. To process the data Leica infinity was used. The raw data was analyzed with different number of satellites (from 4 to 20) in different session length (from 5 min. to 30 min.). This paper demonstrated that the accuracy that can be achieved using 4 satellites in 30 minutes, a better accuracy can be achieved by using 20 satellites in 5 minutes.

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