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Assessment of the Accuracy and Convergence Period of Precise Point Positioning

تقدير دقة ومدة تقارب التموضع الدقيق

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KEYWORDS:
Precise point positioning, PPP accuracy, convergence period and geodetic control surveying

الملخص العربي:- التموضع الدقيق هو طريقة مشهورة للتموضع التي تزيل وتنمذج وتقدر اخطاء نظام الملاحة العالمي لتصل الي الدقة القصوى من مستقبل واحد. دقة التموضع الدقيق في الوضع الثابت كانت مختبرة لعينة من ٥٢٣ ملف أرصاد يومية عند ٧٥ محطة موزعين عالميا في الفترة من يوم ٤٩ الي ٥٥ في سنة ٢٠١٢. أيضا، مدة التقارب كانت ممتحنة للوصول لمستويات مختلفة من الدقة الأفقية لكي تخدم التطبيقين: الزراعة الدقيقة و مساحة الضبط الجوديسي. دقة التموضع الدقيق الثابت كانت ٤، ٥ و٩ مليمتر لاتجاهات الشمال والشرق والرأسي علي التوالي. التموضع الدقيق الثابت يحتاج ٦٠ دقيقة ليصل لدقة أفقية من ٥ سم عند مستوى ثقة ٩٥% و ٢٤ ساعة ليحقق دقة أفقية من ١ سم عند مستوي ثقة ٩٥%.

Abstract— **Precise Point Positioning (PPP) is a well-known positioning method that removes, models, or estimates GNSS system errors to reach the optimal position accuracy from a single receiver. The accuracy of static PPP was tested for 523 daily observation files from 75 IGS globally distributed stations observed at the period from DOY 49 to 55 in 2012. Also, the convergence period was examined to reach different levels of the horizontal accuracy to serve two applications: precision agriculture and geodetic control surveying. The accuracy of static PPP was 4, 5 and 9 mm in the north, east and vertical components, respectively. Static PPP needs 60 minutes to reach five-centimeter horizontal accuracy at the 95% confidence level and 24 hours to achieve one-centimeter horizontal accuracy at the 95% confidence level.**

I. INTRODUCTION

Precise Point Positioning is a famous positioning technology that relies on observations from a single receiver along with precise satellite orbits and clock corrections. In the PPP approach, observations from a single receiver are used to estimate the receiver position, the ambiguities, the receiver clock offset and the wet tropospheric delay (Zumberge et al. 1997; Kouba and Heroux 2001). PPP serves a wide range of applications such as: precise positioning (Geng et al. 2010), atmospheric water vapor sensing (Douša, 2010), earthquake and tsunami monitoring (Shi et al. 2010), orbit determination of low Earth orbiting satellites (Bock et al. 2003) and precision agriculture (Dixon, 2006). PPP have demonstrated a high ability to become the next-generation positioning technology.

GPS community has given an increased attention for improving the PPP accuracy. Collins (2008) achieved improvements of 2 cm by ambiguity resolution for hourly solutions. Also by ambiguity resolution, Geng et al. (2010) improved the accuracy of hourly results from 1.5, 3.8 and 2.8 to 0.5, 0.5, 1.4 cm for north, east and vertical components, respectively.

II. PPP PROCESSING TECHNIQUE:

When PPP uses the sequential (epoch-by-epoch) least-squares estimation. Mitigation of all potential effective errors in PPP functional model is mandatory to get results with improved accuracy. Mitigation of PPP errors can be done through modeling such as (troposphere, relativity, and earth tide); estimation like (receiver clock offset); or elimination like (the first-order effect of the ionosphere by linear combinations). Table (1) illustrates a summary of all

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mitigative strategies of PPP error sources.

TABLE (1): MITIGATION STRATEGIES OF PPP ERROR SOURCES (TÉTREAULT ET AL., 2005; BERAN, 2008).

Effect	Magnitude	Domain	Mitigation strategy	Residual error
Ionosphere	10s m	range	ionosphere-free linear combination	mm
Troposphere	few m	range	modeling; random-walk estimation	dm - mm
Relativity	10 m	range	modeling	mm
Satellite antenna PCO/PCV	m - cm	position; range	modeling	mm
Solid earth tide	20 cm	position	modeling	mm
Phase wind-up	10 cm	range	modeling	mm
Ocean loading	5 cm	position	modeling	mm
Satellite orbits/clocks	few cm	position; range	modeling	mm
Pseudorange multipath and noise	1-3 m	range	filtering	dm-mm
Receiver antenna PCO/PCV	cm-mm	position; range	modeling	mm

III. THE TESTED SAMPLE AND PROCESSING PARAMETERS

523 daily observation files from 75 IGS globally distributed stations observed at the period from DOY 49 to 55 in 2012 were processed using the PPP approach. The places of the tested stations is illustrated in Figure (1). Dual-frequency pseudorange and carrier-phase observations were used. 2 m and 15 mm are the priori standard deviations for traditional pseudorange and carrier-phase ionosphere-free linear combination observations, respectively, and an elevation cut-off angle of 10°. IGS final 15-minute orbit and 30-second clock products were used.

Figure (1): the distribution of examined 75 IGS stations.

IV. ACCURACY OF PPP

To determine the accuracy of PPP, the estimated positions were examined against the IGS weekly SINEX solution (Crustal Dynamics Data Information System, 2012). The main factors affecting the convergence period and the accuracy of PPP are the limited precision of current precise orbit and clock corrections and the effects of remaining un-modelled errors. Solution here refers to the solution that is obtained by processing the daily observations. The distribution of the absolute horizontal and vertical errors is illustrated in Figure (2) and Figure (3), respectively, for a sample size of 523.

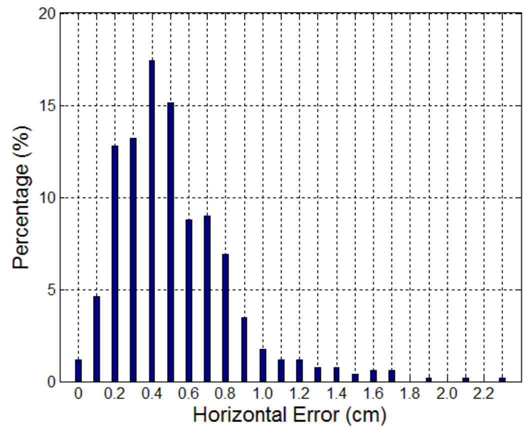

Figure (2): Distribution of absolute horizontal error

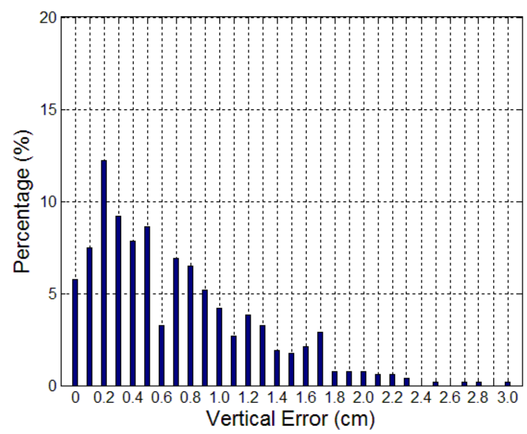

Figure (3): Distribution of absolute vertical error

PPP can provide sub-centimeter accuracy level in the horizontal direction and centimeter accuracy level in the vertical. 99% of the processed sample had an absolute horizontal error less than or equal to 17 mm and 95% of the results of the sample had an absolute horizontal error less than one centimeter. 99% of the processed sample had an absolute vertical error less than or equal to 25 mm and 95% of the results of the sample had an absolute vertical error less than 17 mm. PPP solutions had an rms of 4, 5 and 9 mm in the north, east and up, respectively. Table (2) shows the statistics of solutions obtained by PPP.

TABLE (2): STATISTICS OF SOLUTIONS OBTAINED BY PPP FROM DAILY DATASETS FROM 75 STATIONS ON DOY 49-55, PROCESSED IN STATIC MODE.

	Rms (mm)	Bias (mm)	Std (mm)
North	4	3	2
East	5	4	1
Up	9	8	5
Horizontal	6	5	2
3D	11	10	5

V. PPP CONVERGENCE

PPP convergence can be defined as position estimates reach steadily to a specific accuracy level without leaving this level, or float ambiguities reach steadily to constant values, then do not leave these values. The convergence in PPP depends on a set of factors including: (1) the number and geometry of observed satellites, (2) the environment and dynamics of the receiver and (3) the observation quality and sampling interval. As these previous factors changes, the convergence period will vary.

To clarify the definition of PPP convergence, PPP daily solutions for the station ALBH (Albert Head, Canada) within DOYs 49-55 were illustrated in Figure (4). Similar convergence performances were presented through all DOYs. The convergence period average was 5 minutes in order to reach 30 cm three-dimensional (3D) accuracy level at this week of observations. Unsettling period was present in-between 2-hour and 4-hour that is attributed to the slow changing of the satellite geometry and the receiver environment. Table (3) gives the statistics for the final position estimates for the station ALBH. The rms errors of 1.5 mm, 4.5 mm, and 4.5 mm at the north, east, and up directions, respectively, were present at the static processing. Sub-centimeter 3D accuracy was done by PPP approach at this station.

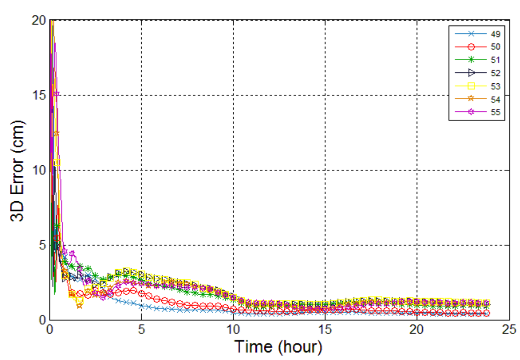

Figure (4): PPP daily solutions for the station ALBH (Albert Head, Canada) within DOYs 49-55.

TABLE (3): STATISTICS OF FINAL POSITION ESTIMATES FOR THE STATION ALBH (ALBERT HEAD, CANADA) WITHIN DOYS 49-55.

	RMS (mm)	Bias (mm)	Std (mm)
North	1.5	0	1.5
East	4.5	4	1
Up	4.5	2	3.5
Horizontal	5	4	2
3D	6.5	4.5	4

VI. APPLICATIONS OF PPP CONVERGENCE PERIOD TYPES OF GRAPHICS

Although PPP needs a long convergence time to reach the steady state, it can be used with this limitation to achieve different horizontal accuracies for many applications in different periods. Applications such as precision agriculture and geodetic control surveying are tested to determine the required convergence periods in order to achieve many horizontal accuracy levels. This section discusses these previous applications, their accuracy levels, and the required convergence periods for these accuracy levels.

VII. PRECISION AGRICULTURE

Precision agriculture (PA) is a management strategy that uses GPS and Geographic Information System (GIS) to ultimately maximize productivity and minimize waste and cost. Real-time PPP has a capability to help farmers in many processes such as: farm planning, field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications, and yield mapping (Pierce & Nowak, 1999). PA provides great advantages like: maximizing productivity and net profit, improving water quality and wildlife habitat, saving valuable time, fuel and fertilizer, reducing the farmers fatigue and stress by providing better decision making ability (Reid et al., 2000).

Wang and Feng (2009) mentioned the requirements of horizontal accuracy for farming operations in precision agriculture, as illustrated in Table (4). The dataset was processed each hour to examine the required convergence time to achieve these previous requirements for farming operations in the static mode. Figure (5) shows the percentages of the data converged to the horizontal accuracies 100, 50, 20, 10, and 5 cm each 5 minute bin size. All farming operations except plowing and traffic farming can be performed within a period varying from 5-60 minutes. Due to the high horizontal accuracy level of 1-2 cm, the required convergence period for these levels is long. As a result, plowing and traffic farming are not impractical by this PPP technique.

To determine the required convergence period for each accuracy level, the confidence level was 95% of the data. A quasi-linear relation is noted between the time and the percentage of the data converged to the horizontal accuracy level at 5cm. Also, an exponential relation is observed between the time and the percentage of the data converged to the horizontal accuracy levels at 10 cm and 20 cm. the required convergence periods are 60, 55, 30, 15, and 5 minutes at horizontal accuracy levels 5, 10, 20, 50, and 100 cm, respectively.

TABLE (4): RECOMMENDED PPP PERIODS FOR THE DIFFERENT HORIZONTAL ACCURACY LEVELS OF PRECISION AGRICULTURE

Horizontal accuracy (95% confidence level)	Recommended PPP period
100 cm	5 min
50 cm	15 min
20 cm	30 min
10 cm	55 min
5 cm	60 min

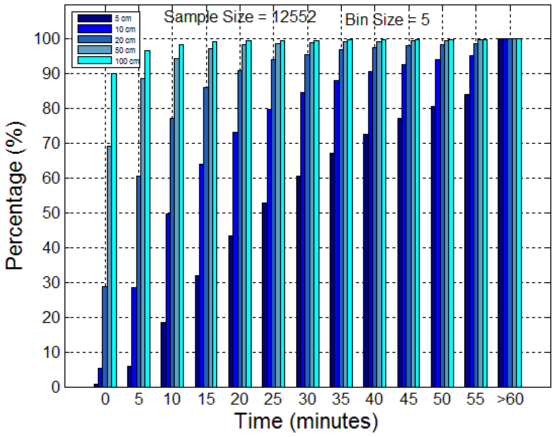

Figure (5): Convergence periods for horizontal accuracy levels used in precision agriculture with the static mode.

VIII. Geodetic Control Surveying

Geodetic control surveying is usually performed to establish the basic positional framework from which supplemental surveying and mapping are performed. Geodetic control surveying is distinguished by use of redundant, interconnected, permanently monumented control points. Geodetic control surveying is performed to far more rigorous accuracy and quality assurance standards than those for local control surveying for general engineering, construction, or topographic mapping purposes (Federal Geographic Data Committee, 1998). Table (5) illustrates the horizontal accuracy levels at the 95% confidence level, which were found in Federal Geographic Data Committee (1998), and the recommended PPP convergence period to reach these levels of horizontal accuracy.

Table (5): Recommended PPP periods for the different horizontal accuracy levels of geodetic control surveying

Horizontal accuracy (95% confidence level)	Recommended PPP period
0.1 cm	-
0.2 cm	-
0.5 cm	-
1 cm	24 hours
2 cm	5 hours

To determine the required PPP convergence period to achieve horizontal accuracy levels of geodetic control at 0.5, 1, and 2 cm, the dataset was processed each 24 hours at the static mode. Figure 6 shows the percentages of the data converged to the horizontal accuracies 0.5, 1, and 2 cm with a bin size of one hour. An exponential trend is observed between the time and the percentage of the data converged to the horizontal accuracy levels at 2 cm and 1 cm. A quasi-linear relation is present between the time and the percentage of the data converged to the horizontal accuracy level at 0.5cm. After 23 hours, 56% of the data only were converged to 0.5 cm horizontal accuracy level. Horizontal accuracy levels of 1 and 2 millimeter cannot be done with PPP.

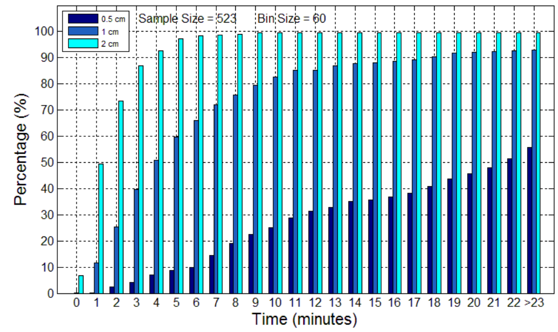

Figure (6): Convergence periods for horizontal accuracy levels used in geodetic control surveying at the static mode.

Conclusions

PPP still needs improvements for its long initial convergence period, real-time kinematic positioning accuracy, and single frequency PPP. PPP accuracy was tested by processing GPS data observed at 75 IGS stations within days 49 to 55 in 2012 at the static mode. The accumulated weekly SINEX station positions from IGS were used as the reference solution. The accuracy of static PPP was 4, 5 and 9 mm in the north, east and vertical components, respectively. PPP Convergence period was examined for achieving different levels of horizontal accuracies. For precision agriculture, PPP convergence periods are 60, 55, 30, 15, and 5 minutes at horizontal accuracy levels of 5, 10, 20, 50, and 100 cm, respectively. For geodetic control surveying, PPP convergence periods are 5, and 24 hours at horizontal accuracy levels of 2, and 1 cm, respectively. For future work, we suggest applying multi-GNSS PPP that uses the four constellations to improve the performance of PPP solution.

1) Contain new, useable, and fully described information. For example, a specimen's chemical composition need not be reported if the main purpose of a paper is to introduce a new measurement technique. Authors should expect to be challenged by reviewers if the results are not supported by adequate data and critical details.
2) Papers that describe ongoing work or announce the latest technical achievement, which are suitable for presentation at a professional conference, may not be appropriate for publication.

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