Research on Multimodal SBAS Technology Supporting Precision Single Point Positioning

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Abstract: To make satellite navigation system have centimeter positioning accuracy, the technique of combining precision point positioning (PPP) with multimodal space based augmentation system (SBAS) was put forward in this paper, some key technology and function of SBAS system was research. Firstly, by the way of analyzing fundamental principle of PPP, some necessary conditions for the PPP were determined. According to those conditions, preliminary design of the multimodal SBAS was finished. Finally, summarizing usable navigation frequency of the multimodal SBAS, and according to ITU rule, the frequency band of might carrying high precision orbit and time correction data was determined.

Key words: satellite wide area augmentation system; Precision Point Positioning; Multimodal

1. Introduction

With the expansion of satellite navigation system application field, aviation, ocean mapping application demands for navigation system service capacity have become more strict, which promoted the development of SBAS, for example, USA WAAS, European EGNOS, Japan QZSS, and India GAGAN. But the positioning accuracy of these systems only has decimeter level or sub-meter level. With the modernization of USA GPS and the building of satellite navigation systems of China Compass and Europe Galileo, the PPP technology using single station double-frequency receiver will no longer limited by navigation frequency band, and with the increase of compatibility and inter-operation capacity among big navigation systems, users' available navigation frequency points keep on increasing, therefore, it also reduces the convergence time of PPP user machine, and increases the cycle slip detection recovery capacity. At present, PPP users mainly use internet to download high precision orbit, clock, and other products[1] from IGS, it greatly limits the promotion and application of PPP technology. To overcome this kind of restriction factor, Deere Company, Tianbao Company, and StarFire Company began using L-band communication satellite radio to realize the data needed by PPP. Now, it has been applied in precise agriculture, geodetic surveying, ocean survey, and military reconnaissance fields. Through system upgrade, absolute positioning accuracy is increased from decimeter level to centimeter level [2].

The essay mainly studies the ability of using multimodal SBAS system to enhance Compass satellite navigation system, so as to realize precise single point positioning ability. Firstly, by analyzing PPP technology basic theory, obtain the technical condition needed by PPP support. According to these input conditions, finish the initial design of multimodal SBAS system structure. Finally, it summarizes the navigation frequency bands that can be used by SBAS system, and confirms the frequency bands that can carry high precision orbit and time correction data according to ITU principle.

2 PPP Methodology

2.1 PPP overview

At present, there are mainly two kinds of positioning techniques that can provide centimeter level accuracy：Differential RTK and PPP (Precision Point Positioning), PPP technique was initially put forward by Mr. Zumberge of USA Jet Propulsion Laboratory (JPL) [3] to adapt to the demand of dynamic positioning; its basic algorithm is being corrected continuously. Compared with differential positioning technology, PPP technique exists the following characteristics：1)Need precise navigation satellite orbit and timing data support ； 2)Only use one double-frequency receiver, then can realize static and dynamic positioning；3) Need no support from differential reference station, equipment

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operation and maintenance is simple; 4) PPP technique is built under global unified coordinate system frame, positioning results have high consistence. Therefore, PPP technique has been broadly applied in recent years, under the condition that the price of mining resources is increasing continuously, mining survey companies are urged to start deep ocean resource survey. For differential dynamic positioning under the long baseline measurement condition from several hundreds kilometers to a thousand kilometers, positioning accuracy reduces to sub-meter level and meter level, it is difficult to meet the demand of high accuracy positioning. Therefore, it is unnecessary for PPP technique of differential reference station to replace RTK technique and be applied to the field of ocean resource surveying; as geodetic surveying conducted in remote region is concerned, because of the consideration of cost and maintenance factor, it is also difficult to use differential RTK positioning technique to conduct precise mapping.

2.2 PPP theory

As far as non-differential PPP mode is concerned, as there is not any differential form, its measurement equation is original pseudo code and carrier phase measurement equation [7][8]:

$$P_i = \rho + c(dt_r - dt^s) + c\cdot\Delta t_{iono} + c\cdot\Delta t_{trop} + \varepsilon(P) \quad (1)$$

$$\lambda_i\Phi_i = \rho + c(dt_r - dt^s) + c\cdot\Delta t_{iono} + c\cdot\Delta t_{trop} - \lambda_i N_i + \varepsilon(\Phi) \quad (2)$$

In which:

P_i and Φ_i are the pseudo code and carrier observation amount from observation station i to navigation satellite k; c is speed of light; dt_r is the clock correction of receiver; dt^s is the clock correction of navigation satellite; ρ is the geometrical distance from i to navigation satellite k; Δt_{iono} is ionosphere delay; Δt_{trop} is troposphere delay; λ_i is the carrier wavelength of frequency f_i; N_i is the integer ambiguity of frequency f_i; $\varepsilon(R)$ and $\varepsilon(\Phi)$ are the combined error of measurement noise and multi-path.

The geometrical distance ρ from receiver to satellite can be shown as below:

$$\rho = |X(t_s) - X(t_r)| \quad (3)$$

In which:

$X(t_s)$ is the position vector of satellite in inertial coordinate system at the time of signal transmission; $X(t_r)$ is the position vector of receiver in inertial coordinate system at the time of signal receiving.

Therefore, the following conditions are needed to realize PPP:

1) Need high accuracy orbit and time correction data support

To calculate the accurate position of satellite in inertial coordinate system, need the support of precise satellite ephemeris and timing. At present, the accuracy of post processing precise ephemeris provided by IGS has reached 2~5cm, precise satellite clock correction accuracy has reached 0.1~0.2ns. Of course, these precise data is good for PPP application, but a dozen of hours delay time limits users' application. Therefore, IGS began providing real-time data products (orbit determination precision: 10cm, satellite clock precision: 5ns, sampling interval:15min, update 4 times every day)[5][6]. Therefore, the offer of real-time data products has already been quite matured technique, just frequency update would increase greatly.

2) Double-frequency or multi-frequency receivers are needed to eliminate the impact of ionosphere.

Except for orbit and satellite clock error, ionosphere error is another main error of PPP technique; double-frequency measurement can be used to eliminate ionosphere delay error[9], that is,

$$P_{I-F} = \frac{f_1^2\cdot P_1 - f_2^2\cdot P_2}{f_1^2 - f_2^2} = \rho + cdt + m(z)Z_{trop} + \varepsilon(R_{I-F}) \quad (4)$$

$$L_{I-F} = \frac{f_1^2\cdot\Phi_1 - f_2^2\cdot\Phi_2}{f_1^2 - f_2^2} = \rho + cdt + m(z)Z_{trop} - N_{I-F} + \varepsilon(L_{I-F}) \quad (5)$$

In which:

3) P_i and $\Phi_i\,(i=1,2)$ are pseudo code and carrier phase observation values, respectively, Z_{trop} is the troposphere delay of zenith direction; m(z) is projection function; $N_{I-F} = \frac{f_1^2\lambda_1 N_1 - f_2^2\lambda_2 N_2}{f_1^2 - f_2^2}$ ambiguity without ionosphere combination, as double-frequency ionosphere combination is adopted, ambiguity combination does not have integer feature, therefore, it is estimated as unknown parameter,

it is also called floating-point number solution.

4) Need the conversion between ITRF and regional reference coordinate system

The user position estimated by using PPP technique will be in accordance with the reference coordinate system of satellite orbit revised data. When using high precision orbit data provided by IGS, will obtain receiver position under International Terrestrial Reference Frame (ITRF); however, most mapping and navigation applications would convert ITRF coordinate system into local or regional coordinate system, such as CGS2000, WGS84, and GTRF.

3 SBAS system of supporting PPP

3.1 System structure of multimodal SBAS

Figure 2 is the structure figure of multimodal SBAS system, the whole system is composed of the three parts of space section, ground end, and user section. Space is composed of Compass/ GPS/ GLONASS/ Galileo satellite navigation systems and space-based GEO satellite; The SBAS system of supporting PPP does not provide augmentation and PPP service function to all navigation systems, its satellite load constitution is determined according to task demand. Therefore, the navigation augmentation service signal of GEO satellite does not cover all satellite navigation signals, the selection of SBAS service signals will be described in Section 3.2; user section is mainly constituted by multimodal compatible receiver supporting PPP function, this kind of receiver can conduct combined application with RTK, so as to increase positioning accuracy and robustness. Ground section is composed of monitoring receiver network, time synchronization/injection station facility, Data Processing and Analysis Center, IGS data product access terminal, assorted independent data communication network, and other sub-system, in which the functions of each sub-system are as the follows：

- Monitoring receiver network is composed of GNSS monitoring receiver and SBAS signal monitoring receiver; GNSS monitoring receiver provides Compass/GPS/GLONASS/Galileo and other space signals pseudo code and carrier phase measurement, broadcast ephemeris data, and the phase center data of receiver antenna. These data is transmitted to Data Processing and Analysis Center through independent communication network; while SBAS monitoring receiver is mainly used for the closed loop testing of monitoring and PPP function on SBAS space signal state；
- IGS data access facility is used to make IGS public data and data products access multimodal SBAS system; these IGS products will conduct comprehensive application with the data products of Data Processing and Analysis Center；
- Data Processing and Analysis Center includes simulation analysis facility, monitoring station data processing facility, and database facility. Simulation facility mainly uses real-time generated high precision orbit data to conduct analysis and calculation on the DOP value, positioning accuracy, continuity, availability, integrity and other performances of GNSS navigation system. Monitoring station data processing facility provides real-time satellite high precision orbit and time correction parameter, satellite hardware deviation, integrity, and other data. Database is used to supporting, monitoring station input data, IGS access data, and the storage of processing results.
- Time synchronization/injection station facility is mainly used to support the time synchronization of SBAS satellite clock and ground timing system, and inject data products generated by Data Processing and Analysis Center into GEO satellite, and transmit to receivers supporting PPP function for usage through SBAS satellite.

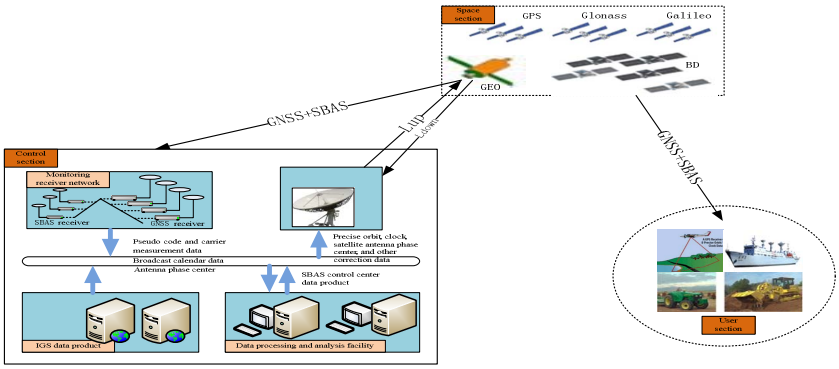

Figure 2 The System Structure Diagram of Multimodal SBAS

3.2 The frequency band selection of multimodal SBAS

Multimodal SBAS system does not provide augmentation service to all satellite navigation systems. The design principal of system aims at meeting usage demand, and also considers the cost of system building. The building of China SBAS system shall be designed by focusing on enhancing Compass system service, therefore, form the mode of Compass/ GPS /Galileo/ Glonass multimodal augmentation. SBAS satellite not only provides the multimodal navigation augmentation signals of positioning service, but also provides the digital transmission carrying high precision orbit and time correction data.

In Table 1, the usage conditions of current and planned GNSS system navigation frequency are listed, the table is finished by using public data, in which, 1164-1188Mhz, 1188-1215Mhz, 1559-1591Mhz, are 1591-1610Mhz suggested by ITU to be specially applied in aviation radio navigation (ARNS) and radio navigation satellite (RNSS), while 1215-1240Mhz, 1240-1260Mhz, and 1260-1300Mhz frequency band are not specially applied in aviation radio navigation. Therefore, these frequency points can be selected to transmit high precision orbit and time correction data.

Table1 Navigation frequency usage conditions of current and planned GNSS systems

Frequency Range (MHZ)	1164-1188	1188-1215	1215-1240	1240-1260	1260-1300	1559-1591	1591-1610
GPS	∨		∨			∨	
GLONASS(current)				∨			∨
GLONASS K-final	∨ (option)	∨				∨ (option)	∨
Galileo(current)	∨	∨			∨	∨	
Galileo 2	∨	∨			∨	∨	
COMPASS-inital		∨			∨	∨	
COMPASS-final	∨	∨			∨	∨	
Multimodal SBAS	∨				∨	∨	

Table2 SBAS Frequency and Function Configuration Items

Frequency	1575.42MHz	1278.75Mhz	1176.45MHz
SBAS plays message	Wide area augmentation	Support PPP decimeter level precise positioning	Wide area augmentation

4. Conclusion

The essay suggests combing PPP and multimodal satellite based SBAS, so as to make satellite navigation system have centimeter level absolute positioning ability. It also initially studies the basic theory of PPP positioning technique, technical conditions required for realizing centimeter level positioning, the structure design of multimodal SBAS system supporting PPP, frequency selection, and other key technique and function system. In future study, above research contents still need to be refined.

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