

ENHANCEMENT POSITIONING PERFORMANCE USING MODIFIED PRECISE POINT POSITIONING (PPP) SOFTWARE

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ABSTRACT

The lack of specialized processing programs for the precise point positioning PPP technique led to not providing optimal solutions for the results. Therefore, the research aims to improve an open-source MATLAB software for processing all available data from the GNSS system constellation in the PPP case. This study applied the modified software to single, dual, and multi-frequencies GNSS signals. Fast Fourier Transform (FFT), Butter worth, and Laplace filters are used for frequency separation. The PPP technique improves the absolute position accuracy; the dependence on the control points is unnecessary. The modified software (PPPHE) gives a more significant opportunity for users to use the PPP technique adapting the single-frequency receivers, thus, reducing the cost. Two empirical tests were designed to evaluate the PPPHE performance for the single and dual frequencies. The results assured that integrating the GPS into other GNSS systems (GLONASS, Galileo, and Beido) has significantly improved position accuracy in both single and dual-frequency.

KEYWORDS: GNSS, PPPHE, Single frequency, Dual frequency, Software enhancement.

تحسين أداء تحديد المواقع باستخدام برمجيات تحديد المواقع الدقيقة (PPP) المعدلة

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المخلص

أدى عدم وجود برامج معالجة متخصصة لتقنية PPP لتحديد المواقع بدقة عالية إلى عدم تقديم الحلول المثلى للنتائج. لذلك ، يهدف البحث إلى تحسين برنامج MATLAB مفتوح المصدر لمعالجة جميع البيانات المتاحة من كوكبة نظام GNSS في حالة PPP. طبقت هذه الدراسة البرنامج المعدل على إشارات GNSS أحادية وثنائية ومتعددة الترددات. يتم استخدام مرشحات تحويل فورييه السريع (FFT) ، و Butter worth ، ولا بلاس لفصل التردد. تعمل تقنية PPP على تحسين دقة الموضع المطلقة ؛ الاعتماد على نقاط التحكم غير ضروري. يوفر البرنامج المعدل (PPPHE) فرصة أكثر أهمية للمستخدمين

لاستخدام تقنية PPP لتكثيف أجهزة الاستقبال أحادية التردد ، وبالتالي تقليل التكلفة. تم تصميم اختبارين تجريبيين لتقييم أداء PPPHE للترددات الفردية والمزدوجة. أكدت النتائج أن دمج GPS في أنظمة GNSS الأخرى (GLONASS و Galileo و Beido) قد حسن بشكل كبير دقة الموقع في كل من التردد الفردي والثنائي.

الكلمات المفتاحية : الترددات الاحادية, الترددات الثنائية, تحسين البرمجيات.

1. INTRODUCTION

All users of GNSS systems strive to reach optimal accuracy at the easiest and lowest cost; this is done by providing GNSS data and suitable software. Nowadays, in the world of GPS, all GNSS data is available through the IGS organization 24 hours a day [1]. Using the Precise Point Positioning (PPP) technique provides satisfactory accuracy for GPS users and results in reliable accuracy reaching to centimeters [2, 3]. It helps the user save time and effort compared to the relative technique. It reduces the number of receivers and, consequently, the number of users and does not need a reference station. Therefore, the project is not affected by the baseline length nor the scarcity of control points in some countries [4, 5].

Many difficulties and problems still face users of the PPP technique, including the difficulty of providing software that helps researchers and GPS users. Increasing the number of satellites and possibly merging between the different constellations GPS, GLONASS, Galileo, Beido, ... and others. That increases the complexity of correcting the resulting errors, which requires a more complex model to process each error alone [6]. The situation becomes more complicated when using a receiver that supports only a single frequency, which GPS users adopt due to the low cost [7].

The surveyor uses a dual and multi-frequency receiver to collect data in the project location, adapting the classical PPP technique. Still, the major shortcoming is un-calibrated biases due to using the ionosphere-free linear combination, which adopted an un-differenced GNSS code and phase observation. Else, it has a noise ratio of about 2.215 times that of single frequency (L1). This limitation affects convergence time and position accuracy [8, 9]. This study presents modified open-source software (PPPHE) to handle these shortcomings. The users and researchers can easily enhance and use it to process and analyze the data in single and dual frequency modes. The error effect caused by the ionosphere layer can be reduced using the Klobucher ionosphere model, in addition to using modern frequencies to reach the best results.

2. THE USED DATA

Observation data files, 24 hours of International GNSS Service (IGS) station points, were downloaded from GNSS websites in row format. The data was recorded every 30 seconds. The row data contains all GNSS frequencies ranges, single, dual, and multi frequencies. MATLAB program version 2020 was used for frequencies separation and signal filtration purposes, where some parameters are required as inputs. Observation file, certain time vector, the parameter of FFT, and the four parameters of the Butterworth function. Time vector as an input in MATLAB software equals $(24 * 60 * 60) / 30 - 1$. It is equal to the number of observations, where (24) is the number of day's hours, $(60 * 60)$ equals the number of seconds in the day, and 30 means the step.

3. METHODOLOGY

This research is based on two main parts. Developed an easy-to-use GNSS analysis program, PPPHE. Separating different frequencies from different GNSS constellations was done for that software. The PPPHE-developed software will be able to perform multi-GNSS PPP processing and analysis in single, dual, and multi-mode. PPPHE software allows users to load GNSS data sources, determine a variety of processing options parameters, and evaluate the results from many

perspectives. Experimental tests and comparisons between different processing results were introduced for software evaluation. The following steps illustrate the work procedures.

3.1. Frequencies Separation

- This study will separate the frequencies to improve the PPPH software and introduce the code. The first, second, and third codes show the single, the dual, and the multi-frequencies (all frequencies) where the frequencies bands are 1561.1 to 1609MHZ, 1207.14 to 1609MHZ and 1176.45 to 1609 MHZ, respectively [10]. Table (1) shows the selected frequencies for the selected codes.

Table 1: The available frequencies [11]

Parameters	GNSS Systems			
	GPS	GLONASS	Galileo	BeiDou
Frequencies (Civil use)	L1:1575.42 MHz	G1:1598~1609 MHz	E1:1575.42MHz E5a:1176.45MHz	B1:1561.1(E2) B2:1207.14(E5b)
	L2:1227.60 MHz	G2:1242~1252 MHz	E5b:1207.14MHz E6:1279.58MHz	B3:1268.52(E6)
	L5:1176.45 MHz	G3:TBD		

- FFT, Butter worth, and Laplace filters are used for frequencies separation.

- Loading the noisy GNSS signals. The received baseband signal of one satellite is given as equations (1) and (2) [12].

$$X(t) = \sqrt{p} = g(t - \tau) c(t - \tau) + n(t) \tag{1}$$

Where (P) is a signal power, c(t) pseudo random (PR) spreading sequence, τ time-delay, $g(t) \in \{-1, 1\}$: Binary navigation message data and n(t) white Gaussian noise with power spectral density $N0/2$. The PR sequence is as follows;

$$c(t) = p(t)/m \tag{2}$$

Where p(t) is a Chip pulse shape that is unnecessarily restricted to be time-limited to only one chip interval, (m) Chip duration and number of chips of the PR sequence. Figure (1) shows the shape of the noisy signal (all frequencies, all noises.... etc.) before the filter in the time domain.

3.1.1 The Signal in Frequency Domain

After defining the time vector in the MATLAB program. FFT is applied to the signal in analog shape to clarify the frequency to be separated in the frequency domain. Else it is used to clarify the location of all noise (GNSS noise, Gaussian noise,.....) in the time and frequency domains so that they can be controlled and reduced.

FFT converts a signal into individual spectral components and provides frequency information about the signal. A GNSS signal is sampled every 30 seconds and divided into frequency components. [13]. These components are single sinusoidal oscillations with amplitude and phase at distinct frequencies [14].

Equations (3) to (5) express the mathematical form of FFT [15]. The number of observations in each epoch is finite, then $x(t)$ can be expanded in terms of the complex exponential signal as equation (3).

$$X(t) = \sum_{n=-\infty}^{\infty} x_n e^{-i2\pi n/T_0} \quad (3)$$

x_n are called the Fourier series coefficients of the signal $x(t)$, the quantity $f_0 = 1/T_0$ is called the fundamental frequency (L1 1575.42MHZ) of the signal $x(t)$. The Fourier transform of $x(t)$ is defined by Equation (4).

$$X(f) = \int_{-\infty}^{\infty} x(t) e^{-i2\pi f t} dt \quad (4)$$

The signal in time domain can be obtained from its Fourier transform by equation (5) to compare the signal shape in the time and frequency domain before and after the filter.

$$x(t) = \int_{-\infty}^{\infty} X(f) e^{i2\pi f t} df \quad (5)$$

Fig. 1 shows the noisy signal in the time and frequency domain before applying the filter.

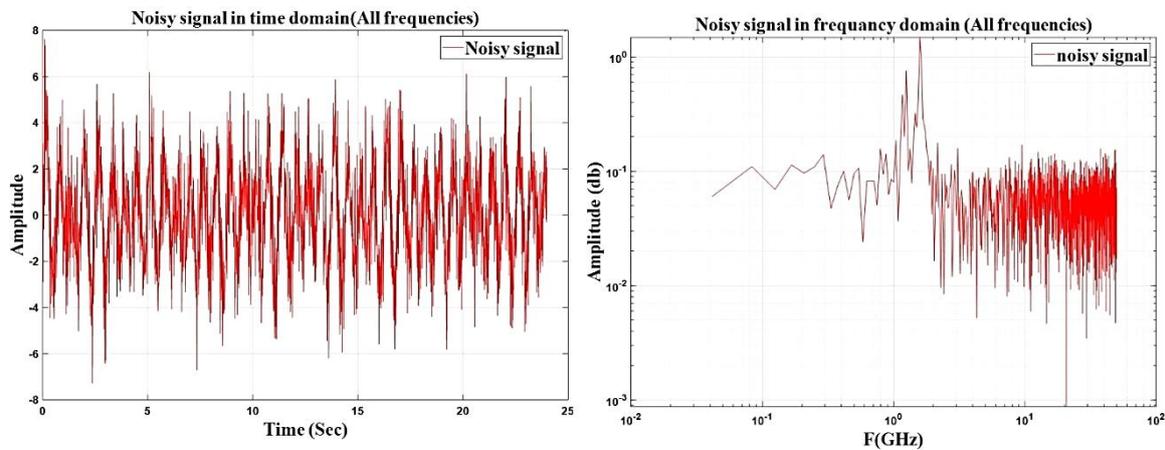


Fig. 1: The signal before the filter in time and frequency domain

3.1.2 GNSS Signal Noises Elimination

Using the Analog Filter Designer tool (AFD) created by the American MIT helps to choose the most appropriate filter and its order according to the accuracy required. The Butterworth filter is a signal processing filter designed to have a frequency response that is as flat as possible in the passband. It is also referred to as a maximally flat magnitude filter. The gain $G(\omega)$ nth-order Butterworth filter is given in terms of the transfer function $H(s)$ as equation (6) and (7) [16].

$$G^2(\omega) = |H(s)|^2 = \frac{G_0^2}{1 + (\frac{j\omega}{j\omega_{fc}})^{2n}} \quad (6)$$

Where $G(\omega)$ is the magnitude of the frequency (1575.42 MHz), n is the order of the filter, F_c is the cut of frequency approximately the -3 dB frequency, G_0 is the gain at zero frequency. Determining the transfer function $H(s)$ as Equation (7) where $s = j\omega$, and ω is the angular distance. Multiplying the transfer function $H(s)$ by the signal $x(t)$ equals the filtered signal [17].

$$x(t) H(s) = \frac{G_0^2}{1 + \left(\frac{-s^2}{j\omega_{fc}^2}\right)^n} \quad (7)$$

The transfer (system) function is written as an equation; its denominator is a Butterworth polynomial in S (Laplace parameter) [18].

3.1.3 Definition and applying the Butterworth in MATLAB Program

The Butterworth filter was defined in MATLAB program by four inputs. The order was determined from the AFD tool. Cut of Frequency (F_c) was defined as a point after which frequency decay occurs. The type of filter used is specified as band pass, and the element (S) is the Laplace parameter. The AFD tool displays the Butterworth filter in the Laplace form [19]. Equation (8) shows the relation between the signal and the noise. The signal-to-noise ratio (S/N) is a significant factor affecting the strength of the GNSS signal since the signal strength is inversely proportional to the noise [20]. FFT converts the noise and the filtered signal to the frequency domain. Fig. 2 shows that relation by helping the MATLAB program.

$$\frac{S}{N} = \frac{\text{Mean}}{\text{standard deviation}} = \frac{\bar{X}}{\sigma} = \frac{RMS(S)}{RMS(N)} \quad (8)$$

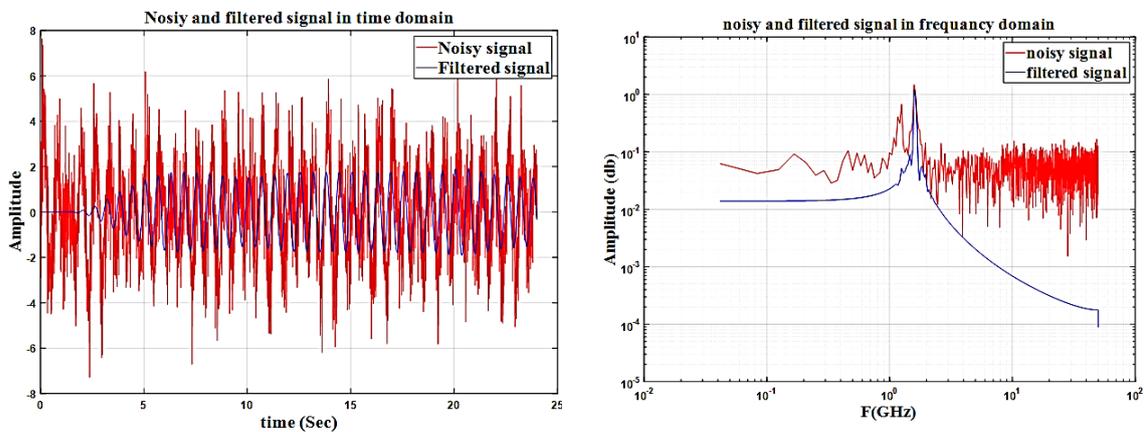


Fig. 2: The noisy and filtered signals in time and frequency domain

3.2. The Modified Software Processing Parameters

The program has been improved after applying the basic steps. Separating the required signal (L1 1557.42MHz). The Klobuchar ionosphere model was used to reduce the error caused by the ionosphere layer [21], and encoding was done for this model. Kalman filter applied for adjustment method. Therefore, the user can efficiently process the data from the simple GUI of the program after the modification. The modified software processing parameters are tabulated in Table (2). Fig. 3 and Fig. 4 show the modified software GUI. Visit the next link for

information about the program and the MATLAB codes for frequency, ionosphere, and troposphere models [25].

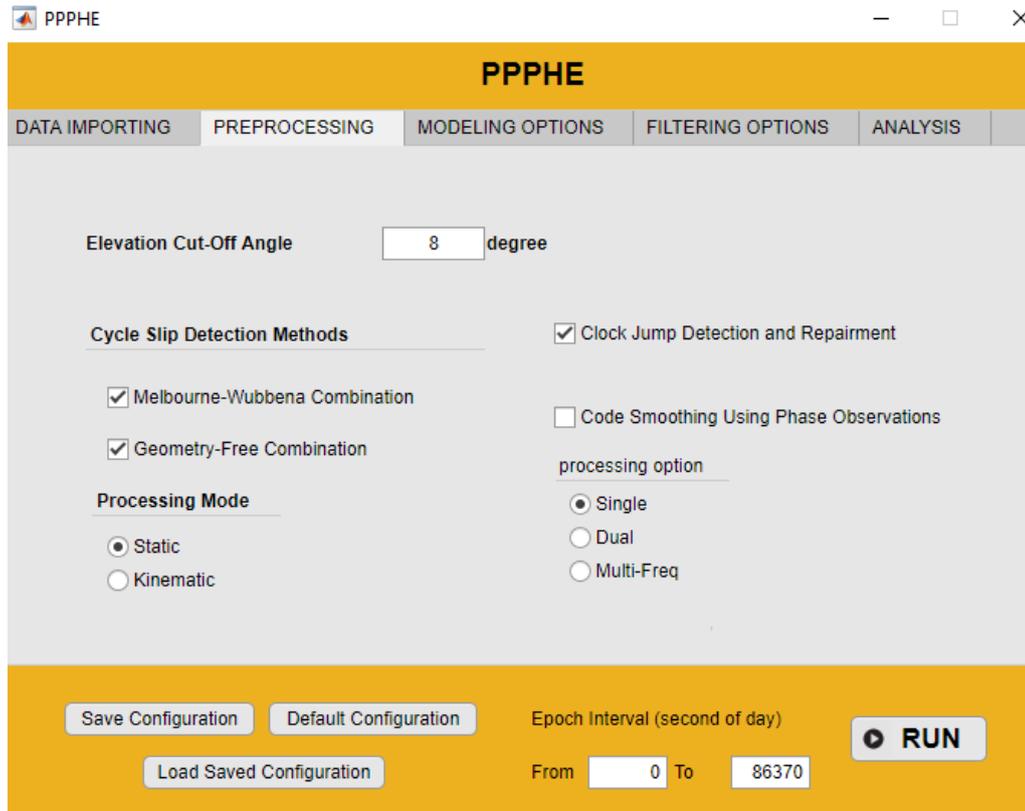


Fig. 3: The modified PPPHE software GUI

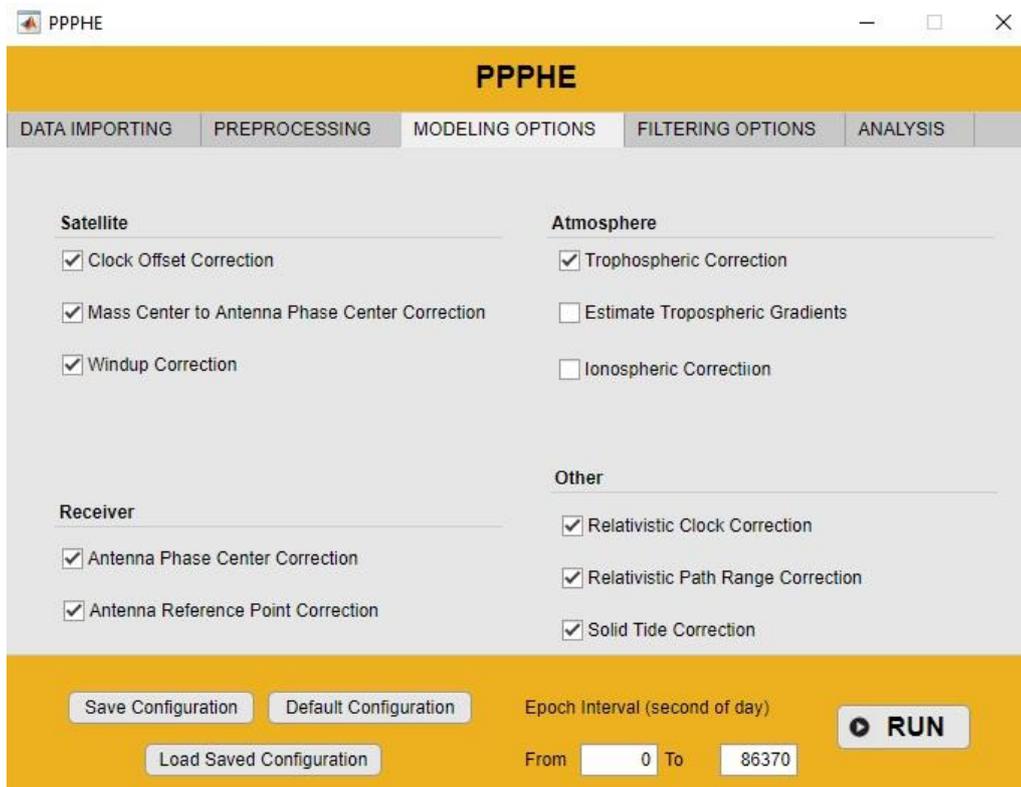


Fig. 4: The modified PPPHE software GUI

Table 2: The modified software processing parameters [22]

Processing parameter	PPPHE
Processing mode	single frequencies dual frequencies multi frequencies
Ionosphere model	klobuchar ionosphere model
Constellation	GPS/only GPS/GLONASS GPS/other GNSS
Processing mode	Static
Satellite orbit and clock	IGS final
Satellite and receiver antenna phase center offset	IGS Antex
Elevation mask	10°
Troposphere model	Saastamoinen (GPT2)
Mapping function	GMF
Relativistic effects	Applied (Kouba 2015)
Phase wind-up correction	Applied (Wu et al. 1993)
position displacement	Solid Earth tides and ocean loading are applied (Petit and Luzum 2010)
Adjustment method	Extended Kalman filter

Practical experiments were conducted for processing and analyzing by PPPHE; then, the results were introduced. Fig. 5 illustrates the sequence of the steps to reduce the GNSS noise and process the data.

4. EXPERIMENT

Experimental tests and results were conducted to evaluate and validate the performance of PPPHE through the following steps.

- Selecting IGS stations, namely PICL, POVE, CHUR, ISTA, and MAT1 (get their coordinated from ITRF 2014). Table (3) and Fig. 6 show the locations of these points. They were chosen where they are not grouped in one country, and all have the exact coordinates on the same datum. They have a receiver that supports GPS and GLONASS, Galileo, and Beidou observations, which are available on the selected date for this study.
- Raw data were collected for 24-hour observation data on 10 July 2017.
- The observation files were obtained from the IGS data server since all IGS stations are MGEX stations equipped with multi-GNSS receivers.
- After separating the frequency, the observation data were processed using PPPHE software in static mode.
- The observation data were processed in case of a single frequency (GPS- only, GPS-GLONASS, and multi GNSS solutions) against dual frequency (GPS- only, GPS-GLONASS, and multi GNSS solutions).

- The comparison was made between the calculated coordinates of IGS stations and the standard coordinates of the same points from ITRF 2014.

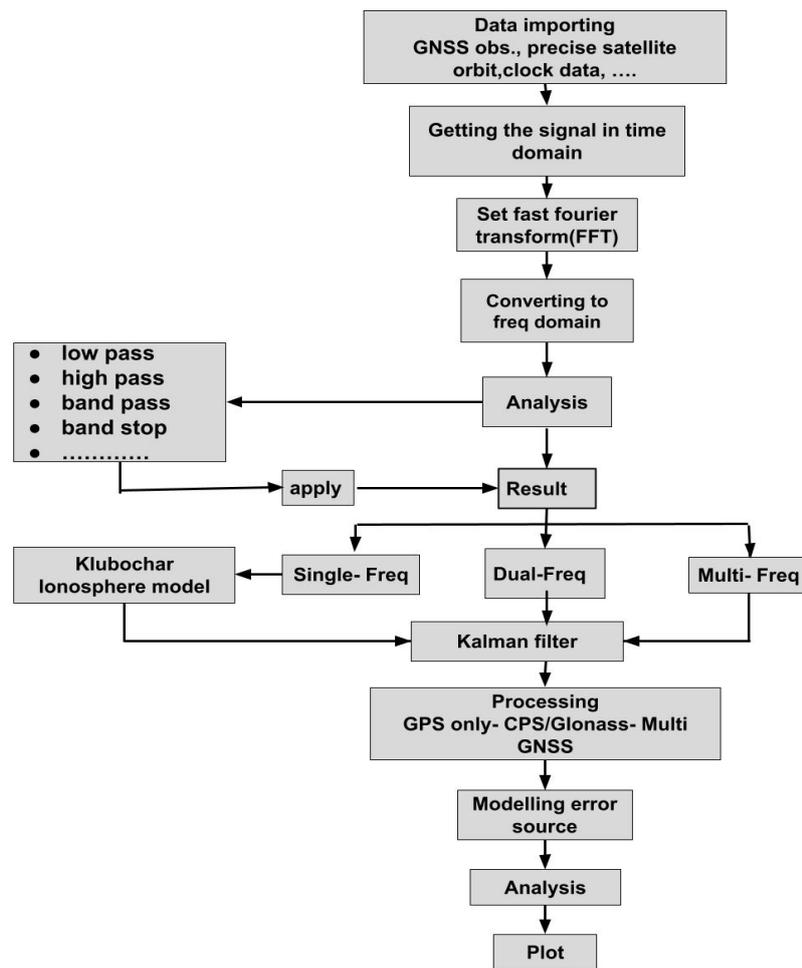


Fig. 5: The steps sequence to reduce the GNSS noise and processing the data

Table 3: The tested points used in this study [24]

Station	Country	Latitude	Longitude	Constellations
PICL	Canada	51°28'48"	-90°9'43"	GPS-GLONASS- Galileo
POVE	Brazil	-8°42'32"	-63°53'45"	GPS-GLONASS- Galileo- Bedio
CHUR	Canada	58°45'32"	-94°5'20"	GPS-GLONASS- Galileo
ISTA	Turkey	41°6'25"	20°1'8"	GPS-GLONASS- Galileo
MAT1	Italy	40°38'56"	16°42'18"	GPS-GLONASS- Galileo- Bedio

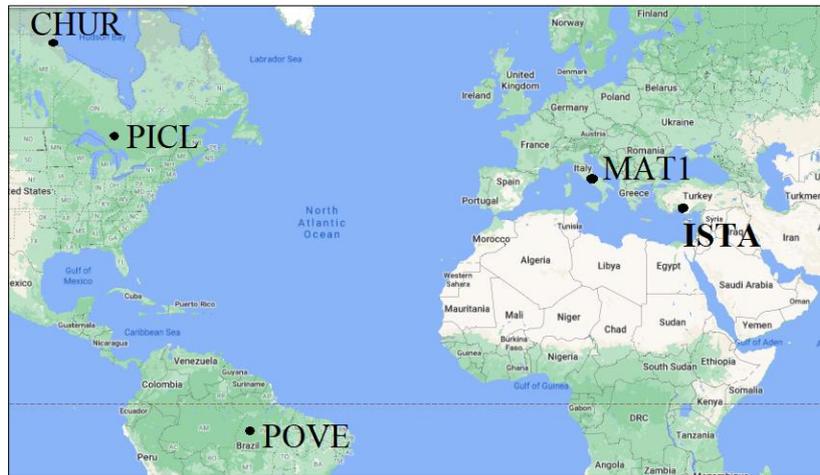


Fig. 6: The steps sequence to reduce the GNSS noise and processing the data [26]

5. THE RESULT AND ANALYSIS

As mentioned, this research calculates the 3-D coordinates of the selected points using a modified MATLAB software PPPHE over a long session of 24 hours using the precise ephemeris. Two processing cases in the static mode were performed: the single frequency adapting klubochar ionosphere model and the dual frequency adapting free linear combination method. The root means square error (RMS) of the horizontal and vertical accuracy coordinates of selected points related to their ITRF 2014 coordinates were calculated. The processing and analysis were in three aspects: GPS/only, GPS/GLONASS, and GPS/multi-constellations. The improvement (%) in the results was calculated compared to the results of the GPS only. Multi GNSS and GPS/GLONASS, position error results, subtracted from GPS position error results divided by GPS results and final results multiplied by 100. The results are shown in Tables (4, 5) and Fig. (7, 8, 9).

Table 4: Results related to single frequency

Station	combination	3-D	2-D	1-D	Improvement (%)		
		position Error (mm)	position Error (mm)	position Error (mm)	3-D	2-D	1-D
PICL	GPS-only	24.6	17.9	18.4			
	GPS-GLONASS	22.6	16.6	15.4	8	8	16
	MULTI GNSS	21.8	15.9	14.4	11	11	22
POVE	GPS-only	49.0	38.9	29.8			
	GPS-GLONASS	43.7	34.2	27.2	11	12	9
	MULTI GNSS	41.3	32.6	25.4	16	16	15
CHUR	GPS-only	26.0	18.4	18.4			
	GPS-GLONASS	20.4	14.4	14.4	22	21	22
	MULTI GNSS	18.6	13.3	13.4	28	28	27
ISTA	GPS-only	29.2	20.3	21.0			
	GPS-GLONASS	25.0	18.4	17.0	14	9	19
	MULTI GNSS	24.1	17.7	16.0	17	13	24
MAT	GPS-only	30.0	22.4	20.0			
	GPS-GLONASS	24.0	16.1	15.0	20	28	25
	MULTI GNSS	21.8	15.8	14.0	27	29	30

Table 5: The statistical result related to dual frequency

Station	combination	3-D	2-D	1-D	Improvement (%)		
		position error(mm)	position error (mm)	position error(mm)	3-D	2-D	1-D
PICL	GPS-only	21.2	10.7	18.4			
	GPS-GLONASS	16.6	7.8	14.6	22	27	20
	MULTI GNSS	15.9	7.6	13.4	25	29	27
POVE	GPS-only	20.1	16.6	16.1			
	GPS-GLONASS	16.3	12.5	13.9	19	24	16
	MULTI GNSS	14.8	11.7	13.7	26	29	15
CHUR	GPS-only	21.1	12.9	18.1			
	GPS-GLONASS	19.6	10.7	13.5	7	17	23
	MULTI GNSS	18.8	9.7	13.6	11	25	25
ISTA	GPS-only	23.4	11.7	16.0			
	GPS-GLONASS	18.3	9.6	14.0	22	12	19
	MULTI GNSS	16.3	8.5	13.1	26	18	19
MAT	GPS-only	23.2	17.1	19.0			
	GPS-GLONASS	20.3	14.7	14.0	18	12	26
	MULTI GNSS	19.6	14.0	12.9	27	16	32

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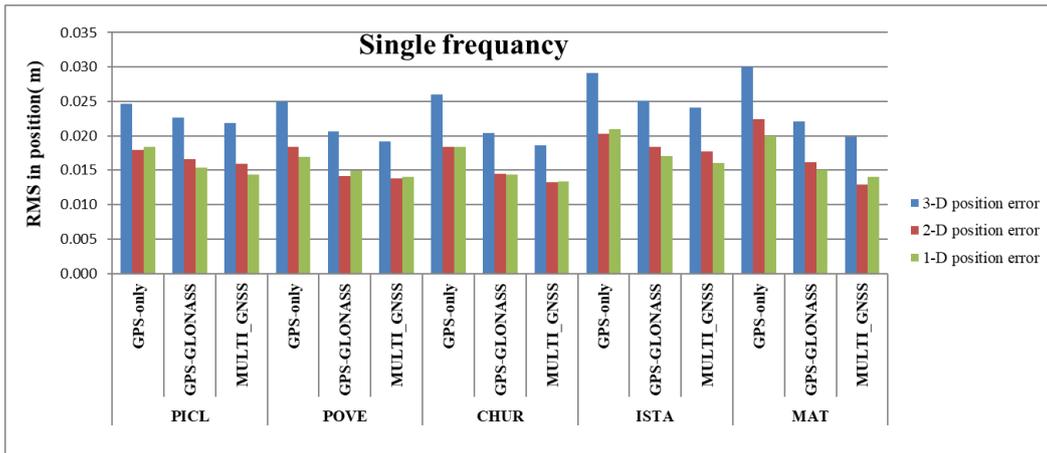


Fig. 7: The errors in single frequency

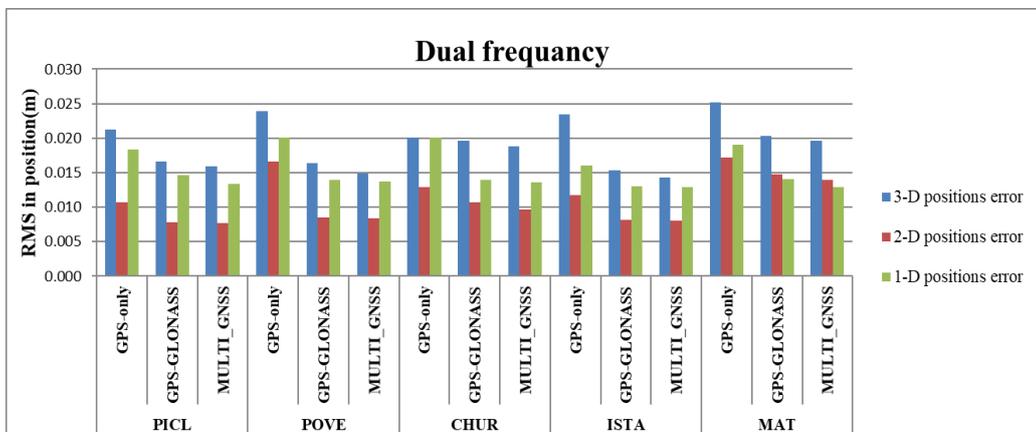


Fig. 8: The errors in dual frequency

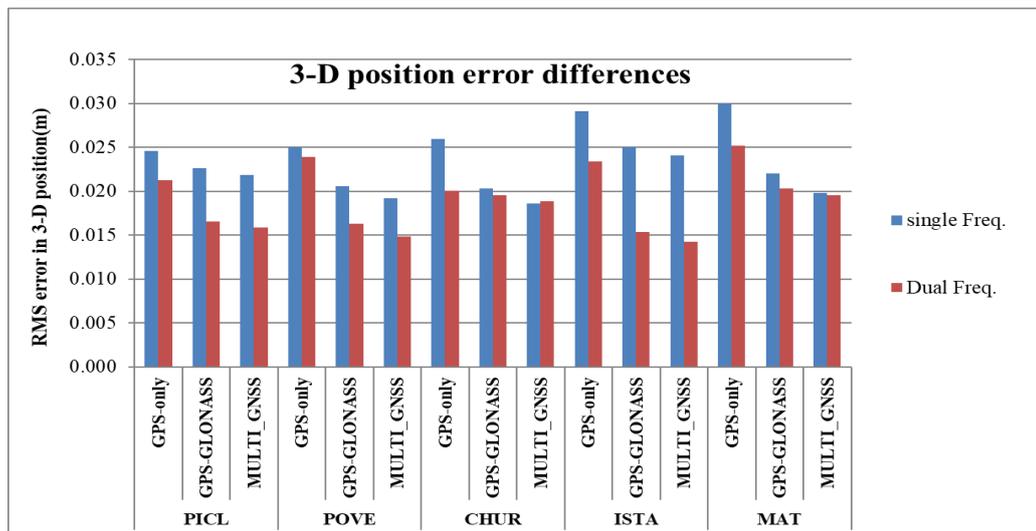


Fig. 9: 3-D position error in single and dual frequency

5.1. Results Related to Satellites Constellation

For all IGS points, RMS in the position is proportional to the type of satellite constellation used for the two processing, single and dual mode. The biggest error was in the case of GPS only, and the least with GPS/GLONASS and GPS/multi GNSS systems. RMS error in position was 31.8mm, 19.5mm, and 18.5mm in 3-D, 2-D, and 1-D in the case of GPS only, and 18.9mm, 15.9mm, and 15.3mm in the case of GPS/GLONASS, and 21.8mm, 15.3mm and 14.4mm in the case of GPS/multi GNSS. On the other hand, the RMS error of positions concerning dual frequency mode was 21.8mm, 13.8mm, and 17.5mm in 3-D, 2-D, and 1-D in the case of GPS only, and 17.6mm, 11.0mm, and 14.0mm in case of GPS/GLONASS, and 17.0mm, 10.3mm, and 13.3mm in case of GPS/multi GNSS. The single mode's results approximately approach the dual mode's results by 68.5%.

5.1.2. RMS Error in the 3-D, Horizontal, and Vertical Position

The value of the RMS error in 3-D positions is greater than the RMS error in horizontal and vertical error for all points concerning the single and dual processing modes. As expected, the RMS error in the vertical position is greater than the RMS in the horizontal. The reason may be that the mathematical method of calculating the horizontal position differs from the mathematical method of calculating the vertical position. It was found that the anomalous RMS error value at the POVE IGS point. The reason is the use of the klobucher Model in processing the ionosphere error. The Klobucher model gives worse results in the northern and southern hemispheres in low latitude regions near the equator [23].

The values of RMS error in the position related to the single frequency mode in 3-D, 2-D, and 1-D components ranged from (18.6mm to 45.0mm), (13.3mm to 22.4mm) and (13.4mm to 21.0mm) respectively. Also, the values of the RMS error in the position related to the dual frequency mode in 3-D, 2-D, and 1-D components ranged from (14.3 mm to 23.2mm), (7.6 mm to 17.1 mm) and (12.9.0 to 20.1mm) respectively. The RMS in the dual frequency mode results is smaller than the RMS error in the single frequency mode with 31.5%. The reason may be the way of treating the ionosphere error.

5.1.3 Improvement Rate in Position Accuracy Concerning to GPS

In the case of single mode, combining the GLONASS and the GPS observation improved the accuracy of the position compared to using the GPS observation only. The results showed that the percentage of improvement was 14.8%, 17.8%, and 18.8% in the case of 3-D, 2-D, and 1-D positions, respectively. Combining GPS observation with all the other systems also improved the results. The improvement percentage was 22.9%, 23.8%, and 23.9% in 3-D, 2-D, and 1-D, respectively. Compared to dual frequency mode, the combination of the GLONASS and GPS observations led to an improvement percentage of 18.4%, 11.0%, and 20.8% for 3-D, 2-D, and 1-D positions, respectively. The integration between all satellite constellations led to improvements was 26.2%, 30.4%, and 24.5% in 3-D, 2-D, and 1-D, respectively.

SUMMARY AND CONCLUSION

MATLAB PPPHE software has been modified to help users to easily use it to process and analyze the data. The PPPHE has been modified to become more flexible with the advanced users' requirements. It allows them to process all GNSS data in single, dual, and multi frequencies. At the same time, the researchers can rely on it because it is open-source and available to everyone without needing annoying cracks or the codes monopolized by some bodies and manufacturers of receiver's devices GNSS signal.

Two empirical tests were performed to verify and evaluate the performance of the PPPHE. They aim to validate the results obtained from the single-frequency adapting of the Klobuchar ionosphere model compared to the dual-frequency results adapting the free linear combination. It was studied attenuating the ionospheric delay in three aspects GPS/only, GPS/GLONASS, and GPS/Multi GNSS system. The results of the practical experiment were compared to evaluate the results.

The position accuracy concerning single and dual frequency improved by combining the available satellites observations with the GPS observation. There are variances in RMS error in position results concerning the dual and single frequency processing modes. The reason is due to the different error handling types in both. This study helped the user to use observations from a single receiver and reached 68.5% accuracy, close to the accuracy obtained from using a dual receiver.

CONTRIBUTION

This research will support many aspects, users, researchers, governmental agencies, and global agencies. Users can use the most appropriate receiver for the accuracy that they desire. They are not forced to use an expensive type of receiver that supports all frequencies. They use the most appropriate processing method. If the signal of a particular type of satellite is interrupted, the observations can be done on the other available GNSS types. Governmental agencies of countries can adopt PPPHE software, especially countries that do not have sufficient ground control points. This program can be provided to users interested in the PPP technology. It is advanced in the PPP solutions instead of using non-professional programs that support the relative solution. Researchers can adapt PPPHE. It is an open-source MATLAB program. It is very convenient for all engineers to complete their calculations efficiently. It can also be improved, and better results can be obtained. It is helpful for global agencies such as the international association of geodesy (IGS). They can trust it and recommend it to users and researchers interested in surveying and geodesy.

CONFLICT OF INTEREST

The authors have no financial interest to declare in relation to the content of this article.

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