Research and Implementation on BDS/GNSS Real-Time Positioning for Urban High-Precision Location-Based Services

Liang Wang, Zishen Li, Hong Yuan, Jiaojiao Zhao and Kai Zhou

Abstract With the deepening development of mobile Internet technology and Global Navigation Satellite System (GNSS), realizing high-precision positioning and navigation on mobile intelligent terminals is not only an important way to achieve the urban high-precision location-based services (LBS) in the future, but is also one of the development trends and major application fields of the satellite navigation industry. Although those mobile intelligent terminals such as smart phones basically have integrated a GNSS module, their positioning accuracies are generally low which cannot meet the requirements of high-precision location-based services. In this work, a system design scheme for realizing high-precision location-based services was studied and proposed, and a set of BDS/GNSS real-time high-precision positioning software for mobile intelligent terminals is developed based on Android platform. By collecting the observation data stream from an external GNSS module through the built-in Bluetooth module on those intelligent devices and receiving the differential correction data from a nearby reference station via 3G/4G or Wi-Fi wireless network, respectively, users' high-precision position then can be calculated in real-time by the software, and the positioning result will be displayed on Google maps simultaneously. At present, this software supports real-time single point positioning and real-time pseudorange differential positioning for BDS/GPS/GLONASS standalone and combined system. The experimental results of combined BDS/GPS/GLONASS real-time positioning show that the accuracies of single point positioning in horizontal and vertical are better than 2.5 and 3.5 m, respectively, and the accuracies of real-time differential positioning in horizontal and vertical are better than 0.5 and 1.0 m, respectively. As a consequence, this contribution can provide some technical references for the realization of urban high-precision location-based services.

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1 Introduction

Navigation and location-based services industry has become one of the most rapidly developing field of emerging information industry after the Internet and mobile communication industry. At the same time, with the development of modern city, the requirements for location-based services (LBS) are become higher and higher, such as vehicle monitoring and scheduling, etc., in which high-precision positioning is the core of location-based services. Meanwhile, with the rapid development of mobile Internet technology, mobile intelligent terminals that are based on the platforms like Android are widely used which play an important role in LBS [1].

Although those mobile intelligent terminals such as smart phones basically have an integrated GNSS module which can provide navigation and positioning services for users, its positioning accuracy is generally low (about 10–20 m) which cannot meet the requirements of high-precision location-based services since they all apply the standard positioning services which provided by Global Navigation Satellite System (GNSS) for positioning [2]. Realizing high-precision positioning and navigation on mobile intelligent terminals is not only an important way to achieve the urban high-precision location-based services in the future, but also one of the development trend and major application field of the satellite navigation industry. In addition, it is also an important form of promoting the industrialization of China's BeiDou Navigation Satellite System (BDS) [3, 4].

GNSS augmentation positioning that is based on the idea of differential positioning is an effective method to realize high-precision positioning which is widely used in practice. The basic idea is using another receiver that is installed on a reference station whose position is pre-known precisely to observe the satellites simultaneously. Thus, the common errors between user and reference station can be eliminated or reduced. As a result, user's positioning accuracy can be improved remarkably. In addition, multi-GNSS combined positioning [5–10] has become an inevitable trend in GNSS-based navigation and positioning and it can significantly increase the number of visible satellites and improve the dilution of precision (DOP), thereby improving the positioning availability, continuity, and accuracy. Especially, with the development of China's BDS and its regional operation in the Asia-Pacific region, it provides excellent opportunities and good foundations for multi-GNSS combined positioning and high-precision navigation services.

Faced with the urgent demand of urban high-precision LBS in the future, a system design scheme for realizing high-precision LBS was studied and proposed in this work, and a set of BDS/GNSS real-time high-precision positioning software for mobile intelligent terminals which aimed at providing users real-time positioning and navigation services is developed based on Android platform.

2 System Design Scheme

Currently, the built-in satellite navigation module in smart devices (like smart phones) usually cannot output the real-time pseudorange and carrier phase measurements, as a result, it is unable to provide differential users positioning solutions, that is to say, it can only output single point positioning results instead whose accuracy is generally low (about 10–20 m) that cannot meet the requirements of high-precision location-based services. In addition, the positioning accuracy is usually poor due to the influence caused by the complex environment in urban.

In view of this, a system design scheme was proposed for realizing high-precision location-based services. By collecting the observation data stream from an external GNSS module through the built-in Bluetooth module on those intelligent devices and receiving the differential correction data from a nearby reference station via 3G/4G or Wi-Fi wireless network, respectively, user's high-precision position then can be calculated in real-time. The designed system mainly consists of a ground network of reference stations, data processing center, broadcast network for differential information, GNSS module, and mobile intelligent terminal. The main system design scheme and implementation framework is shown in Fig. 1 and the main data processing flow is shown in Fig. 2.

Where, the ground network of reference stations is responsible for receiving BDS, GPS and GLONASS satellite signals and getting the real-time pseudorange and carrier phase measurements and ephemeris, and then sending them to the data processing center through a data communication link (via Internet); the data processing center is used to receive the data stream from each reference station in

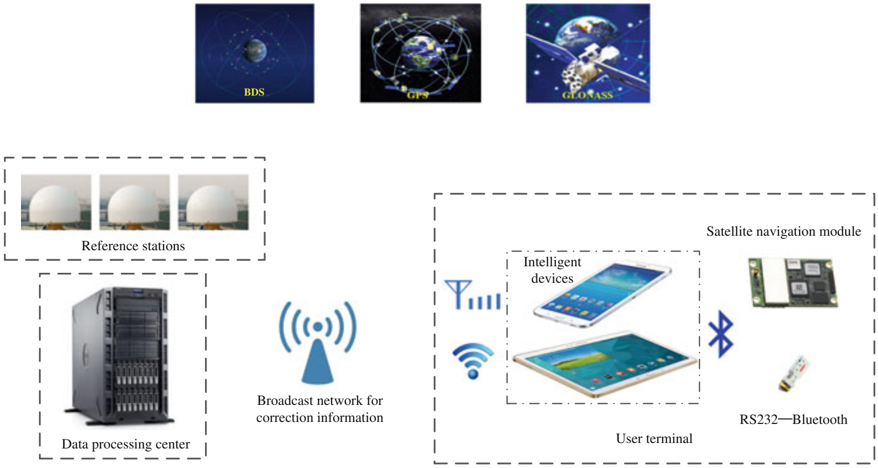

Fig. 1 The design scheme and framework of the BDS/GNSS real-time high-precision positioning system

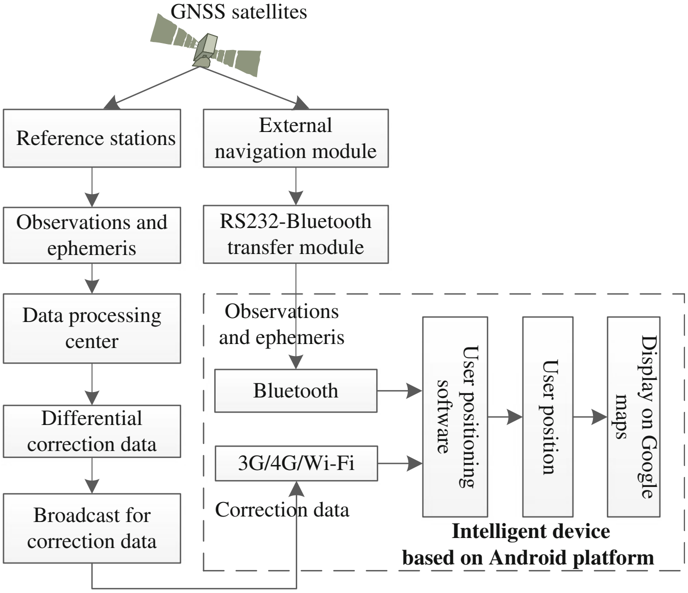

Fig. 2 Flow chart of the main data processing

real-time and calculate the differential correction information and broadcast them to users through a wireless network.

For the user terminals, they are equipped with an external satellite navigation module for receiving satellite signals to get the observations and ephemeris. The satellite navigation receivers usually output its data through a serial port (RS-232), but the intelligent terminals usually do not have the function of serial communication. So, in order to send the navigation data to an intelligent device, a transfer module of RS-232 to Bluetooth is used so that the intelligent terminal can collect the navigation data with its built-in Bluetooth module. Meanwhile, the intelligent terminal receives the differential correction data from a nearby reference station via 3G/4G or Wi-Fi wireless network. Then, the user can calculate its position precisely in differential positioning mode. When it is unable to obtain the differential correction data, the user will get it position that calculated by standard single point positioning. The user's position will be displayed on the online or offline Google maps in real-time.

3 Software Implementation

Based on the scheme designed above, a software run on intelligent devices for user to realize BDS/GNSS real-time high-precision positioning is developed based on Android platform. Currently, the software supports real-time GPS, BDS and

基本参数 (Basic Setting)

卫星系统 (Satellite system)

☑ GPS
☑ BDS
☑ GLONASS

所用频点 (Frequency)

☑ F1(L1/B1/G1)
☑ F2(L2/B2/G2)

数据类型 (Observation)

☑ 伪距 (Pseudo-range)
☐ 载波相位 (Carrier phase)

(Cutoff elevation)
截止高度角 10.0 (degree)

Fig. 3 The operation interface of the software (**a**) The interface for positioning parameter configuration (**b**)

GLONASS standalone and combined single point positioning and pseudorange differential positioning. When the user is in real-time differential positioning mode, it needs to receive the real-time differential data that broadcasted by the data processing center.

The software's running interface and its main operation options are shown in Fig. 3a, the configuration interface for positioning parameters is shown in Fig. 3b, where users can set the corresponding positioning settings based on their own situations. For example, users can choose any combination of GPS, BDS and GLONASS in positioning; at the same time, users can also choose whether to use the dual-frequency observation data. If users are equipped with a satellite navigation module which can output dual-frequency observation data, they are suggested to use the dual-frequency data to get more accurate positioning results.

After positioning successfully, the user's position then can be displayed on maps in real-time. Like the example shown in Fig. 4a, the pink marker in the figure is user's current position. At the same time, the user can see the current sky plot of visible satellites though the option of 'display', as shown in Fig. 4b.

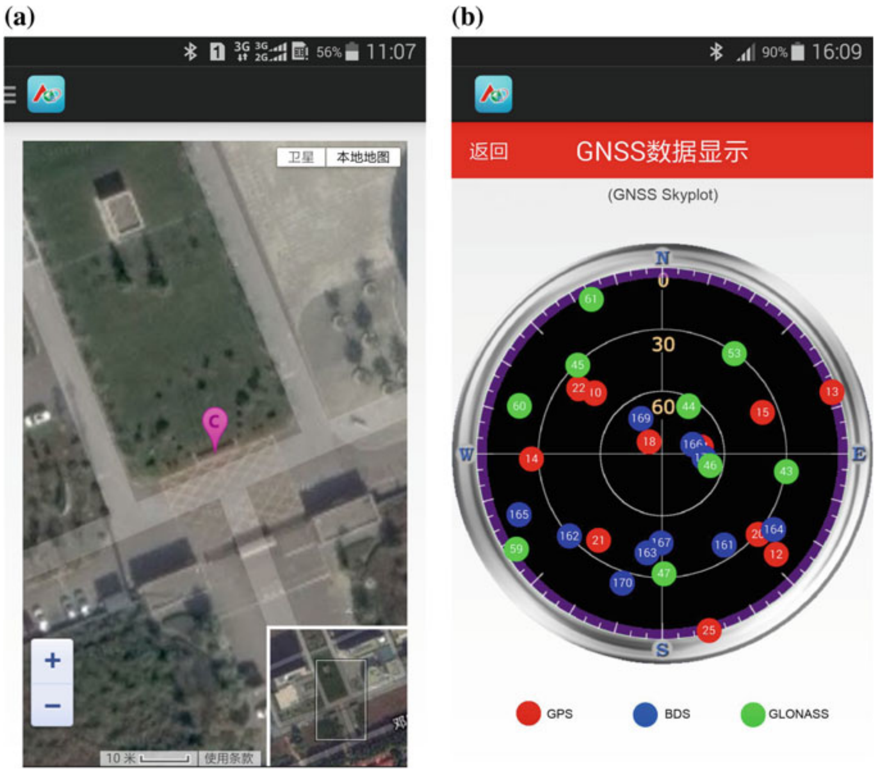

Fig. 4 Display user's position on map (**a**) The sky plot of current visible satellites (**b**) (Color figure online)

4 Experimental Results

In order to validate the positioning performance in static and dynamic situations, a single point positioning test and a real-time differential positioning test are carried out respectively. The reference station (named as AOE) was installed on the roof of the main building of Academy of Opto-Electronics (AOE), Chinese Academy of Sciences in Beijing, China. The observation condition at AOE is very good, i.e., no obstruction in the sky.

In the experiments, the differential positioning were carried out in real-time, while the single point positioning results were obtained by post-processing with the stored data which collected by the software while in real-time differential positioning. All the positioning results were update in 1 Hz. The satellite navigation receiver module in user terminal is NovAtel OEM615 navigation module with the signal processing ability of BDS single frequency (B1) and GPS/GLONASS dual frequency (L1/L2).

Fig. 5 The experimental scene in static test

In addition, in order to analyze the user's positioning accuracy, we used another GNSS receiver as rover station to collect the real-time observation data. It was connected to the same antenna that for the tested user terminal via a power divider. After the experiment, the raw observation data collected by the reference station and the rover station were converted to RINEX format. Then the user's "true" positions were obtained by post-processing RTK positioning via the open source software RTKLIB. What's more, we only use the ambiguity fixed solutions for comparison when analyzing the experimental results.

The static test was carried out in Zhongguancun Park which nearby AOE on January 10, 2016 with an experiment period of about 30 min. The experimental scene is shown in Fig. 5 with good observation conditions around the user. The dynamic test was carried out on the Beiqing Road in Haidian District, Beijing on January 25, 2016 with an experiment period of about 35 min. The GNSS antenna was installed on a car, and the user trajectory was shown in Fig. 6.

The errors in the directions of East (E), North (N), and Up (U) for BDS/GPS/GLONASS combined real-time differential positioning in the static and dynamic test are shown in Figs. 7 and 8, respectively. The statistical positioning accuracies are shown in Table 1, in which the results refer to the statistical accuracy for the probability of 2σ (95.44 %).

Fig. 6 The user trajectory in dynamic test

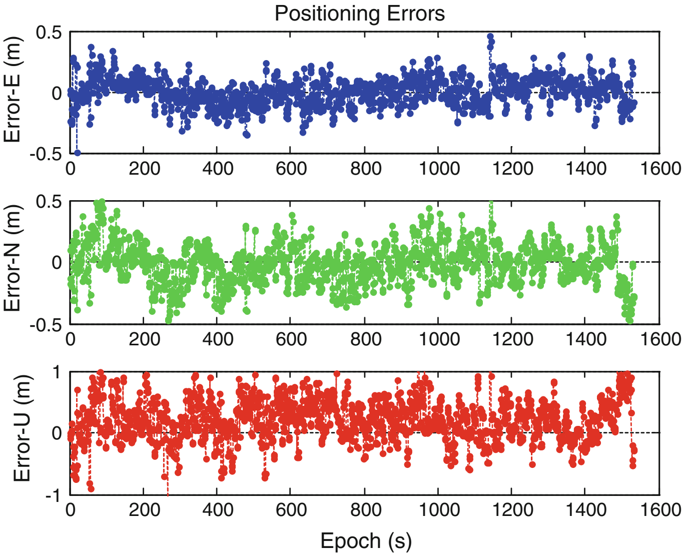

Fig. 7 Real-time differential positioning errors in static test

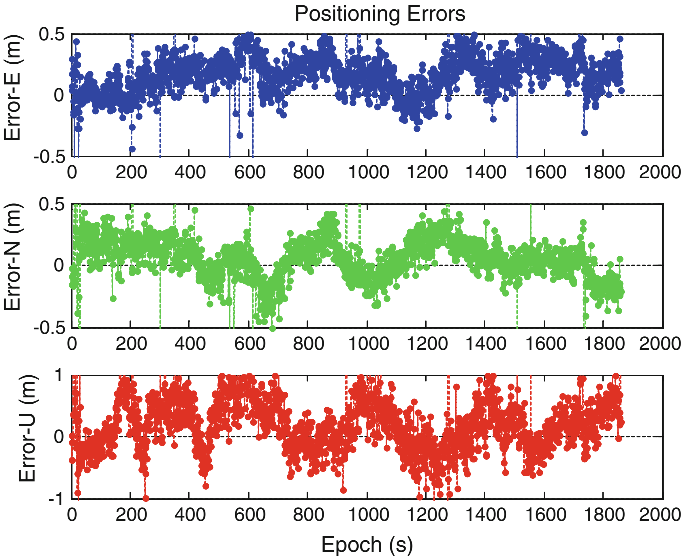

Fig. 8 Real-time differential positioning errors in dynamic test

As it can be seen from the experimental results, the single point positioning accuracies in horizontal are about 1.5 m for static test and 2.5 m for dynamic test, respectively. When it was in differential positioning mode by receiving differential

Table 1 Statistical performances for user positioning

No.	Tests	2σ (95.44 %) accuracy/(m)	
		Horizontal	Vertical
1	Single point positioning in static	1.74	2.68
2	Real-time differential positioning in static	0.37	0.82
3	Single point positioning in dynamic	2.31	3.42
4	Real-time differential positioning in dynamic	0.48	0.94

correction data from reference stations, the positioning accuracies are better than 0.5 m in horizontal and 1.0 m in vertical, respectively, for both static and dynamic test. As a result, the acquired positioning accuracy in this work can meet the needs of urban high-precision location-based service. It should be pointed out that the results presented here are in the experimental conditions of this work. Since the satellite visibility and the surrounding environment in different areas of the city are different, the corresponding results may be different in other areas.

5 Conclusion

Realizing high-precision positioning and navigation on mobile intelligent terminals is an important way to achieve the urban high-precision location-based services in the future. A system design scheme for realizing high-precision location-based services was studied and proposed in this work, and a set of BDS/GNSS real-time high-precision positioning software for mobile intelligent terminals is developed based on Android platform. By collecting the navigation data stream from an external GNSS module through the built-in Bluetooth module on those intelligent devices and receiving the differential correction data from a nearby reference station via 3G/4G or Wi-Fi wireless network meanwhile, respectively, user's high-precision position then can be calculated in real-time by the software. The results show that its positioning performance can meet the requirements of high-precision location-based service in urban. As a consequence, this contribution can provide some technical references for the realization of urban high-precision location-based services.

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