IOP Conf. Series: Materials Science and Engineering **719** (2020) 012069 doi:10.1088/1757-899X/719/1/012069

Measurement and Evaluation of Marine Intelligent Transportation PNT Data Based on BDS and DGNSS

Xiang Wang[1, 2] Jingxian Liu[1], Zhao Liu[1] and Zhi Yuan[1]

[1.]Hubei Key Laboratory of Inland Shipping Technology, School of Navigation Wuhan University of Technology, Wuhan, Hubei, China
[2.]Donghai Navigation Safety Administration (DNSA) of the Ministry of Transport (MOT), Shanghai, China
Email: 2444984719@qq.com

Abstract. This paper proposes the acquisition of PNT data based on Beidou navigation satellite system and the joint BDS/GPS joint pseudorange difference algorithm. This paper relies on the DGNSS infrastructure of the Dajishan lighthouse management station of the Donghai Navigation Safety Administration (DNSA) of the ministry of transport of china. BDS and DGNSS were measured and evaluated using static measurement and evaluation methods. The results show that in the scene with strong interference, the static positioning level error of BDS exceeds 20 meters, DGNSS, static positioning level error is less than 2 meters. Therefore, the DGNSS algorithm is used to acquire the PNT data method, which has the characteristics of availability, accuracy, reliability, continuity and robustness, and can be used in the marine intelligent transportation system.

1. Introduction

Differential Global Navigation Satellite System (DGNSS) is a shore-based radio-directed broadcast system that uses DGNSS differential data and is broadcast to the sailing vessel in Radio Technical Commission for Maritime services - Special Committee (RTCM-SC) 104 format [1-3]. It is a precision positioning navigation aid system [4]. The DGNSS provides voyage users with differential global positioning data with availability, accuracy, reliability, continuity and robustness [5]. The International Maritime Organization (IMO) and the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) have indicated that DGNSS is recommended for PNT data for navigation users [6,7]. This paper relies on the DGNSS base station of the Dajishan Lighthouse Management Station of the Donghai Navigation Safety Administration (DNSA) of the Ministry of Transport (MOT) [8]. We conducted experiments and evaluations of BDS and DGNSS in Shanghai, China.

This paper is organized as follows. In Section 2, this paper describes the DGNSS data broadcast method based on BDS. In Section 3, experimental design. In Section 4, the results of the experiment and discussion. In Section 5, conclusions and work to be carried out in the next step.

2. Method

2.1. The Basic Principle of Pseudorange Difference

According to the literature, at t_0, the distance from the base station to the satellite i that is accurately calculated by the known coordinates of the base station and the satellite ephemeris is t_0, and the rate of change of the pseudorange correction number and the pseudorange correction number are respectively:

$$\Delta P_b^i = R_b^i - P_b^i = c\delta\tau_b - c\delta\tau^i + d_{b,orb}^i + d_{b,trop}^i + d_{b,ion}^i$$
$$\Delta\dot{P}_b^i = \frac{\Delta P_b^i}{\Delta t} \tag{1}$$

The base station sends ΔP_b^i and $\Delta\dot{P}_b^i$ to the user in a timely manner, and the corrected pseudorange observation value is:

$$P_{u,corr}^i = P_u^i + \Delta P_b^i + \Delta\dot{P}_b^i(t-t_0) = R_u^i - c(\delta\tau_u - \delta\tau_b) - \left(d_{u,orb}^i - d_{b,orb}^i\right) - \left(d_{u,ion}^i - d_{b,ion}^i\right) - \left(d_{u,trop}^i - d_{b,trop}^i\right) + \Delta\dot{P}_b^i(t-t_0) \tag{2}$$

Among them, $d_{*,orb}^i$ is the distance deviation caused by satellite ephemeris error, $\delta\tau_*$ is the receiver clock difference, $d_{*,ion}^i$, $d_{*,trop}^i$ are the ionosphere and tropospheric delay respectively ($* = b, u$,b is the base station, u is the user rover); $\delta\tau^i$ is the satellite clock difference; c for the speed of light; Δt is the correction time calculation interval.

When the distance between the user and the base station is relatively close, the spatial correlation of the error is strong. At this time, it can be considered that the tropospheric delay, the ionospheric delay, and the distance deviation caused by the satellite ephemeris of the base station and the user are approximately equal, then:

$$P_{u,corr}^i = R_u^i - c(\delta\tau_u - \delta\tau_b) + \Delta\dot{P}_b^i(t-t_0) \tag{3}$$

In order to avoid solving the whole-circumference ambiguity, in practical applications, the pseudo-range observations after solving the following formula are:

$$\begin{cases} \breve{P}(k) = \frac{P(k)}{k} + \frac{k-1}{k}\left(\breve{P}(k-1)\right) + \Delta L(k,k-1) - \frac{2\Delta\left(dL_{1,2}\right)(k,k-1)}{\gamma-1} \\ \breve{P}(1) = P(1) \end{cases} \tag{4}$$

Among them, $\breve{P}(k)$ is the phase smoothing pseudorange $(k = 2,\cdots,n)$ of the k epoch, $P(k)$ is the original pseudorange observation value of the k epoch, $\Delta L(k,k-1)$ is the difference of the phase observation values of the two epochs before and after, $\gamma = f_1^2/f_2^2$, $\Delta\left(dL_{1,2}\right)(k,k-1)$ are the front and rear the difference between the phase observations of the different frequency of the epochs and the difference between the epochs, the formula is as follows:

$$\Delta\left(dL_{1,2}\right)(k,k-1) = \left(L_2(k) - L_1(k)\right) - \left(L_2(k-1) - L_1(k-1)\right) \tag{5}$$

2.2. Beidou Pseudorange Difference Algorithm

The Beidou pseudorange difference algorithm is the same as GPS, but since the issue of data ephemeris (IODE) is the same in the big dipper calendar, the GPS number method is used to correct the number broadcast, and the rover cannot guarantee that the same ephemeris is used for the correction number calculated by the base station. This paper proposes to use the reference time in the ephemeris to generate a new IODE (0-252) in the following way to solve the problem.

The time of ephemeris (TOE) range is (0~ 604/ 800), and the TOE is different at different times in the same week. The IODE can be uniquely determined by a mapping function that uses a range of TOE in chronological order:

$$\text{IODE} = \begin{cases} int(TOE/1\,200), 0 \le TOE \le 302\,400 \\ int(TOE - 302\,400), 302\,400 < TOE < 604\,800 \end{cases} \tag{6}$$

Where int is the rounding symbols. After obtaining the new IODE, the Beidou pseudorange differential positioning can be performed according to the conventional pseudorange difference algorithm.

2.3. BDS/GPS Combined Pseudorange Difference Algorithm

Firstly, the above algorithm is used to calculate the Beidou and GPS carrier phase smoothing pseudoranges after the correction of the rover. Then, according to the BDS/GPS joint single-point positioning mode, the corrected carrier phase smoothing pseudorange is used to solve the rover coordinates. The error equation as follows:

$$\mathrm{BX} = \mathrm{L} \tag{7}$$

which is:

$$\begin{bmatrix} b_0^1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ b_0^{n+m} & \cdots & 1 \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \\ c\delta\tau_{u,GPS} \\ c\delta_{u,BDS} \end{bmatrix} = \begin{bmatrix} l^1 \\ \vdots \\ l^{n+m} \end{bmatrix} \tag{8}$$

Among them, b represents the direction cosine of the satellite, and the satellite is represented above, the first n is a GPS satellite, the last m is a Beidou satellite, and $n + m \geq 5$, and the subscripts 0, 1, and 2 respectively represent x, y, z axes. $\Delta x, \Delta y, \Delta z$ represents the receiver clock difference between GPS and BD, respectively, $c\delta\tau_{u,GPS}$ and $c\delta\tau_{u,BDS}$ represent the receiver clock difference between GPS and Beidou, respectively, and l represents a constant term. Can get $X = (A^T PA)^{-1}(A^T PL)$, where P is the weight matrix, expressed as follows:

$$\mathrm{p} = \begin{bmatrix} P_{GPS} & 0 \\ 0 & P_{BDS} \end{bmatrix} = \begin{bmatrix} P_1 & & \\ & \ddots & \\ & & P_{n+m} \end{bmatrix} \tag{9}$$

The weight P is selected by the height angle, namely:

$$\mathrm{P} = \begin{cases} \sin(ele), \frac{\pi}{6} \leq ele \leq \frac{\pi}{2} \\ \sin^2(ele), 0 \leq ele \leq \frac{\pi}{6} \end{cases} \tag{10}$$

3. Experiment

Relying on the infrastructure of the DNSA, it can help the precise navigation of vessels and provide PNT data for marine intelligent transportation systems. On august 8, 2019, we conducted experiments in the waters of the Yangtze River estuary in Shanghai, China.

The base station, the DGNSS base station is located at the DNGSS base station at the Dajishan lighthouse management station in Shanghai, as shown in Figure 1.

Figure 1. DGNSS infrastructure

The receiver was set up in Pudong New Area, Shanghai. The experimental scene setup of the receiver is located between Shanghai Tower, Shanghai World Financial Tower and Shanghai Jinmao Tower, as shown in Figure 2.

IOP Conf. Series: Materials Science and Engineering **719** (2020) 012069 doi:10.1088/1757-899X/719/1/012069

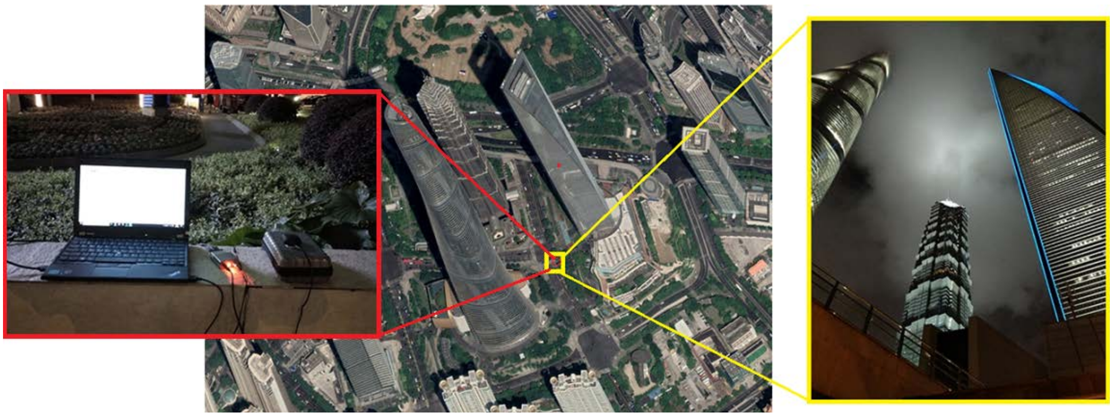

Figure 2. Experimental scene

4. Results and Discussion

4.1. Results

We use PNT data similar to that required for intelligent ship navigation as a base scene. The specific conclusions are as follows:

Result 1: Through the measurement, we set the receiver in a high-rise scene. The use of BDS to obtain PNT data has a large position error, which is more than 20 meters than the actual position of the receiver and the location of the PNT data, as shown in Figure 3.

Result 2: Through the measurement, we set the receiver in a high-rise scene. Using DGNSS to obtain PNT data, there is an error compared to the actual position of the receiver, only within 2 meters, as shown in Figure 3.

Result 3: Through measurement, it shows that the DGNSS method can greatly improve the receiver's ability to acquire PNT data. Compared with the single-frequency BDS receiver, the ability to acquire PNT data can be improved to less than 2 meters. Vessels navigation, narrow waterways, PNT data within 2 meters, can support the ability of intelligent ship positioning, navigation, timing and data acquisition.

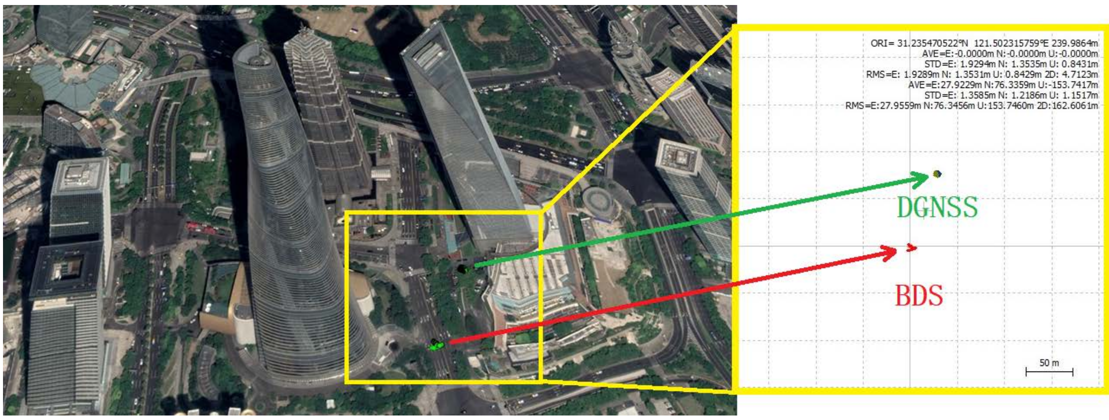

Figure 3. Experimental results

4.2. Discussion

The core of the marine intelligent transportation system at sea is to obtain low-latency PNT data. In all kinds of environments, obtaining PNT data with high reliability is the most important when the ship sails to a narrow waterway, taking into account the rich water depth, the navigation capacity of the channel, the collision avoidance of the ship, and the accurate PNT data. In this paper, the BDS-based DGNSS joint positioning differential positioning method can improve the ability of the marine intelligent transportation system to acquire PNT data. The most demanding marine traffic conditions provide PNT data with availability, accuracy, reliability, continuity and robustness for marine vessel navigation.

Through experiments, it is shown that the DGNSS joint differential method can increase the PNT data of the marine intelligent transportation system to about 2 meters, which can effectively improve the navigation capability of the seaborne vessels.

5. Conclusion

In this paper, the algorithm of obtaining PNT data based on BDS-based DGNSS is used to measure and evaluate in the waters of the Yangtze River estuary. Experiments show that this method can greatly improve the ability of multi-system and multi-source navigation satellites to obtain PNT data. Compared with navigation satellite systems, the availability, accuracy, reliability, continuity and robustness of PNT data can be greatly improved. The experimental scenes of high-rise buildings show that the static positioning data of PNT to about 1 meter. On the one hand, the vessels can rely on DGNSS to obtain reliable PNT data, which can effectively manipulate the ship and carry out precise navigation. On the other hand, marine intelligent transportation systems require PNT data with availability, accuracy, reliability, continuity and robustness. Therefore, DGNSS can be used as an important PNT data acquisition method. Next, we will conduct data fusion researchs on more systems and more data sources for marine intelligent transportation.

6. Acknowledgment

This work was supported in part by the National Natural Science Foundation of China (No. 51809207), and a grant from the Fundamental Research Funds for the Central Universities (No. 2019IVB040).

7. References

[1] Yijun T, Dong Q, Zhao Q, Zhou C and Sai W, BDS ambiguity resolution with the modified TCAR method for medium-long baseline 2017 *J. Advances in Space Research* **59** 670-681.
[2] Chuang S, Fu Z, Yidong L, Shengfeng G, Weixing Z, Xiaolei D, Xianjie L, Hailin G and Xiaopeng G, National BDS Augmentation Service System (NBASS) of China: Progress and Assessment 2017 *J. Remote Sensors* **9(8)** 837.
[3] Ying X, Chen W, Lei L, Lizi Y, Min L and Shengli W, GPS/BDS Medium/Long-Range RTK Constrained with Tropospheric Delay Parameters from NWP Model 2018 *J. Remote Sensors* **10(7)** 1113.
[4] Xin X, Tao G, Qile Z, Jingnan L and Bin W, Performance of BDS-3: Measurement Quality Analysis, Precise Orbit and Clock Determination, 2017 *J. Sensors* **17(6)** 1233.
[5] Wujiao D, Qiang S and Changsheng C, Characteristics of the BDS Carrier Phase Multipath and Its Mitigation Methods in Relative Positioning 2017 *J. Sensors* **17** 796.
[6] Gangyuan Y, Dongdong L, Ying-Chang Z, Rui L and Victor C. M., Optimal Resource Allocation in Full-Duplex Ambient Backscatter Communication Networks for Wireless-Powered IoT, 2018 *J. IEEE Internet of Things* **25**.
[7] Rui T, Rui Z, Pengfei Z, Jinhai L and Xiaochun L, An approach for real-time fast point positioning of the BeiDou Navigation Satellite System using augmentation information, 2017 *J. Measurement Science and Technology* **29**.
[8] Xuan Z, Zongnan L, Min L, Weiming T, Chenlong D, Liang C, Chen W and Chuang S, Modeling BDS pseudorange variations and models assessment, 2017 *J. GPS Solutions* **21** 1661.