

Overview of Beidou 3 Precision Single-point Positioning

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Abstract: With the increasing maturity of precision point positioning (PPP) technology, PPP-B2b becomes the research focus and hot spot of real time PPP (RT-PPP). This paper firstly introduces the service of PPP with B2b signals, sum-marises the research progress of B2b signals in terms of availability, correction effect and positioning accuracy under different conditions and environments; the influence of choosing different filtering methods on positioning accuracy during the positioning process; and discusses the future development trend and challenges faced by PPP-B2b.

Keywords: PPP-B2b; BeiDou-3 (BDS-3); Real-time Precision Single-point Positioning (PPP).

1. Introductory

In recent years, with the increasing maturity of precision point positioning (PPP) technology, real time PPP (RT-PPP) has gradually become a research hotspot, and RT-PPP is mainly based on Internet communication and satellite augmentation service. The former is mainly the open-access real-time service (RTS) provided by International GNSS Service (IGS), i.e. IGS-RTS service. The latter is mainly the RT-PPP service system provided by some commercial companies. Both types of RT-PPP technology can achieve real-time positioning accuracy from decimetre to centimetre level. The advantage of the former is that the service can be accessed for free through the Internet, but its service range is limited by the Internet facilities, while the latter can provide worldwide service, but its high equipment and maintenance costs limit the use of individual users.[1]. In addition, some scholars have studied RT-PPP based on satellite-based augmentation system (SBAS) correction information and BeiDou short message communication.[3] and RT-PPP based on BeiDou short-message communication (SMC) service.[6] RT-PPP.

With the gradual maturity of satellite-based augmentation RT-PPP technology, BeiDou-3 Navigation Satellite System (BDS-3) takes PPP technology as one of the standard services of the system, and takes PPP-B2b signal as the data broadcasting channel to broadcast the correction information of BDS-3 and other GNSS precision orbits and clock differentials to users in the neighbouring areas of China by means of BDS-3 geosynchronous orbit, GEO, and so on. orbit (GEO) satellites to broadcast BDS-3 and other GNSS precision orbit and clock difference correction information, providing dynamic decimetre-level and static centimetre-level RT-PPP services for users in China and surrounding areas [8] The real-time precision single-point positioning of the BeiDou-3 navigation satellite system has become a hot content of research.

PPP-B2b service system is that the ground monitoring station continuously monitors all the visible satellites of GNSS, generates pseudo-range and carrier observation information, and collects meteorological data, and sends the raw data to the ground master control station through the network after pre-processing; the ground master control

station verifies and evaluates the raw data, solves the satellite orbits and clock correction, and generates the number of corrections and the enhancement information of other relevant parameters according to the protocol. The uplink station transmits the information to the GEO satellite, which then broadcasts it through the PPP-B2b signal; after receiving the corrected information, the user can carry out real-time precision single-point positioning.

2. Introduction to PPP-B2b Signalling PPP Services

BDS-3 will mainly provide six types of services, including radio navigation satellite service (RNSS), regional short message communication (RSMC), global short message communication (GSMC), SBAS, international search and rescue (SAR) and PPP services. regional short message communication (RSMC), global short message communication (GSMC), SBAS, international search and rescue (SAR) and PPP services. Its PPP service uses the PPP-B2b signal, with a centre frequency of 1207.14 MHz and a bandwidth of 20.46 MHz, as a data broadcasting channel, and broadcasts correction parameters such as BDS-3 and other GNSS precision orbits and clock differentials through the BDS-3 GEO satellite, providing services to users in China and the surrounding areas.

2.1. PPP-B2b Signal Correction Parameters

PPP-B2b signal correction message now mainly defines 7 types of correction information types, mainly used for broadcasting track correction number, clock difference correction number, differential code biases (DCB) and user range accuracy index (user range accuracy index, URAI) 4 types of information, and each message data frame consists of 486 bits, which contains 6 bits of information types (MesTyPeID), 24 bits of cyclic redundancy check bits (CRC) and 456 bits of data fields. Each message data frame consists of 486 bits, which contains 6 bits of information type (MesTyPeID), 24 bits of cyclic redundancy check bits (CRC) and 456 bits of data field, and the corrected message information type and corresponding information content are given in Table 1. It should be noted that currently BDS-3 only broadcasts correction parameters for BDS-3 and GPS.

Table 1. PPP-B2b signal correction message information types

Type of information	Information content
1	satellite mask
2	Satellite orbit corrections and user ranging accuracy indices
3	differential bias coding
4	Corrections to satellite clock errors
5	User Ranging Accuracy Index
6	Clock Difference Correction Number and Orbital Correction Number - Combination 1
7	Clock Difference Correction Number and Orbital Correction Number - Combination 2
8~62	reserve
63	unoccupied

Information is identified using an issue of data (IOD) version number, which ensures that information content is relevant across different information types. This includes:

(1) IOD SSR (State Space Representation)

The IOD SSR is the version number of the state-space description data, and if different information types have the same IOD SSR, it means that these data are matchable for use. The IOD SSR is updated when the system configuration changes.

(2) IODP (Issue Of Data, PRN mask)

The IODP is the data version number of the satellite mask broadcast in message types 1 and 4, and the user can determine whether the data in the message type matches or not based on the IODP.

(3) IODN (Issue of Data, Navigation)

IODN, broadcast in message type 2, is the data version number of the clock and ephemeris of the GNSS downlink signal broadcast, which can be used by the user to judge whether the ephemeris and clock parameters of the navigation message match the number of orbital corrections in type 2. Information type 2 simultaneously broadcasts IOD Corr used to correlate the number of clock difference corrections in information type 4, and the user can use IOD Corr and IODN to determine whether the clock difference parameters of the navigation message match the number of clock difference corrections in information type 4.

(4) IOD Corr

IOD Corr is the version number of the orbital and clock correction numbers broadcast in message types 2 and 4. For the same satellite, if the IOD Corr of the clock difference correction number and the IOD Corr of the orbit correction number are the same, it means that they can be matched and used. (When the IOD Corr of multiple sets of parameters can be matched, select the parameter with the nearest calendar element moment to use.)

Orbital correction information and clock difference correction information are used to provide high-precision real-time orbits and clock differences, where the orbital correction parameter is the radial, tangential and normal component of the orbital correction vector δO , and the clock difference correction parameter is the correction parameter of the clock difference with respect to the broadcast ephemeris $\delta\tau^S$. By combining the orbit and clock correction parameters with the broadcast ephemeris, highly accurate real-time orbits and clock differentials can be obtained:

$$\begin{aligned} \chi_{pre}^S &= \chi_{brdc}^S - [e_{radial} e_{along} e_{cross}] \delta O \\ dt_{pre}^S &= dt_{brdc}^S - \frac{\delta\tau^S}{c} \end{aligned} \quad (1)$$

where: e_{radial} , e_{along} and e_{cross} are the unit vectors of the satellite in the radial, tangential and normal directions in the

geocentric coordinate system, respectively; χ_{brdc}^S and δt_{brdc}^S are the broadcast orbit and the broadcast clock differential; χ_{pre}^S and δt_{pre}^S are the corrected high-precision real-time orbit and the clock differential; and C is the speed of light in vacuum.

The user range accuracy index (URAI) parameter is used to provide a priori accuracy for the calculation of high-precision real-time orbits and clock differentials, and it contains two parameters: the user range accuracy class $U_{RA-class}$ and the user range accuracy value $U_{RA-value}$. The DCB parameter is used to correct the inter-code deviation caused by frequency selection, and at present, the DCB correction parameter of BDS-3 is only provided in the correction message of PPP-B2b signals. DCB correction parameters for BDS-3, the BDS-3 broadcast ephemeris uses the B3I signal as the clock differential reference. Since BDS-3 broadcasts not only BDS-2 signals B1I and B3I, but also the new regime signals B1C, B2a, and B2b, the PPP-B2b signal correction message provides various types of DCB corrections, including DCB-B1IB3I, DCB-B1CB3I, DCB-B2aB3I and DCB-B2bB3I. Users can realise BDS-3 multi-frequency RT-PPP through DCB parameter correction.

2.2. PPP-B2b Correction Algorithm

PPP-B2b can provide precision single-point positioning services for the four major GNSS and their combinations, using BeiDou Navigation Satellite System Time (BDT) and the BeiDou Coordinate System (BDCS), for both BDS and GPS. For both BDS and GPS, the reference messages corresponding to the corrections are as follows:

(1) BDS: PPP-B2b is used to correct the CNAV1 navigation message of B1C.

(2) GPS: PPP-B2b is used to correct LNAV navigation messages.

The correction algorithm based on BeiDou-3 PPP-B2b is to correct three types of data, which are based on BeiDou-3 PPP-B2b satellite orbit correction, based on BeiDou-3 PPP-B2b satellite clock difference correction, and based on BeiDou-3 PPP-B2b satellite inter-code bias correction.

3. Research Status

In recent years, with the launch of IGS-RTTPP (IGS Real-Time Pilot Project), the real-time PPP realisation has become possible, according to the network transmission protocol, each institution broadcasts real-time correction numbers to the users through State Space Representation (SSR), while the PPP-B2b signalling. The PPP-B2b signal broadcasts correction information through the satellite base, which solves the problem of PPP relying too much on the communication network, greatly expands the application

scenarios of PPP, and effectively promotes the development of Beidou industry. Precision single-point positioning operation is flexible, the operation is not limited by distance, and it can provide high-precision positioning for remote areas, and it has been widely used in high-precision dynamic positioning in different environments such as sea, land and air, timing, meteorology, early warning of earthquakes, precision agriculture, and many other fields, especially the completion of the BeiDou Navigation Satellite System, which has promoted the development of the related fields in China.

At present, the PPP-B2b signal can provide corrected message information for 59 satellites, of which 27 satellites from C19 to C46 (except C31) in the BeiDou Navigation Satellite System (BDNSS) and 32 satellites from G01 to G32 in the GPS.

With the gradual application of BDS-3 PPP-B2b signalling RT-PPP service, some scholars have already carried out a preliminary assessment of its service performance, and I compare and analyse PPP-B2b from three aspects, namely, performance assessment, positioning accuracy in different environments and filtering algorithms, through the following literature.

3.1. Performance Evaluation

Liu et al.[11] The system design, signal structure, data format and coding method of BDS-3 PPP-B2b signalling PPP service are described in detail. Lu et al.[12] evaluated and studied real-time PPP based on PPP- B2b and BDS/GPS broadcast messages for 8 days. The real-time accurate ephemeris was compared with the Multi-GNSS Experiment (MGEX) final product and the real-time PPP positioning performance was evaluated using MGEX/iGMAS stations. ren et al.[13] and Nie et al.[17] evaluated the real-time orbit and clock difference accuracy of the PPP-B2b signal as well as the RT-PPP positioning performance of the BDS-3/GPS dual system, pointing out that the radial accuracy of the real-time orbit of the PPP-B2b signal is basically better than 10 cm, and the accuracy of the real-time clock difference is about 0.05-0.18 ns, and that the convergence of the real-time dynamic PPP of the BDS-3/GPS dual system can achieve the centimetre level of E-, N-, and U-directional positioning accuracy in E, N and U directions. Jiao Dancheng[18] The positioning accuracies of precision single-point positioning of BDS and GPS are compared, and it is concluded that for static precision single-point positioning, the positioning accuracies of BDS and GPS are more or less the same, and both of them can reach centimetre-level positioning accuracy, while the ZTD accuracy of BDS is higher than that of GPS. The results of Chinese stations are better than those of Japanese stations. Yangyin Xu et al.[19] The systematic analysis using the availability ratio of correction parameters, the average number of available satellites and the matching of correction parameters shows that in China and the surrounding areas, the availability of correction parameters of BDS-3 PPP-B2b signals ranges from 71% to 95%, and it reaches the maximum in the Beijing area, and the availability of GPS correction parameters ranges from 68.5% to 88.6%, which is poorer than that of BDS-3. Xu et al.[20] conducted a comprehensive assessment of the accuracy, availability, matching characteristics and real-time PPP performance of BeiDou-3 PPP-B2b correction. It was found that the PPP-B2b orbit correction contributes more to improve the orbit discontinuity error caused by broadcast ephemeris update, and contributes less to broadcast orbit accuracy. The two-frequency real-time

PPP based on PPP-B2b correction converges to a positioning accuracy of 11 cm horizontally and 17 cm vertically with BDS3. The real-time dynamic PPP using the B1C/B2a IF combination converges horizontally to 27.8 cm, and the vertical heights of the two components of the B1I/B3I IF combination reach 42.8 cm and 53 cm, respectively, in the same positioning time.

Song, Wei-Wei et al.[14] Ionospheric modelling and ionospheric enhancement of PPP-B2b positioning experiments based on reference station data in China region, the enhancement effect of high-precision ionospheric products on the positioning performance of PPP-B2b signals is analysed, and for the static positioning based on PPP-B2b, the enhancement of convergence time by ionospheric modelling products is smaller than that of dynamic PPP positioning. The average convergence time for single BDS-3 positioning is shortened by 47.37%, while that for BDS-3+GPS positioning is shortened by 58.29%, respectively. The ionospheric product accuracies generated from different numbers of reference stations have different degrees of edge effects, and the ionospheric product accuracies in the edge region are lower than those in the central region. Cai Zirui et al.[15] implemented the correction of broadcast ephemeris using B2b products, and evaluated the accuracy of satellite orbit and clock difference products after the correction of B2b products. Taking the ex-post precision products provided by the IGS Analysis Centre of Wuhan University as a reference, it is shown that the RMS of the R, A, and C direction errors of the corrected BDS orbits are 6.26 cm, 24.21 cm, and 21.79 cm, respectively, and the average STD of the clock differentials is 0.33 ns., Jiang Wei et al.[16] Using the precision ephemeris product and its interpolation results provided by the German Research Centre for Geosciences (GFZ) as the reference frame, the sequence of reciprocal differences and the root mean square error (RMSE) between the satellite orbiting results and the reference frame are computed to evaluate the orbital accuracy of the broadcast ephemeris and the precision corrected orbit of PPP-B2b. Zhao Qile et al.[23] implemented a multi-frequency, multi-mode observables PPP method that requires only satellite orbit, clock difference and signal deviation to achieve instantaneous centimetre-level positioning on a global scale. Combining the existing satellite-based augmentation correction coding and broadcasting methods, a wide-area instantaneous centimetre-level service system compatible with the BeiDou PPP-B2b service is constructed, and the accuracy of the augmentation information such as orbit, clock difference and signal deviation is evaluated. The validation results of static and on-board dynamic data in the Chinese region show that the system can achieve centimetre-grade precision positioning within 1 min with 95% confidence rate, which can meet the demand for fast, high-precision and high-reliability positioning in the field of automated driving and other areas. Zha Jiuping[25] An enhanced positioning method fusing PPP-B2b precision satellite orbit products and regional sparse reference station observation data is proposed, i.e., a non-differential and non-combined precision single-point real-time dynamic positioning technique based on PPP-B2b, which is constrained by single-difference ionospheric pseudo-observations between the stations, so as to achieve tight estimation of parameters such as ionospheric delay. A single-star real-time modelling scheme for the regional ionospheric oblique delay and its accuracy information is designed, which effectively compresses the broadcast data volume while

improving the application performance of PPP-RTK. On this basis, the above method is verified in near real-time using the Beijing-Tianjin regional reference network. Shi Junbo et al.[26] conducted 108 fast static experiments and 1 low dynamic rail experiment on the received GNSS navigation signals and PPP-B2b augmented signals. The results show that: for fast static PPP, 97% of the samples have an average convergence time of 34.6 min, and the horizontal and elevation direction accuracies after convergence are 5.9 cm and 9.7 cm, respectively; after restarting the receiver for 10 min, 20 min, and 30 min, the horizontal direction accuracies of 78%, 83%, and 86% are better than 10 cm, and the elevation direction accuracies of 75%, 84%, and 86% are better than 15cm; for the low-dynamic guide experiment, the RMS in E, N, and U directions reaches 24.3cm, 1.1cm, and 12.2cm, respectively, after 30min of convergence time.

3.2. Different Environments

Tang Shoupu et al.[21] evaluated the PPP positioning performance in the area without public network based on the PPP-B2b service, analysed the accuracy of the correction number of BeiDou 3 PPP-B2b service, and then used the BeiDou system PPP-B2b service and satellite broadcast ephemeris to carry out precision single-point positioning, and analysed the real-time positioning accuracy under the condition of using the satellite signal of the BeiDou system only to provide a reference for the formulation of standards for the application of natural resource surveying in the area without public network. Provides reference for the development of standards for the application of natural resources surveying in areas without public network. The accuracy of correction number of PPP-B2b service is evaluated, the mean value of GPS orbit error correction number is 0.25m, and the standard deviation is 0.28m, respectively; the mean value of BDS orbit error correction number is 0.22m, and the standard deviation is 0.45 m. The accuracy of satellite clock difference of two GNSS systems, GPS and BDS, reaches the consistency, and the mean value is 0.09ns, 0.11ns, and the standard deviation is 0.02ns, 0.05ns, and the standard deviation is 0.05 ns. ns, 0.05ns, the satellite pseudorange hardware delay correction number changes steadily, the error in one day in 0.04ns; assessed the dynamic and static PPP positioning performance, the results show that the PPP in 15min after the convergence of the positioning accuracy to the centimetre level, can be stabilized in 1h within 5cm, the dynamic positioning results show that the open environment positioning under the conditions of the public network without the mean value of 0.12m, the standard deviation of 0.10m. 0.10 m. It shows that the results obtained by using the precision single-point positioning service provided by BeiDou 3 system for real-time positioning can meet the needs of natural resources exploration in the area without public network, and it plays an important role in calibrating and mapping of natural resources reserves in remote mountainous areas and uninhabited areas. Wang Xiang et al.[22] By analysing the BeiDou-3 PPP-B2b NAV message format, giving the BeiDou-3 PPP-B2b precision orbit, clock difference calculation and pseudo-ranging deviation correction methods, establishing a real-time precision single-point positioning model based on the BeiDou-3 PPP-B2b service in the ocean, and adopting the oceanic measurement data, evaluating and analysing the positioning performance of the BeiDou-3 PPP-B2b service in the oceanic environment and comparing the positioning

accuracy of BeiDou-3 PPP service with that of the commercial PPP service, the results are compared with the positioning accuracy of the commercial PPP service. PPP service and compare it with the positioning accuracy of commercial PPP service. The results show that the positioning accuracy of BeiDou-3 PPP-B2b is slightly lower than that of Starfire differential positioning. However, the positioning accuracy of BeiDou-3 PPP-B2b is better than 10 cm in the horizontal direction and 15 cm in the vertical direction, which can meet the requirements of real-time high-precision positioning at sea in the centimetre level in the horizontal direction and the decimetre level in the elevation direction. Tian Xiangyu[24] The reliability of the two techniques in GNSS buoy application is verified by analysing the three-dimensional position changes of the positioning results of the different techniques in the dynamic ocean scenario, and exploring the relationship between the motion state and the quality of the solved results. The results show that both techniques have good applicability in marine buoy positioning applications, with good performance in terms of ambiguity fix rate and accuracy compliance level. Comparatively speaking, PPK can achieve 81% of fuzzy fix, which can better adapt to the complex sea state and effectively obtain high-precision fixed solutions. PPP-AR can get 71% of the fixed solution, and the fix rate is worse than PPK, especially when the sea state is worse, it is difficult to fix the ambiguity effectively, but under smooth sea state, it can achieve good ambiguity fix, and the deviation between PPP-AR and PPK is 18cm in the 3D direction, which is still a certain gap compared with the dynamic centimetre-level positioning on land, and the metre-level deviation is introduced by the complex sea state in particular. Zhao et al.[27] A preliminary evaluation of the performance of combined LEO/GNSS PPP in harsh environments was carried out. Firstly, a three-frequency non-combined PPP model was established. Then, a LEO constellation consisting of 180 polar-orbiting satellites was designed and simulated and analysed for BDS-3 and the current GPS constellation. In the float solution, BDS-only convergence to 5 cm usually takes about 30 minutes, while the BDS/LEO combination only takes about 10 minutes in extreme harsh environments. Compared with BDS-only, the float solution accuracies of BDS/GPS, BDS/LEO, and BDS/GPS/LEO combination PPP are improved by 42.44%, 73.77%, and 77.43%, respectively. In terms of fix solution, the average time to first fix (TTFF) of the BDS/GPS, BDS/LEO, and BDS/GPS/LEO combinations are reduced from 20.0 min to 10.3 min, 4.8 min, and 4.0 min, respectively, compared with BDS. epoch fixation rate is improved from 83.8% to 91.6%, and in harsh environments, respectively, to 96.1% and 96.7%.

4. Literature Review

By analysing and sorting out the above articles, it can be found that many domestic and foreign experts, scholars and scientific research institutions have carried out a large number of studies and analyses on B2b signals, and they have respectively analysed the different methods of data acquisition, environment and error analysis to specifically analyse the accuracy of precision single-point positioning obtained by using B2b signals to correct the broadcasting ephemeris and to obtain corrected precision orbits and clock differential products under different conditions. Positioning accuracy of the corrected precision orbit and clock difference products for precision single-point positioning under different

conditions.

Comprehensively, the above scholars' research in precision single-point positioning, comparison found that although they evaluated the positioning accuracy of BDS and GPS system after the B2b signal participated in the solving, but there is no research on precision single-point positioning under the conditions of triple-frequency and high-frequency with the participation of B2b in the solving. Secondly, adaptive Kalman filter or root-mean-square information filter can be adopted in data processing, which may be optimised in terms of convergence speed and positioning accuracy.

5. Future Outlook

The development of BeiDou-3 PPP-B2b precision single-point positioning technology is promising, and in the future, positioning accuracy and system robustness will be further improved through the optimisation of high-precision positioning algorithms, the application of multi-frequency band combined positioning and anti-differential adaptive filtering technology. This technology will be widely used in the fields of unmanned driving, precision agriculture, disaster warning and emergency response, unmanned aerial vehicles and aerial surveying, etc., enhancing the efficiency and safety of these industries. Global compatibility and interoperability, as well as the development of international standards, will facilitate the global promotion and standardisation of PPP-B2b technology. With the development of IoT, smart cities and 5G technology, the market demand for high-precision positioning services will continue to grow, and PPP-B2b technology will gradually achieve commercial application, promote the rapid development of related industries, and create huge economic benefits and social value. The positioning service platform based on PPP-B2b technology will provide a unified interface for high-precision positioning services to meet different user needs and promote the popularisation and application of high-precision positioning services. Through continuous technological innovation and international cooperation, PPP-B2b technology will certainly play an increasingly important role in the field of global navigation and positioning.

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