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Evaluation of GPS Precise Point Positioning for Geoinformatics Community

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Abstract. Precise Geodetic GPS applications has evolved during the last two decades as the GPS processing and analysis techniques become more robotics and complicated. These progresses cover both the traditional relative positioning methods where more than one receiver are used simultaneously and the single positioning technique. In this study, GPS Precise Point Positioning (PPP) method, that does not require data from any other GPS receiver, was tested and evaluated through various computations environments. The un-differenced dual-frequency pseudo range and carrier phase observations were downloaded from one permanent international GNSS Service (IGS) station and one permanent CORS station. The GPS data were processed using various IGS orbit data in a post-processing manner using the ESA/UPC GNSS-Lab (gLAB) software. The results for various observations scenarios of the PPP solutions were investigated and analyzed. The conclusion and suggested future works are outlined in the research.

Key words: GPS, Precise Point Positioning, IGS data

List of Symbols

ℓ_P *(P3)* is the ionosphere-free combination of P1 and P2 pseudo ranges ($2.546P_1$-$.546P_2$),
ℓ_ϕ *(L3)* is the ionosphere-free combination of L1 and L2 carrier-phases ($2.546\lambda_1\varphi_1$-$1.546\lambda_2\varphi_2$),
dT is the station receiver clock offset from the GPS time,
dt is the satellite clock offset from the GPS time,
c is the vacuum speed of light,
T_r is the signal path delay due to the neutral-atmosphere (primarily the troposphere),
N is the non-integer ambiguity of the carrier-phase ionosphere-free combination,
λ_1, λ_2, λ are the of the carrier- phase L1, L2 and L3-combined wavelengths respectively,
ε_P , ε_Φ are the relevant measurement noise components, including multipath.
ρ is the geometrical range from the satellite position and the station position
SINEX Solution Independent Exchange

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1. Introduction

The Global Positioning System (GPS) is commonly used to compute receiver location coordinates using the traditional relative positioning technique. In this method, precise user location is obtained while mitigating some of the measurements errors such as atmospheric delay, the satellite clock error, satellite coordinates errors, and site dependent effects (multipath, measurement noise and receive clock error) [1, 2]. The relative positioning technique is very popular and result into positional accuracies ranging from meter into sub-centimeter level depending on the quality of the user receivers types, the distance between the user position and the base station, observation mode of operation and the used observational model [6, 8].

Another method for obtaining precise positioning that can be used for various geospatial applications is the precise point positioning (PPP) method in which a single point position can be determined using undifferenced code and phase measurements with the GPS precise orbits data that can be obtained from the international GPS service (IGS) instead of using the broadcast navigation message. The PPP enhance the single positioning solution by correcting mainly orbit errors, satellite clock bias, atmospheric delays with other errors such as satellite antenna offset, receiver and satellite antenna phase information, earth Tide data, earth orientation parameters, ocean tide loading, etc. [2, 3, 4]. The obtainable accuracy using precise point poisoning (PPP) in general will be affected by the type of the receiver, the used functional model and the used processing software. The PPP can be utilized in many applications such as remote sensing, monitoring natural hazards and vehicular Navigation [5]. In this paper, the PPP solution is evaluated using a static single dual frequency in two separate stations and using IGS products.

2. Point positioning Functional Model

The PPP mathematical model for dual frequency receiver using the ionospheric-free combinations of dual-frequency GPS pseudorange (P) and carrier-phase observations (Φ) can be written as [4]:

$$\ell_P = \rho + c(dT-dt) + T_r + \varepsilon_P \tag{1}$$

$$\ell_\phi = \rho + c(dT-dt) + T_r + N\lambda + \varepsilon_\Phi \tag{2}$$

For equations “1” and “2”, when using the IGS orbit/clock products, the satellite clocks can be considered known and the remaining tropospheric path delay error can be estimated based on zenith path delay. The least squares solutions can be undertaken based on periori values for the parameters and observations. The parameters contains: station position (x,y,z), satellite clock (dt), troposphere zenith total delay, and real-valued carrier-phase ambiguities (N) [6].

The IGS orbit products can be categorized into Ultra-rapid, rapid and final products. The Ultra-rapid GPS Ephemerides/Satellite & station clocks are available with latency from 3-9 hours with updates every 6 hours with satellite clocks sample interval 15 minutes. The rapid GPS Satellite Ephemerides are available with latency from 17-41 hours while the final products are available with latency 12- 18 Days [7]. Currently, the final orbit product includes the final clock combination with 30-sec sampling [6].

The highest possible PPP solution can be achieved by using the precise satellite orbits and clocks, applying all of the required corrections including the satellite attitude effect and site displacement effect [8].

3. Data Testing and Results

Two permanent stations, one IGS station named “WES2” and one CORS station named “INWB” that located in USA were used in this study. Station “INWB” has slightly better sky visibility more than Station “WES2”. Two different days of RINEX data of GPS week 1690, Day 153, year 2012 and GPS week 1696, Day 190, year 2012 were downloaded from the CORS database [9]. Different days were chosen as final orbit data is usually available after 12-18 days from the last observation [7]. The data includes both phase measurement of the carrier waves both for Ll and L2, Pl, P2 and C/A pseudo-range code at 30 seconds intervals. Also the precise ephemeris at a sampling interval of 15 min and high-rate precise satellite clocks at a sampling of 30 seconds were downloaded from the IGS website [7]. The data were selected and tested for evaluating the quality of the PPP solutions using GLAB software [10]. The data was also examined and compared with IGS “ROAP” station in terms of site location and data. The “ROAP” station is located at (36° 27′ 51.4″N, 6° 12′ 22.55″ W, 73.7m) in San Fernando, SPAIN and the data was provided with gLAB software.

Various IGS products and ephemerides data with GPS satellite high-rate clock information were used to investigate the effect of various IGS products on the attainable accuracy. Also various factors that may affect the quality of the PPP results were examined such as particular site location data, observation, observation duration and kinematic solutions at fixed stations. The station locations and receiver configuration are given in Table (1). The coordinates of station “INWB” are based on the coordinates provided on the CORS site, while the coordinates of “WES2” are based on SOPAC website solution [11]. Different observations scenarios were investigated and analyzed in this study as illustrated in following subsections:

Table (1). Stations Information

	WES2	INWB
Location	Westford, MA.	Wabash, IN.
Receiver Type	LEICA GRX1200GGPRO	LEICA GRX1200GGPRO
Coordinates	Latitude = 42° 36′ 48.009″N, Longitude = 71° 29′ 35.982″ W, Height =85.0087m	latitude = 40° 49′ 29.0517″N, longitude = 085° 48′11.646″W height = 217.349m

3.1 Location and site data

The difference between the computed PPP coordinates solutions and the published coordinates were computed for the two examined sites with the IGS "ROAP" Station. The three stations were computed using the GLAB software under the same processing settings using the final IGS orbit data with the final clock combination with 30-sec sampling. The impact of the site location on the resulting PPP solution is shown in Table (2) for 24 hours measurement period for the two examined stations (for day 153, 2012) and the "ROAP" station (for day 181, 2009). The resulting north, east and up error components are computed as shown in Table (2). The 3D errors vary from 9 mm (for point ROAP) into 12.7cm (for point INWB). The high accuracy results that obtained for point "ROAP" could be based on the quality of the pre-estimated station coordinates and the quality and the availability of the station data such as precise receiver antenna data and precise a priori SINEX (position data) that was available for the "ROAP" station. The relatively high coordinate component error (dE), for station "INWB", may be due to systematic error in the published coordinate component. The 3D error of station "WES2" show that the result matches the expected high quality results for the IGS station coordinates although the station suffer from lower sky visibility than that of the other two stations. The better sky visibility of station "INWB" when compared with station "WES2", does not affect greatly on the obtained results as the measurements was taken over long observation period (24 hours).

Table (2). The Resulting errors for the location and site data case (units are in meter)

Station, Date and Year	dN	dE	dU	3D Error
INWB- Day 153, 2012	0.005	-0.125	-0.022	0.127
WES2- Day 153, 2012	0.008	0.007	-0.016	0.019
ROAP – Day 181, 2009	-0.004	0.000	-0.008	0.009

3.2 Orbit variables

The impact of using different IGS orbit data on the resulting PPP solution is investigated and presented in Table (3) and Fig. (1). The IGS data include ultra-rapid data (IGU), rapid data (IGR) and final data (IGS) with final clock combination with 30-sec sampling. The results are shown for 24 h measurement period for the two examined stations on Day 190, 2012 for ultra-rapid and rapid data and day 153, 2012, for final orbit data. The resulting 3D errors vary from 19 mm into 19.9cm for station WES2 and 11.9 cm into 12.7 cm for station INWB. The high accuracy that obtained for station WES2 may be based on the quality of the pre-estimated station coordinates and the quality of the station data such as receiver antenna phase data. The nearly equal error values of point “INWB” for the three cases may reveal systematic errors in the pre-assumed station coordinates as the errors was mainly affect the Eastern components (dE).

3.3 Observation period

The impact of using different observation durations on the resulting PPP solution is examined and presented in Table (4) and Fig. (2) for the two examined stations. The tested observation durations were 2, 6, 12, 24 hours. While, station INWB seemed to be suffered from a systematic error in the east components in various observation durations, the accuracy of the WES2 coordinates were refined from 37 cm for two hours observation to 19mm for 24 hours observation. The unexpected error results for the two hours observation period for station WES2 (that was concentrated in the eastern component) lead to study the observation time effect on the PPP solution as illustrated in the next subsection.

Table (3). The Resulting errors for the orbit variables case (units are in meter)

Station	Orbit data	dN	dE	dU	3D
INWB	Ultra-rapid data (IGU)	-0.071	0.099	0.006	0.121
	Rapid data (IGR)	0.018	-0.116	0.019	0.119
	Final orbit data (IGS)	0.005	-0.125	-0.022	0.127
WES2	Ultra-rapid data (IGU)	-0.0527	0.127	-0.144	0.199
	Rapid data (IGR)	0.021	0.010	-0.028	0.036
	Final orbit data (IGS)	0.008	0.007	-0.016	0.019

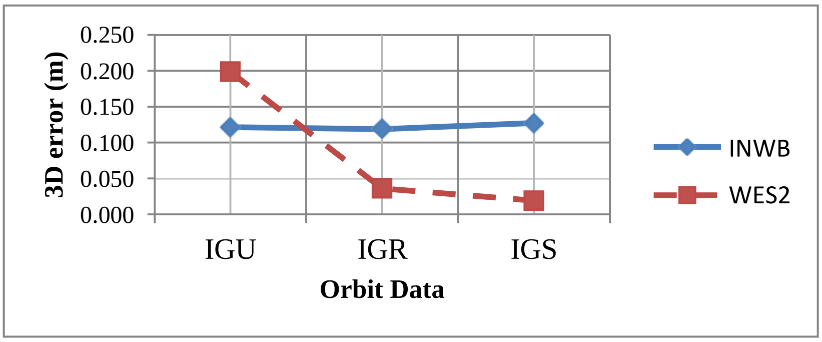

Fig. (1). The Resulting errors for the orbit variables case

Table (4). The Resulting errors for the observation period case (units are in meter)

Station	Duration (hours)	dN	dE	dU	3D
INWB	24	0.005	-0.125	-0.022	0.127
	12	0.006	-0.126	0.007	0.126
	6	0.004	-0.120	0.013	0.121
	2	-0.009	-0.143	0.017	0.144
WES2	24	0.008	0.007	-0.016	0.019
	12	0.009	0.006	-0.021	0.023
	6	0.012	-0.025	0.000	0.028
	2	0.077	-0.367	0.039	0.377

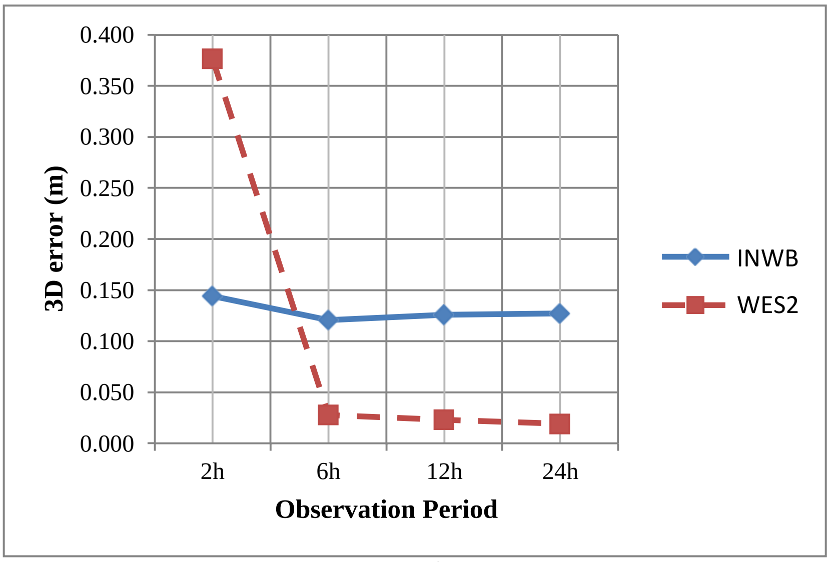

Fig. (2). The Resulting errors for the observationperiod case

3.4 Observation time

The impact of using different observation time on the resulting PPP solution is presented in Table (5) and Fig. (3) for the two examined stations using 2 h observation period and using the final data product of Day 153. The errors resulting from varying the observation time were varying between 37.7 cm and 1.8 cm with a mean value of 11.5 cm. The same note concerning the systematic bias for station INWB was still valid here as the error range from 11.1 cm and 14.5cm with a mean value of 13.3 cm while the most affected component was the eastern coordinate component.

Table (5). The Resulting errors for the observation time case (units are in meter).

Station	Observation Time	dN	dE	dU	3D
INWB	0 – 2 h	-0.009	-0.143	0.017	0.144
	2 – 4 h	0.014	-0.139	-0.039	0.145
	4 – 6 h	0.010	-0.135	0.031	0.139
	6 – 8 h	0.010	-0.129	-0.022	0.131
	8 – 10 h	0.006	-0.126	-0.032	0.130
	10 – 12 h	0.009	-0.106	0.032	0.111
WES2	0 – 2 h	0.077	-0.367	0.039	0.377
	2 – 4 h	-0.033	-0.058	0.121	0.138
	4 – 6 h	0.005	-0.003	-0.018	0.019
	6 – 8 h	-0.032	0.044	0.037	0.065
	8 – 10 h	0.004	0.012	-0.013	0.018
	10 – 12 h	0.018	0.033	-0.065	0.076

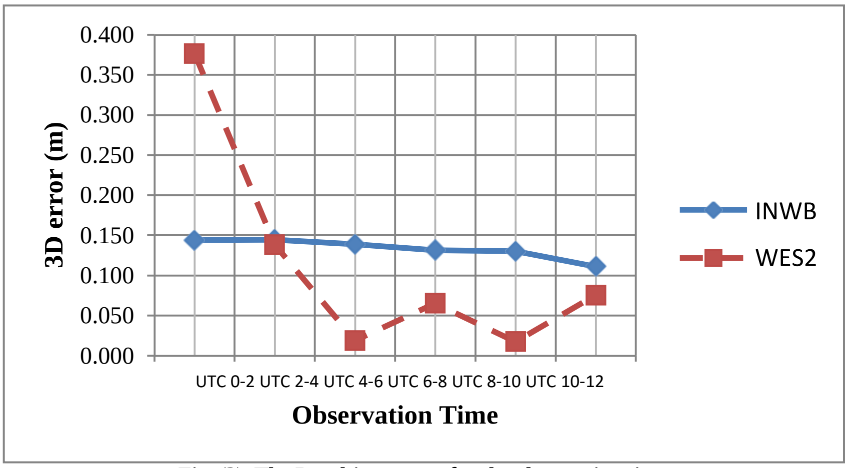

Fig. (3). The Resulting errors for the observation time case

4. Conclusions and Future Works

Geospatial community may be utilizing the more precise results of the PPP solutions in different applications. The GPS field costs and mobilization can be justified using PPP solutions when compared with the traditional relative positioning technique. The PPP solution can produce the required accuracy using dual frequency receivers with sufficient observation duration to ensure eliminating of most of the errors. Using of the PPP solution with insufficient observation duration and poor DOP values may result into a substantial degradation in the attainable accuracy in such environments as illustrated using 2 h observation period. The examined cases in this research study show that the PPP can be used in static mode to achieve the required data accuracy and productivity that is required for many of the geospatial applications.

The research study shows that the quality of the observed site can be evaluated in terms of existence of systematic errors on the published coordinates can be addressed. Comparing the various data products, the Ultra-rapid data products may produce results in the decimetre level while the rapid data may produce results that reach to few centimetres as derived in table (3). Reducing the observation period from 24 hours up to 6 hours would affect slightly on the resulting error as presented in table (4). For observation period of 2 hours, better results can be obtained by selecting the appropriate observation time such as from 10:00-12:00 for station INWB and from 4:00-6:00 and from 8:00 to 10:00 for station WES2.

The proposed future PPP works is to investigate handling of upcoming GALILEO data with the GPS data in a single positioning mode to enhance both the availability and accuracy of the satellite data. Also, the PPP algorithms should be added to the traditional double –differencing techniques to allow for through GPS measurements analysis and comparison of relative positioning and PPP solutions.

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تقييم تحديد المواقع المطلق الدقيق لنظام جي بي اس لمجتمع المعلوماتية الجغرافية

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ان تطبيقات GPS ملخص البحث التطبيقية الدقيقة قد تطورت خلال العقدين الماضيين نتيجة لتطور برمجيات معاجلة وتحليل بيانات GPS واصبحت هذه البرمجيات اكثر تعقيدا واليا. وقد غطي هذه التقدم كلا من األساليب التقليدية لتحديد املواقع النسبية حيث يتم استخدام أكثر من جهاز االستقبال في وقت واحد املوقع وكذلك تقنية حتديد املواقع املطلقة. في هذه الدراسة، مت اختبار وتقييم حتديد املواقع املطلق الدقيق باستخدام GPS باسلوب (PPP)، الذي ال يتطلب أي بيانات من اي جهاز استقبال GPS اخر ، من خالل بيئات خمتلفة. وقد مت حتميل ارصاد GPS املطلقة وتشمل اشباه املسافات والطور املوجي باستخدام موجات ثنائية التردد من حمطة دائمة دولية خلدمات GNSS (IGS) وحمطة اخري دائمة CORS. وقد مت معاجلة بيانات GPS باستخدام معلومات مدارات االقمار الصناعية املختلفة IGS بعد انزال البيانات وذلك باستخدام برنامج (gLAB). وقد مت فحص نتائج سيناريوهات خمتلفة حلساب املواقع باستخدام اسلوب PPP وحتليلها وكذلك مت ذكر استنتاجات البحث واملقترحات املستقبلية.

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