USING MULTI TECHNIQUES BY COMBINING TRIPLE-CONSTELLATION (GPS, GALILEO AND BEIDOU) FOR ENHANCING LEVEL OF ACCURACY AND THE CONVERGENCE TIME OF THE GNSS SOLUTION*

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ABSTRACT

This paper will discuss the" Between-Satellite-Single-Difference" (BSSD) ionosphere-free linear combination of pseudoranges and carrier phase measurements from GNSS constellation namely "GPS, GALILIO and BeiDou". Inter system Biases will be removed from both code and phase. The using of BSSD technique can improve the precision of the latitude, longitude and altitude components, by comparison it with the traditional undifferenced technique the result show better positioning precision. This method will present an efficient model for precise point positioning (PPP). BSSD "Between satellite signal difference" can cancel out the receiver hardware delay, receiver clock error, and the non-zero initial phase of the receiver will illustrate that the PPP solution will be improved by using our BSSD-based model in comparison with traditional undifferenced PPP model.

Key word: BSSD - Undifferenced Technique - Precise Point Positioning (PPP).

1-INTRODUCTION

The Between Satellite Single Difference (BSSD) ionosphere free linear combination of pseudoranges and carrier phase measurements from GNSS constellation namely "GPS, GALILIO and BeiDou". Inter system Biases will be removed from both code and phase. The using of BSSD technique will improve the precision of the latitude, longitude and altitude components, in comparison with the traditional undifferenced technique the result will show better positioning precision this can be obtained by using BSSD technique. The receiver related biases from both code and phase GNSS observations can be cancelled out from both code and phase GNSS observations. However, In BSSD technique, the satellite differential code biases are still affecting the phase ambiguities due to the dissimilarities of satellites code biases which produced from the signals spectrum dissimilarities in the filtering and correlation processes (Phelts 2007).

In multi-GNSS observations level, multiple GNSS satellites are used the satellite observation references which is referred to loose BSSD combining. Theoretically, undifferenced and BSSD PPP solutions should be statistically equivalent if stochastic errors are modelled correctly. However, due to the time varying nature of the receiver biases, this technique is minimum use two satellites should be available in each GNSS system which sometimes is still not guaranteed especially for Galileo and BeiDou systems. GPS satellite is taken as a reference satellite for the other GNSS satellites observations here in which is called tight BSSD combining. The drawback of using the tight combining is that the receiver DCBs will not be completely removed due to the difference between the receiver DCB of GPS and other GNSS satellites as a result, GNSS PPP model is developed, which combines the observations of GPS, Galileo and BeiDou systems, for precise applications. Both undifferenced and BSSD ionosphere-free linear combinations of pseudoranges and carrier phase GNSS measurements are processed using precise clock and orbital products obtained from the multi-GNSS experiment MGEX (Montenbruck et al 2014).

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The performance of the developed PPP techniques is assessed using a number of IGS MGEX GNSS stations data. It is shown that the positioning accuracy is improved when the observations of the constellations are combined. In addition, the positioning accuracy of BSSD IF model is superior to that of the traditional un-differenced model. Investigation the performance of the BSSD ionosphere-free PPP model compared to the standard undifferenced ionosphere-free PPP model.

2- GNSS OBSERVATIONS EQUATIONS

The general ionosphere-free equations for pseudoranges and carrier-phase can be written as (Shi, J., & Gao, Y. 2013). and (Hofmann-Wellenhof, B., Lichtenegger, H., and Walse, E. 2008)

$$P_3 = \frac{f_1^2 p_1 - f_2^2 p_2}{f_1^2 - f_2^2} = \rho + cdt_r - cdt^s + T - C\,(Ad_{r1} - Bd_{r2}) + C\,(Ad^{S1} - Bd^{S2} + e \quad \text{...(1)}$$

$$\phi_3 = \frac{f_1^2 \phi_1 - f_2^2 \phi_2}{f_1^2 - f_2^2} = \rho + cdt_r - sdt^s + T - C\,(A\delta_{r1} - B\delta_{r2}) + C\,Ad^{S1} - Bd^{S2}) + (\overline{\lambda N}) + e \quad \text{...(2)}$$

Where P_1 and P_2 are GNSS pseudoranges measurements on L_1 and L_2, respectively; ϕ_1 and ϕ_2 are the GNSS carrier phase measurements on L_1 and L_2, respectively; dt_r and dt_s are the clock errors for receiver and satellite, respectively; d_r and d_s are frequency-dependent code hardware delay for receiver and satellite, respectively; δ_r and δ_s are frequency-dependent carrier phase hardware delay for reveiver and satellite, respectively; e,ε are relevant system noise and un-modeled residual errors; and $\overline{\lambda}\,\overline{N}$ is the ambiguity term for phase measurements. For the un-differenced ionosphere free linear combination, this term is not integer due to the non-integer nature of the combination coefficients,

$$\overline{\lambda N} = \frac{f_1^2 \lambda_1 N_1 - f_2^2 \lambda_2 N_2}{f_1^2 - f_2^2}$$

where N_1 and N_2 are the L_1 and L_2 non-integer ambiguity parameters, including the initial phase biases at the satellite and the receiver, respectively λ_1 and λ_2 are the wavelengths of the L_1 and L_2 carrier frequencies, respectively; c is the speed of light in vacuum; T is the tropospheric delay component; ρ is the true geometric range from the antenna phase center of the receiver at reception time to the antenna phase center of the satellite at transmission time. A and B are frequency dependent factors

$$A = \frac{f_1^2}{f_1^2 - f_2^2} \quad B = \frac{f_2^2}{f_1^2 - f_2^2}$$

3-STANDARD UN-DIFFERENCED GNSS PPP TECHNIQUE

Using Equations (1) and (2) and consider GPS time as a reference time system, the un-differenced ionosphere-free linear combinations of GPS, Galileo and BeiDou observations can be written as (Rabbou, M. A., & El-Rabbany, A. 2015)

$$P3_G = \rho_G + c\,(d_{tr} + B^r{}_G) - c\,(dt^r{}_G + B^r{}_G) + T_G + e_G \ \ldots\ldots\ldots\ldots\ldots(3)$$

$$P3_E = \rho_E + c(d_{tr} + B^r{}_G) - c(dt^r{}_E + T_E + (ISB_E) + e_G \ \ldots\ldots\ldots\ldots\ldots(4)$$

$$P3_C = \rho c + c\,(d_{tr} + B^r{}_G)) - c\,(dt^r{}_C + B^r{}_E) + T_C + (ISB_C) + e_C \ \ldots\ldots\ldots(5)$$

$$\Phi_{3G} = \rho_G + c\left[dt_r + B_G^r\right] - c\left[dt_G^s - B_G^s\right] + T_G + (\overline{\lambda N} + \Delta B^r - \Delta B^S)_G + \varepsilon_G \ \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$\Phi_{3E} = \rho_E + c\left[dt_r + B_G^r\right] - c\left[dt^s{}_E - B^s{}_E\right] + c\left[ISB_E\right] + (\overline{\lambda}\,\overline{N} + \Delta B^r - \Delta B^s)_E + \varepsilon_E \ \ldots\ldots\ldots(7)$$

$$\Phi_{3C} = \rho_C + c\left[dt_r + B_G^r\right] - c\left[dt^S{}_C - B^S{}_C\right] + T_C + c\left[ISB_C\right] + (\overline{\lambda}\,\overline{N} + \Delta B^r - \Delta B^S)_C + \varepsilon_C \ \ldots\ldots\ldots\ldots(8)$$

where G, E and C refer to GPS, Galileo and BeiDou systems observations, respectively; ISB is the inter-system bias; B^r, B^s are ionosphere-free differential code biases for receiver and satellites, respectively ΔB^r is the difference between receiver differential code and phase biases; ΔB^S is the difference between satellite differential code and phase biases., the un-calibrated biases such as ΔB^r and ΔB^S are lumped with the ambiguity parameters. e,ε

Table 1 - shows the mathematical equations for the different GNSS biases.

$B_G^r = [A\,d_{r1} - B\,d_{r2}]_G\,;\ B_G^s = [A\,d^{s1} - B\,d^{s2}]_G$
$B_E^r = [A\,d_{r1} - B\,d_{r2}]_E\,;\ B_E^s = [A\,d^{s1} - B\,d^{s2}]_E$
$B_C^r = [A\,d_{r1} - B\,d_{r2}]_C\,;\ B_C^s = [A\,d^{s1} - B\,d^{s2}]_C$
$\Delta B^r = c(B_\Phi^r - B_P^r)\,;\ \Delta B^s = c(B_\Phi^s - B_P^s)$
$ISB_E = B_E^r - B_G^r\,;\ ISB_R = B_R^r - B_G^r\,;\ ISB_C = B_C^r - B_G^r$

4-BETWEEN SATELLITES SINGLE DIFFERENCE GNSS PPP TECHNIQUE

To completely remove the receiver related biases from both the code and phase GNSS observations, between-satellite-single-difference (BSSD) ionosphere-free PPP technique can be used for combined GNSS observations model. For each system, a reference satellite is selected while the other GNSS satellites observations are subtracted from it. To develop the mathematical equations of BSSD technique, four GNSS satellites are selected mainly GPS l, Galileo n and BeiDou o, to be reference satellites to the four constellation systems observations. Following (Rabbou, M. A., & El-Rabbany, A. 2015), GNSS-BSSD model can be written as:

$$P_{3G} - P_{3G}^1 = \rho_G - \rho_G^1 - c\left[(dt^s{}_G + B^s{}_G) - (dt^s{}_G + B^s{}_G)^I\right] + T_G - T_G^I + e_G - e_G^I \ \ldots(9)$$

$$P_{3E} - P_{3E}^{m} = \rho_{E} - \rho_{E}^{m} - c\left[(dt_{E}{}^{s} + B^{s}{}_{E}) - (dt_{E}{}^{s} + B^{s}{}_{E})^{m}\right] +$$
$$T_{E} - T_{E}^{m} + e_{E} - e_{E}^{m} \quad (10)$$

$$P_{3C} - P_{C}^{o} = \rho_{C} - \rho_{C}^{o} - c\left[(dt_{C}{}^{s} + B^{s}{}_{C}) - (dt_{C}{}^{s} + B^{s}{}_{C})^{o}\right] +$$
$$T_{C} - T_{C}^{o} + e_{C} - e_{C}^{o} \quad (11)$$

$$\Phi_{3G} - \Phi_{3G}^{I} = \rho_{G} - \rho_{G}^{I} - c\left[(dt^{s}{}_{G} + B^{s}{}_{G}) - (dt^{s}{}_{G} + B^{s}{}_{G})^{I}\right] +$$
$$T_{G} - T_{G}^{I} + \left[(\overline{\lambda}\overline{N} + \Delta B^{s})^{I}\right] + \varepsilon_{G} - \varepsilon_{G}^{I} \quad (12)$$

$$\Phi_{3E} - \Phi_{3E}^{m} = \rho_{E} - \rho_{E}^{m} - c\left[(dt_{E}{}^{s} + B^{s}{}_{E}) - (dt_{E}{}^{s} + B^{s}{}_{E})^{m}\right] +$$
$$T_{E} - T_{E}^{m}\left[(\overline{\lambda}\overline{N} + \Delta B^{s})_{E} - (\overline{\lambda}\overline{N} + \Delta B^{s})_{E}^{m}\right] + \varepsilon_{E} - \varepsilon_{E}^{m} \quad (13)$$

$$\Phi_{3C} - \Phi_{C}^{o} = \rho_{C} - \rho_{C}^{o} - c\left[(dt_{C}{}^{s} + IFCD^{s}{}_{C}) - (dt_{C}{}^{s} + IFCD^{s}{}_{C})^{o}\right] +$$
$$T_{C} - T_{C}^{o} + \left[(\overline{\lambda}\overline{N} + \Delta B^{s})_{C} - (\overline{\lambda}\overline{N} + \Delta B^{s})_{C}^{o}\right] + \varepsilon_{C} - \varepsilon_{C}^{o} \quad (14)$$

The mathematical correlation between the observations should be taken into account when forming the observation weighted matrix for thids model (Cai, Gao.2007, Rabbou, M. A., & El-Rabbany, A. 2015).

4- ANALYSIS AND RESULTS

GNSS PPP Techniques namely the undiffrenced, between satellite single differences (BSSD) were developed to process the multi-constellation GNSS observation. The BSSD model can cancel out the receiver related biases and errors from both GNSS code and phase measurements. The contribution of BeiDou observation can be considered geographically dependent based on the BeiDou satellite availability in each station GNSS PPP technique present comparable convergence time compared with the standard un-differenced technique due to the lack of code and phase –based satellite clock product and the mathematical correlation between the positioning and clock ambiguity parameters. the availably of signals on three or more frequencies produced from multiple GNSS constellation offer a good chance for enhancing precise point positioning (PPP)convergence time and accuracy, compared to dual-frequency observations from single constellation. After three hours of GNSS processing data compared with undiffrenced. It can be seen that the BSSD model enhances the convergence time and the positioning accuracy during the convergence time while the BSSD PPP present comparable positioning accuracy to The undiffrenced PPP at the end of three hours GNSS processing in figure (1,2,3,4,5)

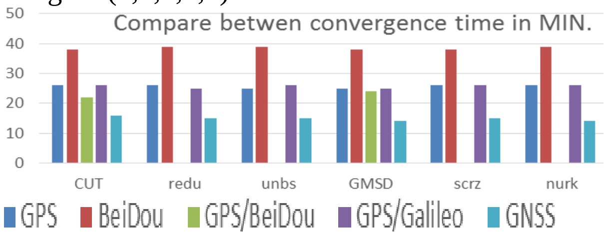

Fig. 1- Convergence time for used statins by using BSSD technique (Sour. Researcher)

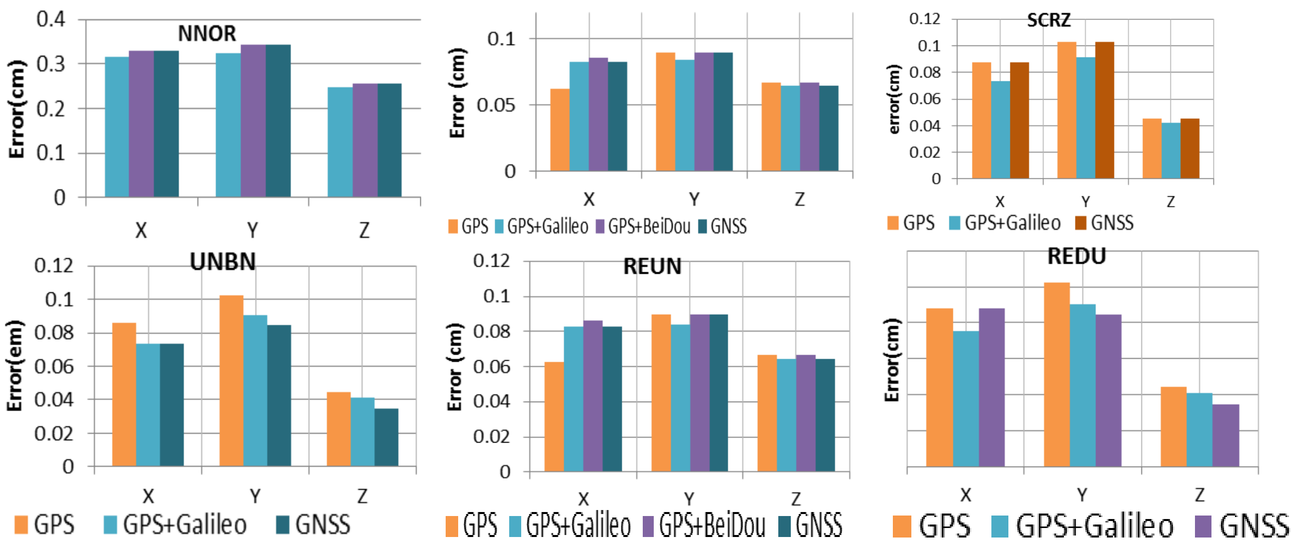

Fig. 2- Positioning accuracy summary for different GNSS combination for multiple points (Sour. Researcher)

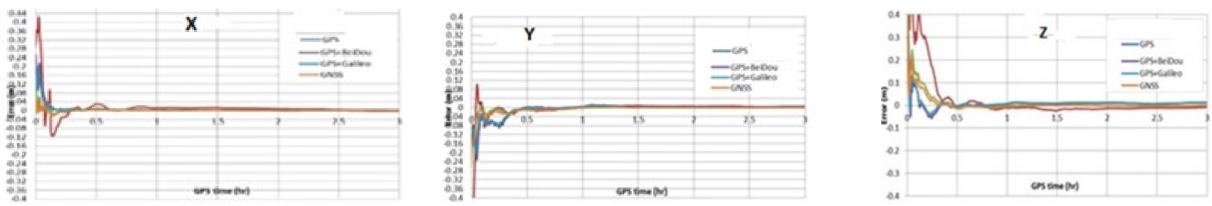

Fig. 3-BSSD-PPP positioning error for different GNSS combinations for station KNZ (Sour. Researcher) Station: KNZ at DOY 1/4, 2016

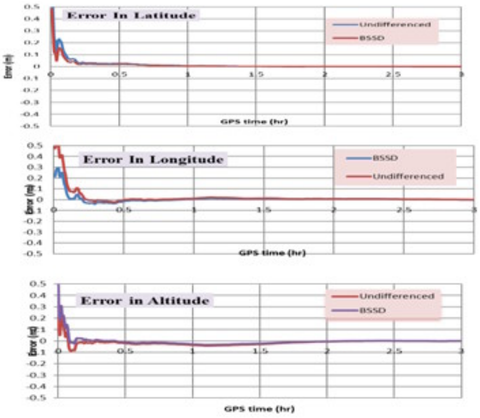

Fig. 4- The positioning accuracy for the Two GNSS PPP techniques for station KNZ and REDU (Sour. Researcher)

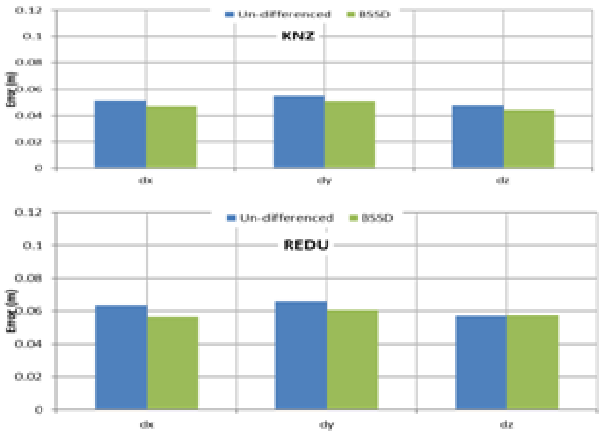

Fig. 5- The positioning accuracy for the Two GNSS PPP techniques for station KNZ and REDU (Sour. Researcher)

The positioning accuracy for different GNSS PPP combination after 20 minutes processing will be shown in table (2).

Table 2- The positioning accuracy for different BSSD GNSS PPP combinations after 20 minutes processing

GNSS-PPP Combinations	X (m)		Y (m)		Z (m)	
	RMSE	Max	RMSE	Max	RMSE	Max
GPS	0.09	0.23	0.06	0.21	0.16	0.29
BeiDou	0.16	0.48	0.09	0.35	0.22	0.43
GPS/ BeiDou	0.07	0.13	0.03	0.15	0.09	0.20
GPS/Galileo	0.08	0.22	0.05	0.20	0.17	0.28
GNSS	0.04	0.11	0.01	0.13	0.06	0.18

5-CONCLSION

The use of BSSD linear combination improved the convergence time of the GNSS PPP solution by about 50%, in comparison with the un-differenced GPS-only PPP model. By applying BSSD technique, GPS satellite is selected as a reference, a Galileo satellite is selected as a reference, and BeiDou is selected as a reference. However, combining the observations of multi-GNSS constellateions comes at the expense of introducing additional biases to the observation mathematical models. These include the GPS to Galileo time offset, GPS to BeiDou time offset and the hardware delays of both Galileo and BeiDou. The test results showed improvement in both of the PPP solution precision and convergence time. However, those studies were limited to the post-processing mode. The values of the ISB have been obtained for various days and receiver types. Almost identical results have been obtained with both of the un-differenced and BSSD modes. It has been found that the values of the ISB are largely stable over the observation time periods. There is slight improvement in the solution convergence time obtained with the loose combination in comparison with the tight combination.

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