PERFORMANCE OF OPEN SOURCE PRECISE POINT POSITIONING SOFTWARE USING SINGLE-FREQUENCY GPS DATA

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ABSTRACT: This research aims to assess the performance of GPS Precise Point Positioning (PPP) with code and carrier phase observations from L1 signal collected from geodetic GPS receiver around the world. A simple PPP software developed for processing the single frequency GPS data is used as a main tool to assess a positioning accuracy. The precise orbit and precise satellite clock corrections were introduced into the software to reduce the orbit and satellite clock errors, while ionosphere-free code and phase observations were constructed to mitigate the ionospheric delay. The remaining errors (i.e. receiver clock error, ambiguity term) are estimated using Extended Kalman Filter technique. The data retrieved from 5 IGS stations located in different countries were used in this study. In addition, three different periods of data were downloaded for each station. The obtained data were then cut into 5-min, 10-min, 15-min and 30-min data segments, and each data segment was individually processed with the developed PPP software to produce final coordinates. Results indicate that the use of 5-min data span can provide a horizontal positioning accuracy at the same level as a pseudorange-based differential GPS technique. Furthermore, results confirm effects of station location and seasonal variation on obtainable accuracies.

Key words: GPS, Precise Point Positioning, Single-frequency data

1. INTRODUCTION

Based on the measurements made on the GPS signals, the determination of the receiver's position can be classified into two techniques, *Absolute Positioning* and *Relative Positioning*. The absolute positioning technique, also known as *the single point positioning (SPP) technique*, permits one receiver to determine the 'absolute' coordinates of a point with respect to a coordinate system such as WGS84. The relative positioning technique, sometimes called the *differential positioning technique*, requires the use of two receivers, one as a *reference station* and the other one as a *user station*, in order to determine the coordinates of the user with respect to the reference station. Each technique can be further divided into two classes depending on the measurements used, namely *pseudorange* and *carrier phase*. Since the differential positioning technique uses the measurements simultaneously made at both receivers, many biases (e.g. satellite orbit bias, satellite clock bias, ionospheric and

tropospheric delays) can be largely reduced by forming the difference between the measurements made at both stations. Therefore, the differential positioning technique is extensively used for applications that require high accuracy. However, the effectiveness of the differential positioning technique is largely dependent on the distance between the two receivers. If the distance between the receivers increases, the residual errors will become larger, and hence the quality of the positioning results degrades. This is a major limitation of the differential positioning technique. Furthermore, the requirement of operating at least two GPS receivers simultaneously during data acquisition further complicates the field procedure making the differential positioning technique less attractive for most applications.

With the availability of precise GPS orbits and satellite clock corrections from the International GPS service (IGS) and several organizations, it is possible to improve the positional accuracy of the single point positioning technique. Furthermore, the use of carrier phase measurements can lead to centimetre or decimetre positional accuracy. This positioning method that uses both un-differenced pseudorange and carrier phase measurements with the precise orbits and satellite clock information as well as many corrections (e.g. satellite antenna offset, earth tide, ocean tide loading, atmosphere loading) in the estimation procedure is known as the precise point positioning (PPP) technique. The PPP technique using measurements from dual-frequency receiver was first proposed by Zumberge et al. (1997). Using the PPP technique, the repeatability of positioning results ranges from 10 to 20 cm for one hour of static observation down to a couple of centimetres for 12 hours (Witchayangkoon and Segantine, 1999). Table 1 summarises positional accuracies obtained from each GPS positioning technique.

Table 1. Obtainable accuracy from each GPS positioning technique

Positioning technique	Measurement used	Accuracy
Absolute	Pseudorange	10 metres
Absolute	Carrier phase and pseudorange	cm-decimetres
Relative	Pseudorange	1-5 metres
Relative	Carrier phase	cm-decimetres

Satirapod and Homniam (2006) have recently developed simple PPP software that can provide an accuracy of better than 1 metre, over a 15-minute observation period using a dual-frequency GPS receiver. This developed PPP software opens the door for the use of a single-frequency GPS receiver to replace the traditional differential positioning technique for various applications in remote sensing especially in establishment of Ground Control Point (GCP) (Satirapod et al., 2003). However, the cost of dual-frequency GPS receiver is still far more expensive than the single frequency GPS receiver. Thus, this research aims to develop simple PPP software that can provide positional accuracy at the same level as the pseudorange-based differential GPS technique using a single-frequency GPS receiver. Therefore, our developed PPP software is a simplified version of the above-mentioned PPP technique. This paper will present the level of performance of the developed software using data retrieved from five IGS stations. In the following sections, the components of the developed PPP software are described. Next, tested data and data processing strategy are explained. An analysis of results is presented in the next section to assess the level of positioning accuracy obtained from the developed software. Some concluding remarks are given in the last section.

2. COMPONENTS OF SINGLE-FREQUENCY GPS PPP SOFTWARE

The Matlab-based GPS Precise Point Positioning (PPP) software for single-frequency data was developed at Chulalongkorn University, Bangkok, Thailand. The main purpose of the

software development is to support the use of a simple GPS technique in GCP establishment. In addition, the development of such software is intended for educational and further software development. Thus, the Matlab codes for the developed PPP software are freely available to the reader from www.eng.chula.ac.th/survey/staff/cst/chon.htm. Both carrier phase and pseudorange measurements are used and many error mitigation methods are implemented in the PPP software. An Extended Kalman Filtering technique (Brown and Hwang, 1992; Welch and Bishop, 2006) was implemented in this software as a basis of estimation technique. With regard to the error sources, the PPP software can be considered as consisting of three principal error mitigation components.

2.1 DETERMINATION OF SATELLITE POSITION AND SATELLITE CLOCK CORRECTION

This component refers to the use of the precise orbit in the SP3 format from the IGS to compute the satellite position at any specific time. Since the precise orbit file contains the satellite positions and satellite clock corrections only at 15-minute intervals, polynomial fitting is required in order to enable computation of the satellite positions and clock corrections at the time of signal transmission. The main advantages of this procedure are the simplicity of computation and the rather modest requirements for computer-time and memory. The Lagrange polynomial fitting technique is considered the most convenient and effective method compared to other polynomial representations (Cheney and Kincaid, 1994) and is therefore implemented in the developed software.

2.2 MITIGATION OF IONOSPHERIC BIAS

Since the ionospheric effect disrupts the code and phase differently (Hofmann-Wellenhof et al., 2001; Leick, 2004; Rizos, 1997; Teunissen and Kleusberg, 1998), it is possible to use an ionosphere-free code and carrier phase combination to eliminate common ionospheric bias. Equation 1 represents an ionosphere-free code and carrier phase combination (Witchayangkoon, 2000; Gao and Shen, 2002) and is used as a fundamental observation equation in the developed software.

$$\epsilon p(L1) = \frac{P(L1) + \Phi(L1)}{2} \quad (1)$$

where $\epsilon p(L1)$ is the ionosphere-free code and carrier phase combination (m)
 $P(L1)$ is the measured pseudorange on L1 (m)
 $\Phi(L1)$ is the measured carrier phase on L1 (m)

2.3 MITIGATION OF TROPOSPHERIC BIAS

Unlike the ionospheric delay, the tropospheric delay is not frequency-dependent. It cannot therefore be eliminated through linear combinations of L1 and L2 observations. The tropospheric delay is a function of elevation and altitude of the receiver, and is dependent on many factors such as the atmospheric pressure, temperature and water vapour content. For the sake of simplicity, standard troposphere model is commonly used to estimate the tropospheric delay. In this software, the Saastamoinen troposphere model (Saastamoinen, 1971) was introduced to calculate the total tropospheric zenith delay while the Neill mapping function (Neill, 1996) was used to map the tropospheric zenith delay to the line of sight delay.

3. TESTED DATA AND PROCESSING STRATEGY

3.1 TESTED DATA

Five IGS stations located in different countries, namely ASC1, CAS1, KERG, MAS1 and METS, were selected for the purpose of testing. The locations of the selected IGS stations are shown in Figure 1. In order to investigate an effect of season on positioning results, three different periods of GPS data in year 2003, January, May and September, were selected. Three consecutive days of data starting from the beginning of each period at each IGS station were downloaded from <http://www.hartrao.ac.za/geodesy/data.html>.

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Fig. 1. Locations of the five IGS stations

3.2 ESTABLISHMENT OF REFERENCE COORDINATES

In order to obtain accurate reference coordinates of all stations, the 1-day batches were submitted to the automated GPS data analysis service, the so-called AUSLIG Online GPS Processing System (AUSPOS) service, provided by Geoscience Australia. With the use of 24-hr data set, the coordinates obtained from the AUSPOS service should be accurate to within a centimetre (Dawson et al., 2001). Therefore, the averaged coordinates of an individual station are used as reference coordinates for subsequent analysis.

3.3 DATA PROCESSING STRATEGY

The additional information required for processing are the IGS final orbits and satellite clock corrections. The IGS final orbits and satellite clock corrections can be downloaded from http://igsceb.jpl.nasa.gov/components/prods_cb.html. The GPS data were cut into 5-min, 10-min, 15-min and 30-min data segments, and each data segment was individually processed with the developed PPP software to produce final coordinates. It should be noted that only single-frequency data were selected and used in the data processing step.

4. ANALYSIS OF RESULTS

After all data segments were processed, the solutions were compared with the reference coordinates. The performance of the developed PPP software can be characterized by the Root Mean Square Error (RMSE). Since horizontal positioning results are the quantities of interest in this analysis, the horizontal (2-d) RMSE values are calculated to estimate the horizontal accuracy obtained from all session lengths for each period of data. The 2-d RMSE values of all stations have been presented in Figures 2 to 5, which show the 2-d RMSE values obtained from the 5-min, 10-min, 15-min and 30-min session lengths, respectively. Table 2 presents the averaged RMSE values from each session length for each individual station. Subsequently, the final averaged RMSE values of all stations for each session length were calculated and shown in Table 3.

Fig. 2. Horizontal RMSE values obtained from the 5-min session length at the 5 IGS stations

Fig 3. Horizontal RMSE values obtained from the 10-min session length at the 5 IGS stations

Fig. 4. Horizontal RMSE values obtained from the 15-min session length at the 5 IGS stations

Fig. 5. Horizontal RMSE values obtained from the 30-min session length at the 5 IGS stations

Table 2. RMSE values for different session lengths

Session length	RMSE (m)				
	ASC1	CAS1	KERG	MAS1	METS
5-min	2.88	1.38	2.90	3.71	1.32
10-min	2.75	1.25	1.61	3.13	1.48
15-min	2.60	1.20	1.43	3.26	1.21
30-min	2.03	0.99	1.21	2.36	0.97

Table 3. Averaged RMSE values of all stations at different session lengths

Session length	RMSE (m)
5-min	2.44
10-min	2.04
15-min	1.94
30-min	1.51

With reference to Figures 2 to 5, it is evident that only the ASC1 and MAS1 stations have shown seasonal variations in the RMSE values. Interestingly, both stations are located in low latitude region. It can be seen from Table 2 that the results obtained from the stations located in high latitude region (CAS1, KERG and METS) tend to be more accurate than the other two stations. Results presented in Table 3 have shown that the better positional accuracy can be expected if the longer session length is used.

5. CONCLUDING REMARKS

A simple PPP software based on the use of single-frequency carrier phase and pseudorange measurements has been developed and tested in this paper. Test results indicate that the effect of season on positional accuracy becomes more pronounced when stations are located in low latitude region. In addition, the results obtained from the high latitude stations tend to be more accurate than the low latitude stations. Overall results also reveal that the use of only 5-min data span can produce a horizontal positioning accuracy at the same level as a traditional pseudorange-based differential GPS technique.

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