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Assessment of the Accuracy of Processing GPS Static Baselines Up To 40 Km Using Single and Dual Frequency GPS Receivers.

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ABSTRACT: *GPS applications can be grouped into static applications and kinematic applications. Static applications of GPS can be used in geodetic surveying, Arial photogrammetric surveying, land surveying, orthometric height determination, topographic mapping, monitoring structural deformations, and engineering surveys; while kinematic applications of GPS, can be used in attitude determination of a moving body. On the other hand, GPS receivers can be categorized into two types: single frequency receivers which access the L1 frequency only, while dual frequency receivers which access both L1 and L2 frequencies. Single frequency receivers are affected more by ionospheric errors than dual frequency receivers, but they are less expensive, making them adaptable for certain surveying applications.*

This paper investigates the accuracy of the discrepancies in Cartesian coordinates X, Y, and Z and the horizontal and spatial position P, in case of using single frequency and dual frequency GPS receivers for solving GPS baselines up to 40 km by static GPS technique. The results supported with statistical analysis showed that 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. These findings are satisfying the standard and specification of establishing the first-order geodetic networks, as per the Federal Geodetic Control Committee FGCC. This means that the GPS single frequency receivers, which are less expensive than the dual frequency receivers, can be used in establishing GPS first-order control networks, up to 40 km baseline's lengths.

Keywords: *GPS; Single frequency data; Dual frequency data.*

I. INTRODUCTION

GPS has several applications in the field of geodesy, surveying, and mapping. GPS can be considered as one of the most distinct positioning systems for modern geodetic applications. Its benefits can be clearly shown in its practical applications as applied in surveying tasks. Generally, GPS applications can be grouped into static applications and kinematic applications. Static applications are concerned with positioning of stationary points, while kinematic applications are concerned with the positioning of moving objects. Static applications of GPS can be used in geodetic surveying, Arial photogrammetric surveying, land surveying, orthometric height determination, topographic mapping, monitoring structural deformations, and engineering surveys. On the other hand, kinematic applications of GPS, can be used in attitude determination of a moving body, where the attitude is defined as the orientation of a specific coordinate system in a land vehicle, a ship, or an aircraft, with respect to a global or local coordinate system [1].

GPS measurements are subjected to some errors, which are affecting the accuracy of the final results. There are two basic types of errors, which are the systematic errors or biases, and the random errors. Generally, the biases affecting the GPS measurements fall into three categories, which are: satellite biases, station biases, and signal propagation biases. Satellite biases consist of biases in satellite ephemeris and satellite clock. Ground station biases usually consist of receiver clock bias, receiver noise and antenna phase center variation. The signal propagation biases appear due to tropospheric refraction, ionospheric refraction, and multipath. Biases in GPS are greatly eliminated either by modeling or by using special observing techniques, based on the concept of differenced modes. In addition to the mentioned three groups of GPS biases, the accuracy of the computed GPS position is also affected by the geometric locations of the GPS satellites as can be detected by the receiver. The more spread out the satellites are in the sky, the better the obtained accuracy of the GPS derived 3-d coordinates [2].

GPS receivers can be categorized into two types: single frequency receivers which access the L1 frequency only, while dual frequency receivers which access both L1 and L2 frequencies. The single frequency receivers output the raw C/A code pseudoranges, the L1 carrier phase measurements, and the navigation message, and gives accuracy about 1cm+2ppm. The dual frequency receivers is the most sophisticated and most expensive receiver type. This type of receiver is capable of measuring all the GPS observables, which are: L1, L2 carriers, C/A code, and P-code, and gives accuracy 5mm+1ppm [3]. Single frequency receivers are affected more by ionospheric errors than dual frequency receivers, but they are less expensive, making them adaptable for certain surveying applications. On the other hand, Dual frequency, multiple channel receivers can compensate better for ionospheric errors and these receivers are ideal for geodetic applications.

This paper investigates the accuracy of the discrepancies in Cartesian coordinates X, Y, and Z and the horizontal and spatial position P, in case of using single frequency and dual frequency GPS receivers for solving GPS baselines up to 40 km by static GPS technique. The GPS observables including code and phase measurements will be reviewed. The static GPS technique along with its field procedure and desired accuracy will be introduced. The methodology of investigation and the description of the field test will be presented. Finally, the analysis of the obtained results supported with the statistical analysis will be shown, from which the important conclusions and recommendations will be drawn.

II. REVIEW OF GPS OBSERVABLES

GPS observables are ranges which are deduced from measured time or phase differences based on a comparison between received signals and generated signals. Unlike the terrestrial distance measurements, GPS uses the so-called one-way concept, where, two clocks are used, namely one in the satellite, and the other in the receiver. Thus, the ranges are affected by satellite and receiver clocks errors and, consequently, they are denoted as pseudoranges. There are two types of GPS observables, namely the code pseudoranges and carrier phase observables. In general, the pseudorange observations are used for coarse navigation, whereas the carrier phase observations are used in high-precision surveying applications. That is due to the fact that the accuracy of the carrier phase observations is higher than the accuracy of code observations, [4].

Beside the two GPS observables, the GPS satellite transmits a navigation message. The navigation message is a data stream added to both L1 and L2 carriers as binary biphase modulation at a low rate of 50 Kbps. It consists of 25 frames of 1500 bits each, or 37500 bits in total. This means that, the transmition of the complete navigation message takes 750 seconds. The navigation message contains, along with other information, the coordinates of the GPS satellites as a function of time, the satellite health status, the satellite clock correction, the satellite almanac, and atmospheric data. Each satellite transmits its own navigation message with information on the other satellites, such as the approximate location and health status [5].

2.1 Code Pseudorange Observables

The code pseudorange is a measure of the distance between the satellite and the receiver. The P-code, C/A-code can be used to determine the code pseudorange. These ranges can be determined by multiplying the speed of light by the time shift required to match the code generated in the receiver with the code received from the satellite (figure 1). Analogously, the delays of the clocks with respect to GPS system time frame will lead to timing error. The tropospheric and ionospheric delays affect the measured code pseudorange [6]. The general form of code pseudorange observation equation is:

$$P = \rho + c(dt - dT) + d_{ion} + d_{trop} + d_{orb} + \varepsilon_p \qquad (1)$$

Where: P is the observed pseudorange, ρ is the unknown geometric satellite to receiver range, c is speed of light which is approximately equal to 300,000 km/s, dt and dT are satellite and receiver clock errors respectively, d_{ion}, d_{trop}, are the error due to ionospheric, tropospheric refraction respectively, d_{orb} is the orbital error and ε_p is the code measurement noise.

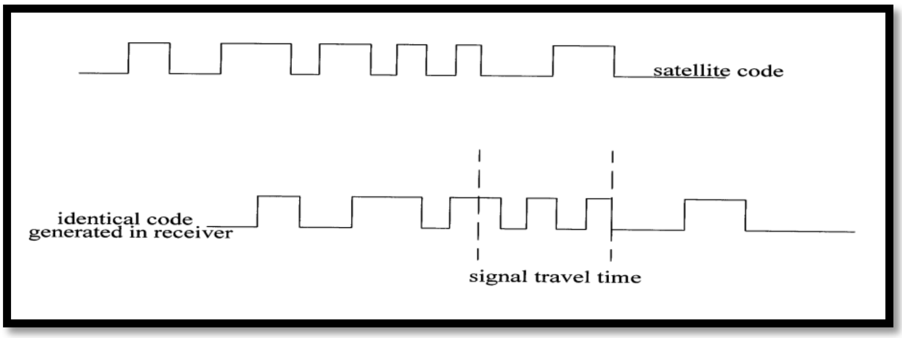

Fig. 1: GPS Pseudorange Observables

The precision of a pseudorange derived from code measurement has been about 1% of the chip length. Consequently, a precision of about 3m, 0.3m is achieved with C/A-code and P-code pseudoranges respectively. However, recent development indicates that a precision of about 0.1% of the chip length may be obtained [7].

Many applications are based on the pseudorange observations, mostly related to the fields of navigation, where the instantaneous positions are required. Note in equation (1) that, the bias term d_{ion} can be determined, with high percentage, in case of using dual frequency receivers, since the ionospheric effect is frequency dependant, and its estimation parameters are usually transmitted within the satellite message [8]. Concerning the tropospheric effect term d_{trop}, it can be evaluated to more than 95%, using an adopted model, which is a function of measured meteorological quantities, such as humidity, pressure, and temperature, of the atmosphere surrounding the receiver position. Concerning the orbital bias term d_{orb}, it can be estimated from satellite orbital dynamics continuous analysis, at the master control station, and included in the satellite-transmitted message also. The satellite and receiver clocks biases term (dt-dT), is usually treated as one unknown parameter. Hence, equation (1) of observed pseudorange will be left out with only four unknowns parameters, which are the 3-d geocentric cartesian coordinates (X, Y, Z) of the receiver antenna position, in addition to the clock bias term. Of course, in order to solve such an equation, for the four unknown parameters, one needs to have four of these observation equations. This is why the GPS system is designed, such that at least four GPS satellites can be observed simultaneously at the same time from the ground receiver. However, for more reliability of the derived receiver 3-d coordinates, collected observations from several satellites, over a certain period called session, must be performed, in order to apply the least squares estimation process, with a high degree of freedom [9].

2.2 Carrier Phase Observables

The range between the receiver and satellite can be obtained through the carrier phase. The range would simply be the sum of the total number of full carrier cycles plus fractional cycle at the receiver and the satellite, multiplied by the carrier wave length (figure 2). The ranges determined with the carriers are more accurate than those obtained by the codes [10]. This is due to the fact that, the wavelength of the carrier signal (19cm in case of L1) is smaller than the codes. However, there is a problem that the carriers are just pure sinusoidal waves, which means that all cycles look the same. Therefore, the GPS receiver has no means to differentiate one cycle from the other. In other words, the receiver cannot determine the total number of the complete cycles between the satellite and receiver when switched on. The receiver can only measure a fraction of a cycle accurately, while the initial number of complete cycles remains unknown, or ambiguous [11]. This initial cycle ambiguity remains unchanged over time as long as no signal loss or cycle slip occurs.

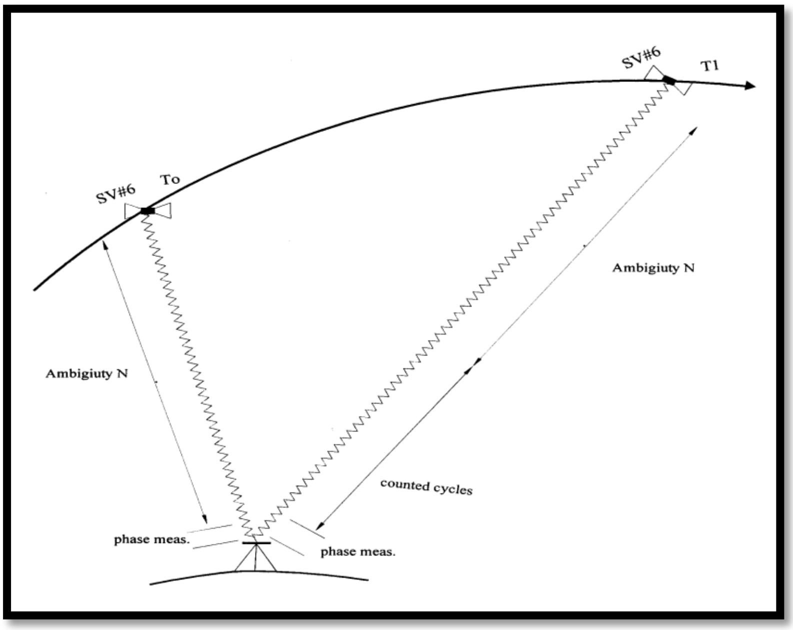

Fig. 2: GPS Carrier Phase Observables

The observation equation of the phase pseudorange is:

$$\Phi = \rho + c(dt - dT) + \lambda N - d_{ion} + d_{trop} + d_{orb} + \varepsilon_{\varphi} \qquad (2)$$

Where, the measured phase is indicated in meters by Φ, λ is the carrier wavelength, N is the phase ambiguity, and ε_{φ} is the combined receiver and multipath noise, and the other remaining symbols are the same as defined in equation (2). The same analysis of the bias terms and unknown parameters, as given in the previous subsection, holds true here also for the case of carrier phase observation equation. The only difference here is the ambiguity term N, which can be solved for, using a certain adopted technique, which will be discussed later. This means, again, that at least four satellites should be in view at the time, which can be simultaneously tracked from the same ground receiver. On the other hand, for both cases of code pseudorange and carrier phase pseudorange, most of the bias terms can be eliminated, or minimized by following a certain technique for collecting GPS measurements, such as single, double, and triple differences; and/or using mathematical model; and/or using linear combination [12].

Accuracy of the carrier phase measurements can reach the centimetre level or even less. Accordingly, all GPS precise geodetic applications are mainly based on this type of observables. Such applications include monitoring of local and regional crustal deformations, and the establishment of geodetic control networks. Both types of GPS observables are different in their nature. The pseudorange is an instantaneous observation, which is in principle independent of post measurements, whereas the carrier phase measurement is continuous and dependent on the tracking history. In fact, the two types of GPS observables can be combined in the so-called phase-smoothed pseudorange, [13]. In this concept, the change of phase over time is added to the initial pseudorange to get an estimate of the current pseudorange observation. The noise of the resulting new observable will be lower than the noise of the original pseudorange. In addition, this approach has the advantage of the significant reduction of multipath effect, which affects the carrier phase observations much less than the pseudoranges.

III. GPS STATIC TECHNIQUE

The selection of the observation technique in a GPS survey depends upon the particular requirements of the project, and the desired accuracy especially is playing a dominant role. The GPS observation techniques include: single point positioning SPP; differential positioning DGPS; and relative positioning. Relative positioning includes: static, rapid static, stop and go, kinematic, real time kinematic RTK. GPS single point positioning employs one GPS receiver, while DGPS and relative GPS positioning employ two or more GPS receivers, simultaneously tracking the same satellites. Surveying works with GPS have conventionally been carried out in the relative and differential positioning techniques. This is mainly due to the higher positioning accuracy obtained from the relative and differential techniques, compared to that of the GPS point positioning. A major disadvantage of GPS relative and differential techniques, however, is the dependency on the measurements or corrections from the reference receiver [14].

GPS Static relative positioning is the common method for control networks, due to its high accuracy. Static relative positioning by carrier phase at present, is the most frequently used method by surveyors, as it is more accurate as compared to the code pseudorange measurements. The principle of static relative positioning, is based on determining the vector between two stationary receivers, this vector is often called baseline. According to this terminology, the process is called single or multipoint baseline determination. In static surveying 1 ppm to 0.1 ppm accuracies are achieved, which is equivalent to few centimetres and millimetres accuracy, for short baselines of some kilometres [3].

The field procedure of relative static survey, is performed by placing a receiver on a known point, and placing the second receiver on the unknown point, and collecting simultaneously data from at least four satellites. The observing time required to fix the position, is called a session. This time is varying according to baseline length, satellite configuration, selective availability, atmospheric conditions, and the required accuracy. Normally, one-hour observation period is required to each baseline. However, to increase the accuracy, the receiver may be kept observing for longer period especially, in case of long length baselines. Figure (3) shows the basic idea of GPS static technique. Typically, the range of accuracy for static survey, is normally 0.3–1.0 cm + 1–2 ppm. [2].

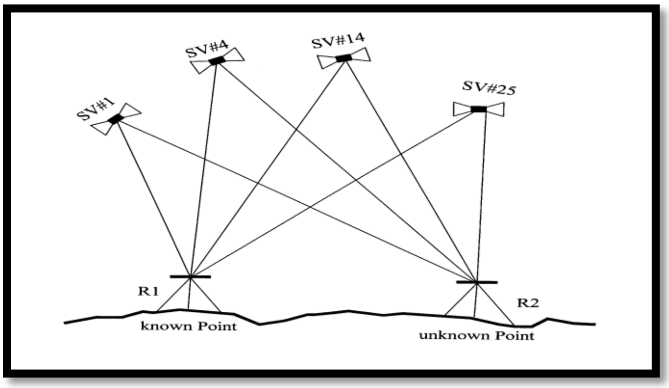

Fig. 3: Concept of GPS Static Technique

After completing the field work, the collected date is downloaded from the receivers to the PC for processing. Different processing options may be selected depending on the baseline length, and other factors. For example, if the baseline is relatively short, say, 15-20km, resolving the ambiguity would be a key issue to ensure high precision accuracy. On the other hand, if the baseline is relatively long, the user may select the ionosphere free linear combination to remove the effect of the ionosphere. For very long baselines, over 1000km, it is recommended to process the data using scientific software such as BERNESE software, developed by the University of Bern, rather than using commercial software [3]. The static surveying is usually applied in high accuracy surveying projects, such as establishing new geodetic networks, densification of existing first order control networks or lower order network, crustal movements, and structural deformation.

IV. METHODOLOGY OF INVESTIGATION

The objective of this paper is to statically analyze the difference in 3-d coordinates, as well as the horizontal and spatial positions, resulted from processing GPS baselines up to 40 km collected by static GPS technique, using single frequency data L1, and dual frequency data L1 and L2. A number of 15 GPS static baselines with approximate distances from 1.5 km to 42.5 km, were processed two times: the first one using single frequency L1 data, and the second one using the dual frequency data L1 and L2.

The field test was conducted at Taif city, Saudi Arabia on April 2012. A dual frequency GPS receiver of Topcon GR3 was setup at a reference control point [15]. A second dual frequency receiver of the same type of Topcon GR3 was set up sequentially on 15 new control points of approximate distances from 1.5 km to 42.5 km, from the base station. The observational operating parameters were the same for the two receivers, which are: static mode, elevation angle 15^0, and 10 seconds rate of observations. The observational durations of the baselines were as shown in table 1.

Table 1: duration of GPS static observation data

Baselines Range (km)	Duration (minutes)
1 to 5	30
5 to 10	45
10 to 15	60
15 to 20	90
20 to 25	120
25 to 30	150
30 to 35	180
35 to 42	210

The raw data of the GPS campaign were downloaded and transferred to Rinex format using Topcon Link software [16]. The processing of the Rinex data was conducted using Leica Geo Office software [17] . The data were processed two times: the first run was using L1 data, while the second run was using L1 and L2 data. The 3-d cartesian coordinates for every baseline in each run were archived for the statistical analysis.

V. ANALYSIS OF RESULTS

The analysis of the results will be based on comparing the discrepancies in X, Y, and Z coordinates between processing 15 GPS baselines using dual frequency data L1 and L2, against processing the same baselines with single frequency data L1 only. The cartesian discrepancies are:

$$\begin{aligned} \Delta X_{dul-sin} &= X_{dul} - X_{sin} \\ \Delta Y_{dul-sin} &= Y_{dul} - Y_{sin} \\ \Delta Z_{dul-sin} &= Z_{dul} - Z_{sin} \end{aligned} \qquad (3)$$

Where: $\Delta X_{\text{dul-sin}}$, $\Delta Y_{\text{dul-sin}}$, and $\Delta Z_{\text{dul-sin}}$: the X, Y, and Z discrepancies between using dual and single frequency data.

X_{dul} , Y_{dul} , and Z_{dul} : the X, Y, and Z coordinates resulted from using dual frequency data L1 and L2.

X_{sin}, Y_{sin} , and Z_{sin} : the X, Y, and Z coordinates resulted from using single frequency data L1.

The 2-d and 3-d positional discrepancy between the two solutions ΔP_{2d} , ΔP_{3d} , as well as the standard deviation $\sigma_{\Delta p_{2d}}$, $\sigma_{\Delta p_{3d}}$ can be calculated from [18]:

$$\Delta P_{2d} = \sqrt{(\Delta X_{dul-\sin})^2 + (\Delta Y_{dul-\sin})^2} \qquad \Delta P_{3d} = \sqrt{(\Delta X_{dul-\sin})^2 + (\Delta Y_{dul-\sin})^2 + (\Delta Z_{dul-\sin})^2} \qquad (4)$$

$$\sigma^2_{\Delta p_{2d}} = \sigma^2_{\Delta X_{dul-\sin}} + \sigma^2_{\Delta Y_{dul-\sin}} \qquad \sigma^2_{\Delta p_{3d}} = \sigma^2_{\Delta X_{dul-\sin}} + \sigma^2_{\Delta Y_{dul-\sin}} + \sigma^2_{\Delta Z_{dul-\sin}} \qquad (5)$$

The discrepancies in X, Y, Z and 2-d and 3-d position P, between processing the GPS data using dual and single frequency data are shown in Table (2).

Table 2: The discrepancies in X, Y, Z, and position P

Baseline Id	Baseline Length (km)	ΔX (mm)	ΔY (mm)	ΔZ (mm)	ΔP_{2d} (mm)	ΔP_{3d} (mm)
1	1.6	-0.9	1.4	0.8	1.7	1.8
2	3.0	4.5	8.2	5.8	9.4	11.0
3	4.8	3.8	0.8	-15.9	3.9	16.4
4	7.3	-0.5	-3.3	-5.0	3.3	6.0
5	9.4	4.0	-1.2	-4.8	4.2	6.4
6	11.0	10.3	3.6	-4.5	10.9	11.8
7	13.7	16.0	15.3	12.6	22.1	25.5
8	15.4	-12.1	-6.4	-2.1	13.7	13.8
9	18.7	16.2	-13.8	11.9	21.3	24.4
10	22.2	-5.2	1.0	1.4	5.3	5.5
11	25.7	-15.6	4.7	1.2	16.3	16.3
12	28.2	-10.0	-14.5	-14.0	17.6	22.5
13	33.4	15.3	-0.4	-17.6	15.3	23.3
14	37.3	6.3	-19.2	-7.2	20.2	21.5
15	42.5	2.0	-7.1	-1.1	7.4	7.5

Figures (4) shows the X, Y, and Z coordinate discrepancies for the 15 baselines derived from dual and single frequency data. In addition, Figure (5) shows the 2-d and 3-d positional discrepancies P for the same baselines.

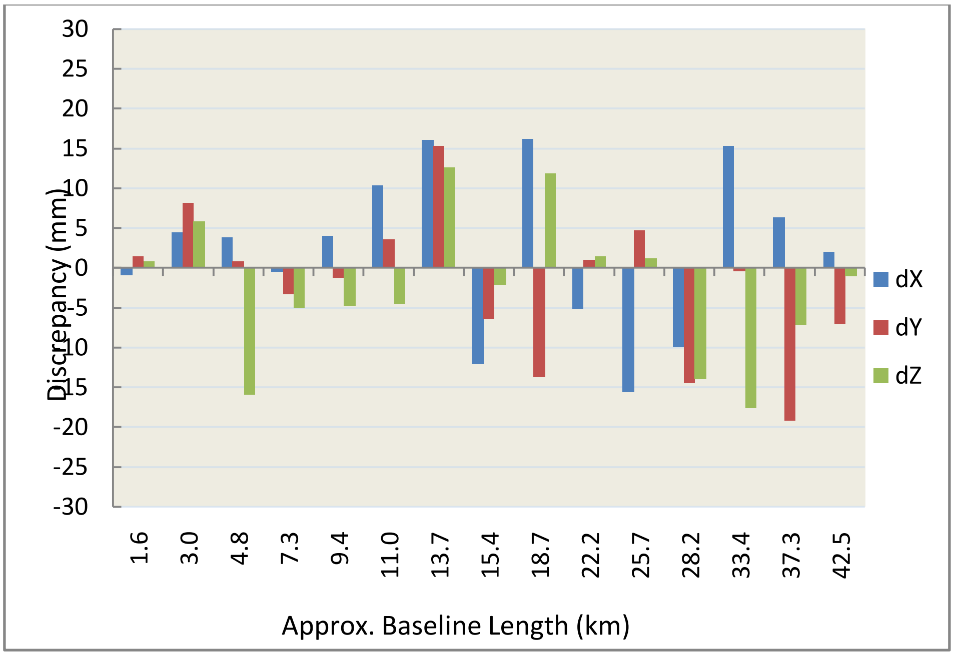

Figure 4: Variation of the X, Y, and Z coordinate discrepancies

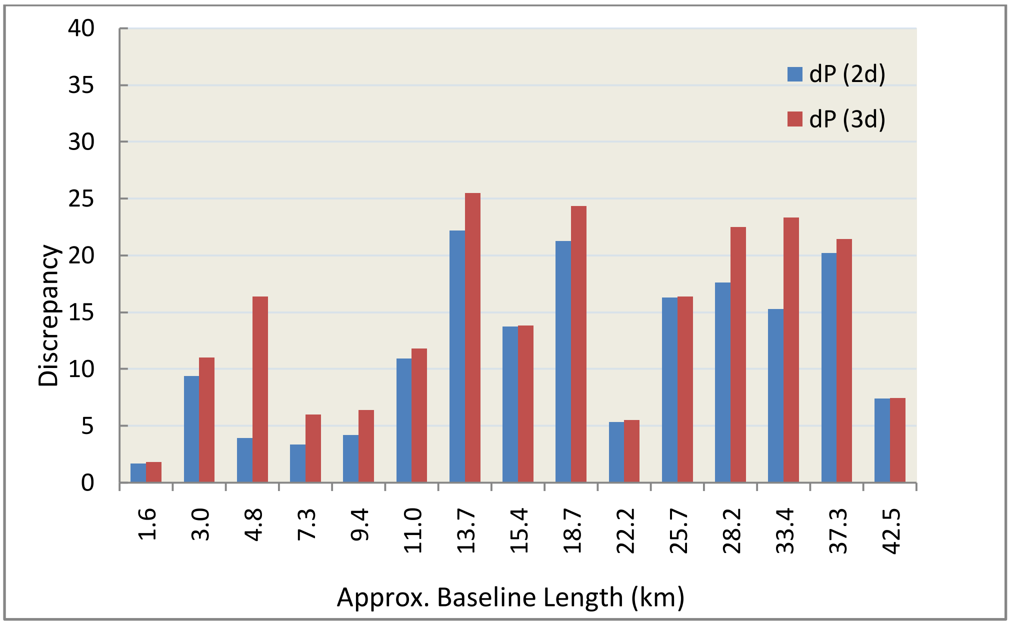

Figure 5: Variation of the Positional discrepancies

The previous figures are supported by descriptive statistics to measure the quality of the obtained results. Table (3) shows these descriptive statistics. For instance, the X-coordinate discrepancies have mean value 2.3mm and SD 10mm for single determination. The Y-coordinate discrepancies have mean value of -2.1mm and 9.1mm SD for single determination. The Z-coordinate discrepancies have -2.6mm mean value and 9mm SD for single determination. Finally, the 2-d and 3-d positional discrepancies have 11.5mm, 14.2mm mean value respectively; with SD 13.5mm, and 16.2mm respectively.

Table 3: Descriptive statistics of the discrepancies (mm)

Disc.	Max.	Min.	Range	Mean	$S.D_{single}$	$S.D_{mean}$
ΔX	16.2	-15.6	31.8	2.3	10.0	2.6
ΔY	15.3	-19.2	34.5	-2.1	9.1	2.3
ΔZ	12.6	-17.6	30.2	-2.6	9.0	2.3
ΔP_{2d}	22.1	1.7	20.5	11.5	13.5	3.5
ΔP_{3d}	25.5	1.8	23.6	14.2	16.2	4.2

In order to check any systematic errors in the sample of the resulted discrepancies, the sample mean should be examined according to its deviation from the mean of the population which equal to zero [18]. This random sample is assumed to be normaly distributed and had taken from a population of unknown true mean µ equal to zero. The following confidence interval can be used:

$$\mu - T\ .SD_{mean} < m < \mu + T\ .SD_{mean} \qquad (6)$$

Where µ is the population mean (µ =0), SD_{mean} is the sample standard deviation, T is the Student t-distribution corresponding to sample size n and degree of freedom df equal to n-1, assuming that the confidence level is 95%. Table 4 shows the results of this test which indicates that no significant systematic errors are existing in the discrepancies between the two solutions.

Table 4: Testing of deviation of the sample mean

Disc.	Df	T	SD_{mean}	Lower limit	Mean	Upper limit	Test result
ΔX	14	2.14	2.6 mm	-5.6 mm	2.3 mm	5.6 mm	pass
ΔY			2.3 mm	-4.9 mm	-2.1 mm	4.9 mm	pass
ΔZ			2.3 mm	-4.9 mm	-2.6 mm	4.9 mm	pass

VI. CONCLUSIONS

This paper analyzes the difference in Cartesian coordinates X, Y, and Z between processing GPS baselines which are collected with static technique, in case of using single frequency data L1, and in case of using dual frequency data L1 and L2. A field test consists of 15 GPS static baselines, was made for the purpose of the analysis. The baseline lengths were ranged from 1.5 km to 42.5 km.

The results supported with statistical analysis showed that the differences in the cartesian coordinates between processing GPS static baselines using single and dual frequency data have mean values of 2.3mm, 2.1mm, and 2.6mm in X, Y, and Z coordinates respectively. The standard deviations of these means are: 2.6mm, 2.3mm, and 2.3mm for the 3-d cartesian components respectively. The horizontal positional discrepancy P_{2d} between the single and dual frequency data has a mean value of 11.5mm with 3.5mm standard deviation, while the spatial positional discrepancy P_{3d} has a mean value of 14.2mm with standard deviation 4.2mm. The relative accuracy of the horizontal positioning using GPS single frequency data is about 1:370,000, which satisfying the standard and specification of establishing the first-order geodetic networks which is 1:120,000, as per the Federal Geodetic Control Committee FGCC.

The previous results showed that there are no significant differences in the resulted cartesian coordinates in case of processing GPS baselines collected with static technique, using single frequency data L1, or using dual frequency data L1 and L2. This means that the GPS single frequency receivers, which are less expensive than the dual frequency receivers, can be used in establishing GPS first-order control networks, up to 40 km baseline's lengths.

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