Application of Inter-system Hardware Delay Bias in GPS/GLONASS PPP

Xiao Pei, Junping Chen, Jiexian Wang, Yize Zhang and Haojun Li

Abstract GPS applies Code Division Multiple Access technique in signal coding, while GLONASS's signal is produced with Frequency Division Multiple Access technique. The differences in signal frequency results in inter-system hardware delay bias for GPS/GLONASS receivers. Subjecting to these hardware delays, strategies and models of GPS/GLONASS PPP based positioning needs to be modified. We derived a GPS/GLONASS combined PPP positioning models by introducing inter-system hardware delay biases. Several scenarios were simulated to test the introduced models using the observation of IGS stations. The results show that: ① Adding a couple of GLONASS satellites can improve the positioning accuracy in the environment without enough GPS satellites being tracked; ② The inter-system hardware delay bias is stable on daily base, and it could be predicted and be fixed in the GPS/GLONASS combined PPP.

X. Pei (✉) · J. Wang · Y. Zhang
Department of Surveying and Geo-Informatics, Tongji University, Shanghai, People's Republic of China
e-mail: pxtoday@hotmail.com

X. Pei · J. Chen (✉) · Y. Zhang · H. Li
Shanghai Astronomical Observatory (SHAO), Chinese Academy of Sciences (CAS), Shanghai, People's Republic of China
e-mail: junping.chen@shao.ac.cn

J. Wang
Key Lab of Advanced Surveying Engineering of SBSM, Shanghai, People's Republic of China

J. Sun et al. (eds.), *China Satellite Navigation Conference (CSNC) 2012 Proceedings*, Lecture Notes in Electrical Engineering 160, DOI: 10.1007/978-3-642-29175-3_34,

1 Introduction

Precise Point Positioning (PPP) is based on un-differenced dual-frequency pseudo-range and carrier phase observations along with precise GNSS orbits and satellite clocks. Precise models of error correction also need to be considered [1]. Although PPP is mostly implemented for GPS system, combined GPS/GLONASS PPP has been recently investigated [2–6]. At present, there are several GNSS Analysis Centers (IAC, ESA, GFZ, CODE, SHA) provide GLONASS products. Their products are different in accuracy and precision because of different data processing approaches and data set were used. GPS is based on code division multiple access (CDMA), while GLONASS is based on frequency division multiple access (FDMA). Carriers with different frequencies have different delays while propagating in both satellite and receiver. For the combined GPS/GLONASS receivers, the difference of GPS and GLONASS carrier frequency produces the inter-system hardware delay bias (ISDB). In this paper, the ISDB is defined as the difference between the receiver clock under GPS system and GLONASS system. For combined GPS/GLONASS PPP, ISDB parameters could be defined in the model, which requires that 4 GPS satellites at minimum must be tracked with additional GLONASS observations for the ISDBs estimation. Based on the routine results of the GNSS data analysis center at SHAO (SHA) [7], we found the ISDBs are stable on daily base and could be well modeled for short period. With the ISDBs be precisely modeled and fixed, combined GPS/GLONASS PPP could be derived with minimum 4 GNSS satellites.

2 Inter-System Hardware Delay Bias

Un-differenced pseudo-range and carrier phase functions can be defined as:

$$P_i = \rho + c(dt - dT) + d_{orb} + d_{trop} + d_{ion} + \varepsilon(P_i) \quad (1)$$

$$\Phi_i = \rho + c(dt - dT) + d_{orb} + d_{trop} - d_{ion} + \lambda_i N_i + \varepsilon(\Phi_i) \quad (2)$$

Where ρ is the true geometric range; P is the measured pseudo-range; Φ is the measured carrier phase; c is the speed of light; dt is the receiver clock offset; d_{orb} is the satellite orbit error; d_{trop} is the tropospheric delay error; d_{ion} is the ionospheric delay error; $\varepsilon(P_i)$ is the pseudo-range measurement error; $\varepsilon(\Phi_i)$ is the phase measurement error.

In PPP data processing, d_{ion} could be ignored by forming the ionosphere-free combination using dual-frequency pseudo-range and carrier phase observations.

dT and d_{orb} can be corrected by precise ephemeris and precise satellite clocks. In this paper, we use products from Shanghai Observatory GNSS Analysis Center (SHA) [7], where its orbit precision is about 2 cm for GPS and 5 cm for GLONASS. By conducting integrated GPS/GLONASS orbit determination, SHA obtains precise ephemeris and precise satellite clock of GPS and GLONASS simultaneously under the same coordinate and time reference frame.

Applying precise ephemeris and precise satellite clock to eliminate satellite orbit error and satellite clock offset, the ionosphere-free code and phase combinations can be expressed as:

$$\begin{aligned} P_{IF}^{g} &= \rho + (cdt + b^{g}) + d_{trop} + \varepsilon \\ \Phi_{IF}^{g} &= \rho + (cdt + b^{g}) + d_{trop} + N_{IF}^{g} + \varepsilon \\ P_{IF}^{r} &= \rho + (cdt + b^{r}) + d_{trop} + \varepsilon \\ \Phi_{IF}^{r} &= \rho + (cdt + b^{r}) + d_{trop} + N_{IF}^{r} + \varepsilon \end{aligned} \tag{3}$$

Where superscript g and r stand for GPS and GLONASS satellite; P_{IF} is ionosphere-free code combinations; Φ_{IF} is ionosphere-free phase combinations; c is the speed of light; dt is the receiver clock offset; b^{g} is the hardware delay for GPS satellites; b^{r} is the hardware delay for GLONASS satellite; d_{trop} is the tropospheric delay error;

Hardware delay b^{g} b^{r} cannot be separated from station clock cdt, therefore they will be estimated as one single parameter as:

$$\begin{aligned} cdt^{g} &= cdt + b^{g} \\ cdt^{r} &= cdt + b^{r} \end{aligned} \tag{4}$$

We can define the inter-system hardware delay bias by taking the difference between cdt^{g} and cdt^{r} :

$$diff\_HD = b^{g} - b^{r} = cdt^{g} - cdt^{r} \tag{5}$$

3 Application of Inter-System Hardware Delay Bias

ISDB parameters are one of the routine products of SHA, which could benefit users for combined GPS/GLONASS PPP positioning. Two groups of experiments with several different scenarios were conducted.

1. Comparison between static PPP result using GPS observation and GPS/GLONASS combined observations. Urban canyon environment were simulated and the results are compared to normal tracking conditions.
2. Pseudo-range is used in real-time navigation and positioning. Considering the inter-system hardware delay bias, a fifth satellite is required to process parameter estimation. In order to overcome this limit, we estimate inter-system hardware delay bias when satellites are adequate, and use it as a known value in case no sufficient satellites are tracked.

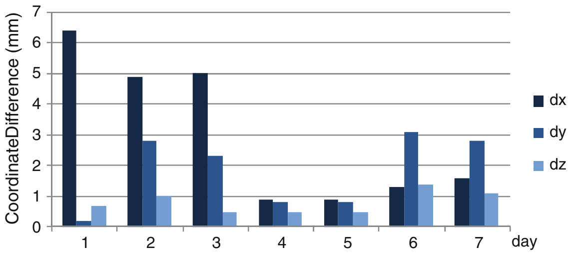

Fig. 1 Comparison between PPP using GPS observations and combined GPS/CLONASS observations

3.1 Combination GPS/GLONASS PPP

In order to compare the precision of combined GPS/GLONASS PPP, we conduct static PPP using GPS observations and combined GPS/GLONASS observations at IGS station BJCO. One week data (from March 18, 2011 to March 24, 2011) was used and Fig. 1 shows the results.

Figure 1 shows that the positioning result from combined GPS/GLONASS PPP is consistent with PPP using GPS system only. Their coordinate differences are within 1 cm.

Given the statistics of Fig. 1, adding GLONASS satellite to PPP will not reduce the precision, so combined GPS/GLONASS PPP can bring many advantages, as enhancing system reliability, improving the accuracy and integrity in positioning. Combined GPS/GLONASS PPP has many important applications especially in certain environment, such as urban canyon, mining areas, gorges and ravines. We simulate a circumstance with limited satellite visibility. Artificial selection is conducted to make sure there are 6 GPS satellites and 2 GLONASS satellites at each epoch. Data of IGS station COCO on August 21, 2011 is processed to compare PPP using GPS only and combined GPS/GLONASS observations. Positioning result is shown in Fig. 2:

Figure 2 shows that when there are few GPS satellites at each epoch, PPP using GPS only is seriously influenced and even failed at some epochs. The accuracy and stability are significantly improved by adding 2 GLONASS satellites.

3.2 Application of Inter-System Hardware Delay Bias

Combined GPS/GLONASS navigation and positioning have great applications for navigation users, especially in limited satellite conditions. However, introducing inter-system hardware delay bias will add in new parameters following the traditional combined GPS/GLONASS PPP, which needs at least 4 GPS satellite together with a fifth satellite to fulfill the parameter estimation. Checking the long-time integrated GPS/GLONASS routine of Shanghai Observatory GNSS Analysis Center [7], we found that the inter-system hardware delay bias is stable, especially

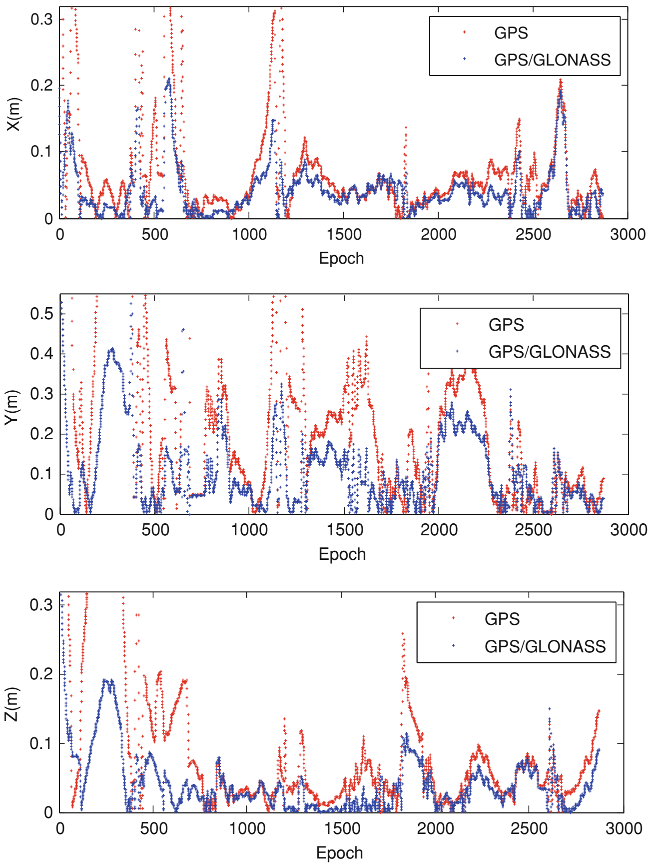

Fig. 2 Positioning results at COCO with 6 GPS satellites and 2 GLONASS satellites at each epoch

for the same satellite in one day. We can carry out a strategy to reduce unknown parameters: we estimate inter-system hardware delay bias when satellites are adequate, and use it as a known value in case no sufficient satellites are tracked. To validate this idea, we make some tests of Kinematic navigation and positioning with the pseudo-range observation data at the station POTS on August 21, 2011. These tests are applied in 4 scenarios:

1. GPS system
2. GLONASS system
3. Combined GPS/CLONASS navigation
4. Based on the third strategy, introduce the inter-system hardware delay bias, which is provided by Shanghai Observatory GNSS Analysis Center [7].

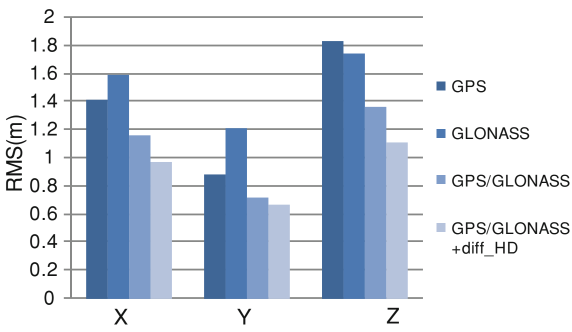

Fig. 3 RMS of coordinate parameters by different strategies

RMS of coordinate parameters calculated by all of the strategies above is shown in Fig. 3:

Figure 3 shows that, pseudo-range point positioning has a precision of 2 m. PPP using GLONASS data only obtains the worst precision; PPP using GPS system only is slightly better than GLONASS system only; precision of combined GPS/GLONASS navigation is obviously better than using data of single system; The forth strategy which introduce inter-system hardware delay bias, provided by Shanghai Observatory GNSS Analysis Center (SHA), obtains the best precision

Based on the above tests, we simulate observation conditions like 3.1 and analyze the effect of inter-system hardware delay bias in combined GPS/GLONASS navigation. Pseudo-range data at IGS station POTS on August 21, 2011 is used.

Two simulated observation conditions are:

1. R1 + G4: 4 GPS satellites and 1 GLONASS satellites at each epoch.
2. R2 + G3: 3 GPS satellites and 2 GLONASS satellites at each epoch. In this test, only one ISDB parameter was set up for the two GLONASS satellites.

Two tests are conducted to ensure the reliability of the conclusion. RMSs of coordinate parameters calculated under both conditions are shown in Table 1.

In GPS/GLONASS combined navigation without known value of inter-system hardware delay bias, there will be 5 unknown parameters at each epoch (3 coordinate parameters, 1 receiver clock offset, 1 inter-system hardware delay bias). Using 5 observations will bring no redundancy, consequently the performance will be affected. As it shows in Table 1, no matter using the R1 + G4 combination or the R2 + G3 combination, the positioning result is rather bad Among the 2880 epochs in the whole day, respectively 27 and 32 epochs has no solution due to the bad GDOP(>200).

The situation is much improved after introducing known value of inter-system hardware delay bias. Unknown parameter numbers declined to 4 (3 coordinate parameters, 1 receiver clock offset). With redundant observations, the numbers of unsolvable epochs both reduce to zero. RMS in all directions (X, Y, Z) is obviously smaller than the traditional strategy. The comparison shows that introducing

Table 1 RMS of coordinate under different conditions

Strategy	Method	RMS X/m	RMS Y/m	RMS Z/m	Invalid epochs
R1 + G4	Introduce diff_ HD	6.38	3.48	7.67	0
	Without diff_ HD	16.08	7.68	16.68	27
R2 + G3	Introduce diff_ HD	4.99	2.96	5.55	0
	Without diff_ HD	10.52	10.56	25.66	32

empirical value of inter-system hardware delay bias can improve the accuracy and validity of positioning, especially when the valid satellite number is low.

4 Conclusion

Several experiments with different scenarios were performed to test the introduced model by using observation data of several IGS stations. Results show that: ① adding a couple of GLONASS satellites can improve the positioning when the number of GPS satellites is not enough. There is a precondition that new parameters need to be added, which is the inter-system hardware delay biases. ② The inter-system hardware delay bias is comparatively stable on daily base, and it could be predicted and be used as a known parameter. By adopting this strategy, the number of necessary observation reduced from 5 to 4, which is efficient to deal with inevitable limited satellite visibility.

Acknowledgments This research is supported by 100 Talents Programme of the Chinese Academy of Sciences. IGS community is acknowledged for providing Rinex data.

References

1. Zumberge, J. F., Heflin, M. B., Jefferson, D. C., Watkins, M. M., & Webb, F. H. (1997). Precise point positioning for the efficient and robust analysis of GPS data from large networks. *Journal of Geophysical Research, 102*(B3), 5005–5017. doi:10.1029/96JB03860.
2. Cai, C., & Gao, Y. (2007). Precise point positioning using combined GPS and GLONASS observations. *Journal of Global Positioning System, 6*(1), 13–22.
3. Habrichm, H. (1999). *Geodetic applications of the Global Navigation Satellite System (GLONASS) and of GLONASS/GPS combinations*. Ph.D. dissertation, Astronomical Institute, University of Berne, Switzerland.
4. Meng, X., & Guo, J. (2010). GPS/GLONASS and their combined precise point positioning. *Geomatics and Information Science of Wuhan University, 35*(12), 1409–1413.
5. Zhang, X., Guo, W., & Li, X. (2010). Study on precise point positioning based on combined GPS and GLONASS. *Geomatics and Information Science of Wuhan University, 35*(1), 9–12.
6. Zhang, Y., Xu, S., & Wang, Z. (2001). Ambiguity processing approach in combined GPS/GLONASS positioning. *Geomatics and Information Science of Wuhan University, 26*(1), 58–63.
7. Shanghai Observatory GNSS Analysis Center. www.shao.ac.cn/shao_gnss_ac.