Vehicle Positioning Based on BeiDou Satellite Navigation System

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Abstract. This paper is mainly based on the BeiDou Satellite Navigation System (BDS) to solve the application of vehicle positioning. First, the paper illustrates the locating theory of BDS. Second, it analyzes the advantages of BDS based on the theory. Next, the paper emphasizes the application of BDS in vehicle positioning, which includes the application of real-time positioning combined with Global Positioning System (GPS), the collection of live traffic information and planning or choosing the best route. Finally, the paper includes the whole article and makes hope for the future.

Keywords: BDS, positioning and navigation, the collection of traffic information, route choosing.

1. Introduction

Recently, China has sped up their BDS construction to make it perfect. Nowadays, BDS has 45 satellites in orbit, which can provide 7 kinds of service [1, 2, and 3]. According to the statistics on the BeiDou website, BDS can serve positioning, navigation, and timing services. In the Global Continuous Monitoring and Evaluation System actual testing, the global positioning by BDS has a gap of about 1.52 meters between the system and the actual situation on the earth's surface [1, 2]. BDS has a gap of about 2.64 meters in height [1, 2]. Speed testing is only 0.1 meter per second gap to the fact. And BDS has 20 nanosecond time lags. BDS performs better in the Asia Pacific region [1, 2, 4, and 5].

Nowadays, the number of cars in China is increasing steadily and become a big number. Therefore, car navigation becomes a significant tool for drivers. During driving, the drivers should know where the destinations are so they can choose suitable routes using the map. However, in real life, it is complex to choose suitable routes due to the variable traffic situation, such as traffic jams or prohibition signs. If drivers do not have navigation, it is easy for them to get lost in the strange region. Drivers find it hard to find correct routes, which makes the passing efficiency go down and causes traffic congestion. So, it is necessary to have a car navigation system. The navigation system can exactly help drivers choose the best routes, which have shorter routes, take less time or less traffic jams.

BDS could be widely used in car navigation. For instance, vehicle autonomous navigation, the application of the Internet of Vehicles and the navigation of unmanned smart vehicles [6]. The positioning accuracy of BDS is slightly better than GPS, especially in the Asia Pacific region. Therefore, if BDS is used in the navigation app, the accuracy and stability of navigation will be improved. At the same time, the occurrence and updates of BDS have already broken the monopoly of GPS in China. The paper is based on the primary theories of BDS to introduce the advantages of BDS and its application to car travel. Finally, the paper concludes and suggests that BDS will be used in the range of artificial intelligence in autonomous driving.

2. The primary theory and the advantages of BDS

BDS now uses a B1C signal, which is not even one, but a composite signal of data and a pilot channel [7]. The navigation channel information is modulated in data channels, which are used for solving the navigation information and measuring the pseudo-distances. Although it's more complex than the B1I signal, the B1C signal can modulate multiplexed signals in a limited frequency band. This can improve the efficiency of the spectrum. Only the Geosynchronous Earth Orbit satellites of

BDS do not send the B1C signal. According to Table 1, the B1C signal uses a carrier frequency of 1575.42MHz as the centre with a bandwidth of 32.736MHz. The data of signal modulation mode and carrier frequency is served in the table 1 below.

Table 1. Signal modulation mode and carrier frequency [8].

signal	Signal component	carrier frequency(MHz)	Signal modulation	symbol rate(SPS)
B1C	B1C_data	1575.42	BOC(1,1)	100
	B1C_pilot		QMBOC(6,1,4/33)	0

The B1C signal has some characteristics: When it has high signal-to-noise ratio conditions, the tap of the code observation accuracy is shorter than 0.5 m, and the tap between the carrier phase measurement and the real one is shorter than 0.5 mm. The horizontal positioning by the B1C signal has a gap of 1.49 meters between the system and the actual situation [8, 9]. It has an accuracy of 3.11 meters in the perpendicular positioning [8, 9]. Both horizontal positioning and perpendicular positioning are the best for using the B1C signal in the world [8, 9]. So, the BDS signal is better than the signals of other systems [10]. Besides, the B1C signal can add the coherence integration time in the receivers' part so that it can enhance the accuracy of pseudo-distance measurement. And it will improve the efficiency of the spectrum in a way. According to Table 2, the stability of BDS is a little bit better than that of the other two systems.

Table 2. The comparison of the accuracy of three navigation systems [11].

navigation system	The average error of the horizontal positioning (meter)	The average error of the perpendicular positioning (meter)	The maximum error (meter)	The minimum error (meter)
BDS	0.65	0.48	1.04	0.36
GPS	0.78	0.52	1.20	0.45
GLONASS	0.82	0.5	1.30	0.50

According to Table 2, no matter the horizontal positioning or the perpendicular positioning, the average error, the maximum error and the minimum error of BDS are all better than those of the other two systems [11].

3. BDS real-time positioning and route planning

BDS must collect the traffic situation and the vehicle information so that it can do real-time positioning and route planning. Therefore, it is necessary to use a system to collect the data that BDS needs. The smart traffic system can collect the traffic situation and vehicle information. This traffic system can also help the drivers choose roads and dispatch driving vehicles, which provides a convenient travelling service for travellers. Figure 1 below describes the smart traffic system [12, 13].

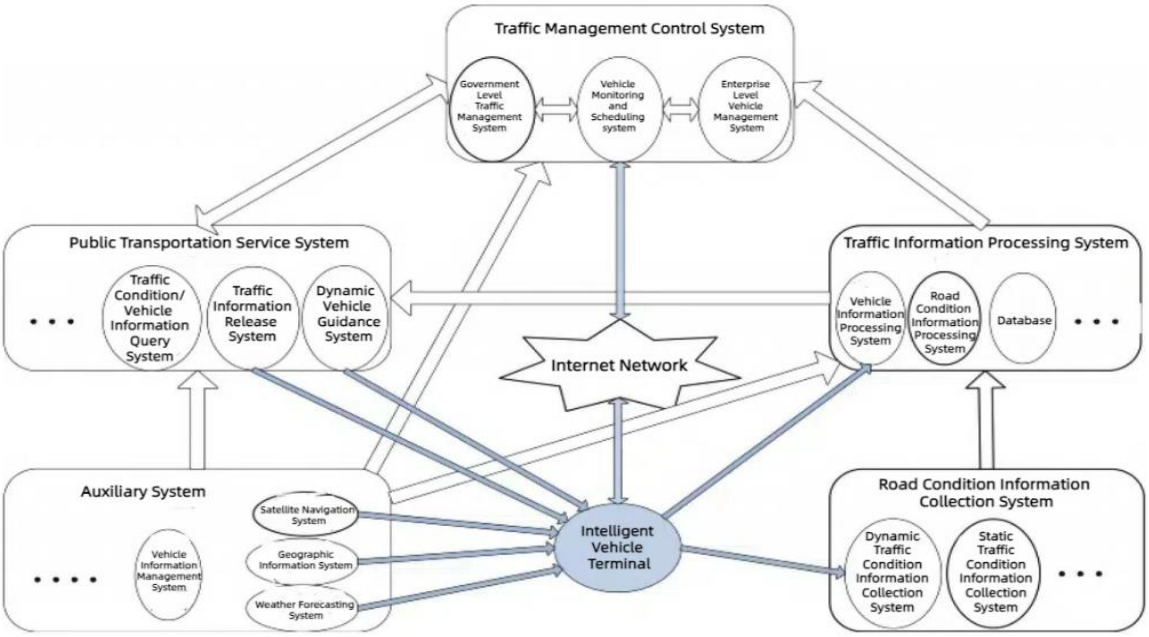

Fig 1. Data collection and output of intelligent vehicle terminal [12].

To make those things in Figure 1 come true, it is needed to have the cooperation of some modules like the main control module, data storage module, location information acquisition module, wireless communication module, vehicle data acquisition module, etc. The main function of the positioning module is to receive and resolve the BDS signal. So, it is considerable whether the module could match the same function of the BDS module or not. Therefore, it is suitable to choose the BDS / GPS dual-mode satellite positioning chip as the positioning module chip [12]. According to the real need, it can be chosen the suitable work mode and can be changed freely, which can control the positioning accuracy below 5 meters [12].

3.1. Application of BDS in-vehicle navigation

3.1.1. The application in vehicle real-time positioning

Most of the time, vehicles can be correctly positioned and navigated by only one navigation system. The satellite receivers collect the signals of each satellite to gain the corresponding time, speed and acceleration, which can mix the information above and give to integrated navigation [14]. During the past decades, researchers at home and abroad suggested some typical solutions for integrated algorithms (like classical Kalman filtering, extended Kalman filtering, etc.) [15]. they can improve the performance of the navigation systems, but there are some shortcomings [16, 17]. So, the paper chooses an integrated algorithm -- Dempster-Shafer-Support Vector Regression (DS-SVR). The algorithm can integrate BDS and GPS. In addition, if the GPS signal disappears, the algorithm can provide an accurate plan of navigation by only using BDS. It's easy to use so it can be used in engineering. Dempster-Shafer theory (DS) is an evidence theory, which can deal with some unsure information. Support Vector Regression (SVR) can solve the regression prediction problem. Therefore, the paper uses SVR to do the regression prediction of the errors. The whole algorithm is in the Figure 2.

Compared to a single positioning system, integrated positioning, which uses multiple satellite navigation and positioning Systems, performs better [4, 9, 18]. There are some advantages below.

First, integrated positioning dramatically boosts the security and stability of positioning [19, 20, and 21]. It does not depend on any single system and builds stable defence through the technique. If one of the navigation systems is broken or cannot be used because of some political reasons, others can take the place of it and continue to provide service. That can avoid the risks of stopping service.

Second, integrated positioning sharply enhances satellite visibility [19]. In the urban and other complex areas, due to the obstruction of buildings and other things, a single system hardly covers every direction. However, integrated positioning collects and analyzes the resources of multiple systems, which increases the number of visible satellites [22]. It can not only make the receivers receive more satellite signals with a high signal-to-noise ratio at the same time but also relieve the problem that the positioning signal from a single system gradually decreases in complex areas. So, this method improves the reliability and the accuracy of positioning.

Third, when BDS and other systems like GPS cooperate to work, they perform strong cooperative effects in solving integer ambiguity [19]. This cooperative working mode can increase the number of observation equations. For the measurement of real-time dynamic carrier phase difference (RTK), it means that the higher accuracy, the faster equation solving and the significant improvement of the real-time performance of fixed ambiguity of RTK for vehicle navigation. So, integrated positioning can bring a smoother and more accurate navigation service to users.

If BDS and GPS run stably, it is an excellent method to use DS to mix up the original satellite data from them. The process is about analyzing the collected data in depth to get the standard deviation and expected value of BDS and GPS. These two statistics are the basis for the subsequent calculations. The quality functions for BDS and GPS are constructed separately based on the statistics. Next, these functions are transformed into basic probability allocation (BPA) functions. They also quantify the confidence level of BDS and GPS-integrated navigation results when they make their systems a resource of evidence. According to this evaluation, if the confidence level of BDS is higher than that of GPS, gives BDS data priority to be used in positioning and navigation. On the contrary, choose GPS data.

At the same time, to improve the accuracy of BDS deeply, the SVR algorithm can be used for predicting and correcting positioning errors. The process begins with a clear definition of variables. It means that set time t as the independent variable and set the errors of BDS positioning as the dependent variable. Next, the data is normalized and makes sure that all the figures are within the range of [0, 1] so that the computer can easily solve them. Choosing kernel functions and regression parameters accurately is vitally important for the learning and predicting abilities of the model. The last step in this part is using the selected SVR model to make a fitting and prediction for the positioning errors of BDS so that the errors will be shorter, and the accuracy will be improved [16].

When the GPS signals are unstable, the BDS signals are used alone to obtain the satellite data. Next, the model that is gotten when two systems are run normally can be used for correcting and adding the results of BDS to get the best results of integrated positioning and navigation. There is a flow chart (Figure 2) of the algorithm below.

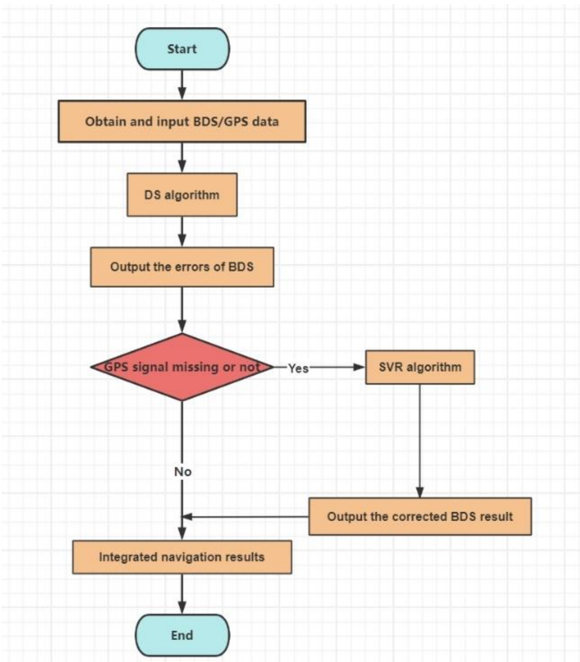

Fig 2. Choose the suitable result based on the DS algorithm.

3.1.2. The application in the collection of live traffic information

Nowadays, the floating car model that gets the information by reporting and summarizing from the floating cars like taxis and buses is usually used for the collection of traffic information. However, it has a low efficiency and cannot predict. So, the collection of traffic information is limited by using this method. Therefore, BDS makes an accurate positioning to calculate the situation of traffic congestion. Next, the data is updated by the platforms (like apps in the smartphone or vehicle navigation system). And the platforms predict traffic congestion the next time. So, the new method became the main goal of research [23].

First, BDS is used for positioning accurately for each vehicle to get the latitude and longitude as positioning information. Next, the real-time information is sent to a remote information platform for analysis. The platform collects and summarizes the information from each vehicle so that they can easy to be handled. Based on the change in speed, acceleration and other parameters, the system transforms the real-time positioning information from each vehicle into the specific vehicle information on the road. To calculate and evaluate the situation of traffic congestion, the system calculates the vehicle density (the number of cars per area) with road parameter information like the width of the road in every road [23]. It is an excellent method that divides traffic congestion into five levels (level 1 - 5 congestion) -- no congestion, going slowly, a little congestion, normal congestion and severe congestion. This information is transmitted to the lower platform and signed in all kinds of navigation apps through different colours or other ways. Figure 2 below describes how the DS algorithm runs.

It is a better choice to collect vehicle information from users, which can be analyzed for predicting traffic accidents by drivers [24]. Drivers can install a real-time traffic information monitor and an auto alarm system. At the same time, users can enter some vehicle parameters (like vehicle length, width, braking efficiency, weight, etc.) into the system. When driving, BDS is used to locate the driving vehicles and collect the information of all the driving vehicles. Combined with the average speed, traffic flow, and traffic congestion of vehicles, BDS analyzes the real-time situation. In areas or periods that have frequent traffic accidents; by using the real-time traffic information monitor and the auto alarming system, the real-time safe driving distance is calculated to alarm the drivers, which can decrease or even prevent the accident happen [25].

At the same time, BDS can judge an accident and analyze the position of the accident approximately by analyzing speed, acceleration, information on turning and lane changing of the vehicles, as well as the location of the accident vehicle and obstacles, and send the messages quickly to the policeman, doctors and other surrounding vehicles, the accident will be handled more efficiently. In addition, other drivers will predict and avoid the accident or choose other convenient routes when they face the situation it sent. So, the passing efficiency of roads will be boosted [24, 26, and 27].

3.1.3. The application in planning or choosing the best route

There are many kinds of routes to choose from. However, the route will be adjusted based on the drivers' needs. In other words, there is no fixed best route, but there is just the most suitable route based on the drivers.

Some researchers have proposed that during the planning of driving travel, by collecting the information from BDS, users give their travelling time and their needs (like not running on the highway, highway advanced, the shortest distance, the shortest time and avoiding congestion, etc.), some apps calculate automatically and provide three or more routes that meet the needs [28]. Next, the users choose the best routes that are suitable to themselves based on their habits. At the same time, the real-time information in BDS is reflected to the navigating map users. In addition, BDS provides a better route based on real-time information for the users to get the correct reflection. The users can decide to change the route or not by themselves, which decreases the passing time and improves the efficiency of passing.

4. Conclusion

This paper significantly introduces the solving of vehicle navigation positioning by BDS and concludes that BDS is beneficial to vehicle navigation and positioning. Using BDS suitably can locate correctly, get traffic information and analyze to choose the best route. BDS has great potential in the application of smart vehicles in future. Therefore, the goal of the paper is that make the users of BDS know more about BDS and use it better. In addition, the paper can enhance the understanding of BDS among researchers in related fields in the future. Nowadays, some tests of smart vehicles use BDS. However, due to many objective factors, BDS is not used widely and smart vehicles are also in their test period. Hope that BDS can be better used in the research of smart vehicles and self-driving cars. For instance, use BDS to choose convenient routes and avoid accidents with artificial intelligence and self-driving system help.

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