Combination Navigation System Applied in Marine Domain

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Abstract

In marine domain, each navigation system has its respective advantages and disadvantages, and don't replace each other. In order to continuous, reliable navigation of vessels, a variety of navigation methods can be combined to improve the accuracy of navigation. This paper firstly introduced GPS, GLONASS and inertial navigation system. Next it discussed based on a combination of GPS and GLONASS navigation. Lastly based on a combination of GPS, GLONASS and INS navigation System is investigated.

Keywords

Combination Navigation System; GPS; BeiDou ; INS; Kalman Filter.

1. Introduction

With the rapid growth of the global economy and the acceleration of the process of economic integration, the volume of maritime transport is growing rapidly. According to statistics, 90% of the world's trade in goods is accomplished by maritime transport [1-2]. The increasingly busy maritime traffic, as well as the impact of human life, property and environment at sea, have promoted the large-scale and specialized marine transport vessels. With the development of industrialization, speediness and automation, it has become a safe and efficient means of transportation. In order to ensure the safe navigation of ships, significantly reduce marine accidents, and enable ships to navigate in the best and shortest routes, creating huge economic benefits, navigation technology has been widely used in the field of navigation.

Navigation is the technology or method of guiding a carrier from its starting point to its destination. The concept of navigation originated from the maritime industry at the earliest. Since the beginning of human navigation activities at sea, various ship navigation technologies have been applied. The basic navigation parameters needed for navigation are the real-time position, speed and heading of the carrier [3]. Navigation is accomplished by navigation system, which is divided into hardware and software. Hardware includes navigation equipment mounted on carrier and navigation platform mounted elsewhere to cooperate with navigation equipment. According to the position of navigation station, navigation system can be divided into land-based navigation system and satellite-based navigation system. The software is divided into navigation program and map data.

Due to any single navigation system can not meet the high reliability and low cost, integrating navigation technologies has gradually become the main research and development object in the field of navigation. Firstly, this paper introduces several commonly used navigation systems, focusing on the application of several integrated navigation systems in the field of navigation.

2. Navigation System

2.1 GPS

GPS (Global Positioning System) is the satellite navigation and positioning system which has been developed in the United States since 1970s [4]. It took 20 years and cost 20 billion US dollars. It was built in 1994. It has the capability of real-time three-dimensional navigation and positioning in all directions at sea, land and air. GPS global positioning system consists of three parts: space part, ground monitoring part and user receiving part.

GPS global positioning system uses multi-satellite, high orbit and ranging system, and takes distance as the basic observation quantity. By measuring the distance of four satellites at the same time, the position of the receiver can be calculated. As shown in Figure 1, GPS receivers measure the distance between themselves and four satellites at the same time, and then form a set of equations to solve the position coordinates (x, y, z) of the receivers.

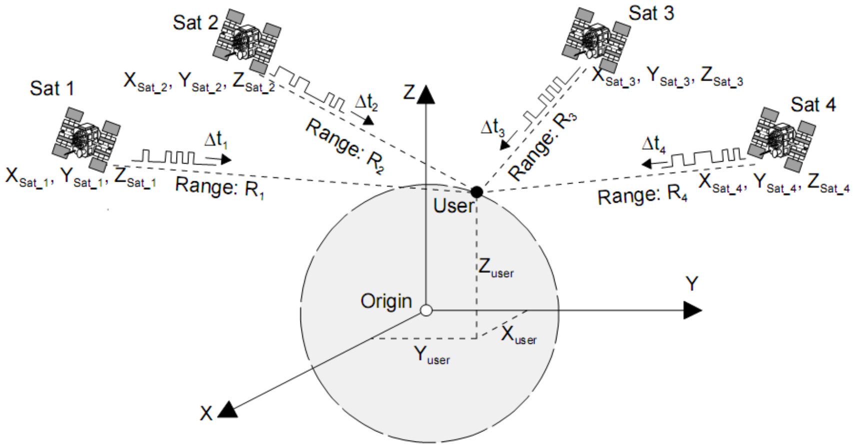

Fig.1 GPS position

Since the birth of GPS, it has demonstrated that it can replace TRANSIT and roadbed radio navigation system and play an epoch-making role in navigation. Today it is hard to imagine that ship is not equipped with GPS navigation system and equipment. Navigation application has become the largest user of GPS navigation application, which is incomparable to users in any other field. There are many users of GPS navigation, and their classification criteria are different. According to the type of navigation, GPS navigation can be divided into five categories: ocean navigation, coastal navigation, port navigation, inland river navigation and lake navigation. According to the function of navigation system, there are roughly the following categories: autonomous navigation, port management and entry. Port guidance, route traffic management system, tracking and surveillance system, emergency rescue system, GPS/sonar combination for underwater vehicle navigation.

The basic data output by the ship navigation system is the position coordinates of the navigation body, and then the navigation information such as yaw angle, yaw distance, speed, distance and time from the next point, distance and time from the terminal point are calculated. If the error of navigation parameters is relatively large, hidden dangers will be buried in the whole voyage, and the ship will be damaged or endangered. The factors affecting navigation accuracy include positioning error, coordinate system error, speed error of navigation body, etc. The positioning error is the main source of navigation system error, because GPS satellite, satellite signal transmission process and ground receiving equipment will produce errors in GPS measurement. Therefore, the sources of positioning errors can be divided into: errors related to GPS satellites; errors related to signal propagation; and errors related to receiving equipment.

2.2 GLONASS

GLONASS (Global Navigation Satellite System) is a satellite positioning system similar to the US GPS system, which was built by the former Soviet Union in the early 1980s [5]. It also consists of satellite constellation, ground monitoring and control station and user equipment. It is now managed by the Russian Space Agency. Unlike GPS, GLONASS does not contain any restrictive policies or services. The Russian government also declared that no selective availability (SA) measures would be introduced in GLONASS satellite positioning services. The accuracy of GLONASS system is 15em/s (99.7%) and LUS (99.7%). The overall positioning accuracy of GLONASS system is much higher than that of GPS under SA. Therefore, GLONASS system has great application potential in the field of navigation and positioning.

GLONASS system is mainly used for navigation and positioning. Of course, like GPS system, GLONASS system can also be widely used in various levels and types of surveying applications, GIS applications and time-frequency applications, and there are errors as well as GPS.

2.3 BDS

BDS (BeiDou Navigation Satellite System) is a self-developed global satellite navigation system in China [6]. The distance measurement between Beidou satellite and users is based on the difference between the transmitting time of the satellite signal and the arrival time of the receiver, which is called pseudorange. Satellite positioning implements the concept of "time difference of arrival" (time delay). It uses the precise position of each satellite and the navigation information generated by successive on-board atomic clocks to obtain the time difference of arrival from satellite to receiver.

As shown in Fig. 2, assuming that BDS receiver is placed at the point to be measured at t time, the time of arrival of BSPS signal to the receiver can be measured.

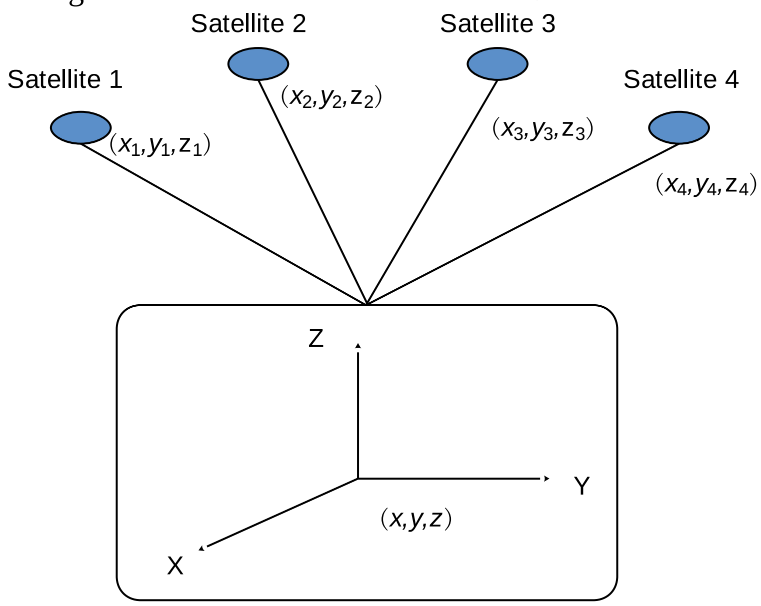

Fig. 2 BDS position

The coordinates *x*, *y*, *z* of the receiver to be measured and the clock difference v_{to} of the receiver can be determined by the following four equations. The clock difference of v_{ti} (*i*=1, 2, 3 and 4) is provided by satellite ephemeris, which are satellite clocks of each satellite, respectively. c is the propagation speed of BDS signal (that is, the speed of light). d_i (i = 1, 2, 3, 4) is the distance from each satellite to receiver, respectively.

$$\sqrt{(x_1-x)^2+(y_1-y)^2+(z_1-z)^2}+c(v_{i1}-v_{to})=d_1 \quad (1)$$

$$\sqrt{(x_2-x)^2+(y_2-y)^2+(z_2-z)^2}+c(v_{i2}-v_{to})=d_2 \quad (2)$$

$$\sqrt{(x_3-x)^2+(y_3-y)^2+(z_3-z)^2}+c(v_{i3}-v_{to})=d_3 \quad (3)$$

$$\sqrt{(x_4-x)^2+(y_4-y)^2+(z_4-z)^2}+c(v_{i4}-v_{to})=d_4 \quad (4)$$

In 2014, the International Maritime Organization Maritime Safety Committee considered and approved the navigation safety letter approved by Beidou Satellite Navigation System, which marks that BDS has become the third global satellite navigation system after GPS and GLONASS system, serving the world navigation users. BDS system can be applied to navigation safety assurance and technical support services such as navigation mark maintenance, port waterway surveying and mapping, water safety communication and so on.

2.4 INS

INS (Inertial Navigation System) is an autonomous navigation technology, which tracks the position and direction of the carrier by measuring the gyroscope and accelerometer when the initial position, velocity and direction are known. Inertial Measurement Units (IMUS) generally consists of three degrees of freedom gyroscopes and three degrees of freedom, which are used to measure the acceleration of three rotational and three translational motions respectively. Gyroscopes are mainly divided into mechanical, optical and micro-electromechanical systems (MEMS). Accelerometers are divided into mechanical, solid-state and MEMS. According to the installation mode of INS integrated on carrier, it can be divided into platform inertial navigation system and strapdown inertial navigation system. The former is mounted on the inertial platform with small calculation and high accuracy, but its structure is complex and occupies a large area. The latter is directly mounted on the aircraft with simple structure and small volume. However, due to poor working conditions, the accuracy of the instrument will be reduced [7].

Inertial navigation is widely used in many fields, such as aviation, navigation, vehicle navigation and so on. It has been a hundred years since the first gyrocompass was first used in navigation in March 1908. Over the past century, inertial technology has made great progress in navigating ships and achieved great success. At the same time, inertial navigation is the only completely autonomous navigation mode. The pure inertial navigation system, which does not depend on any external information, will still occupy a place and become an independent and meaningful research direction. However, due to the influence of noise and temperature on the accuracy of inertial navigation, with the increasing demand for high-performance autonomous navigation system and the wide application of multi-mode GNSS technology (GPS, GLONASS, Galileo, etc.), integrated navigation system will gradually replace pure INS as the main navigation means in the future.

3. Application of Integrating GPS/BDS and INS in Navigation

Because of the need of navigation, and there are various errors in a single navigation mode, in some cases, the space-based navigation system can not accept signals. At this time, it can be combined with inertial navigation to achieve integrated navigation in navigation. Because now the GPS/BDS integrated receiver has formed a whole module, and in the module, the curing program has been used to process the GPS and GLONASS positioning data. And the principle and mechanism of GPS and BDS positioning are the same, so in this paper, simplified processing is adopted in the study of GPS/BDS/INS integrated system, and the combination of the original system is regarded as a combination of satellite navigation system and INS system. Kalman filter is used to realize the fusion of GPS/BDS and INS data. The combination block diagram is shown in Figure 3.

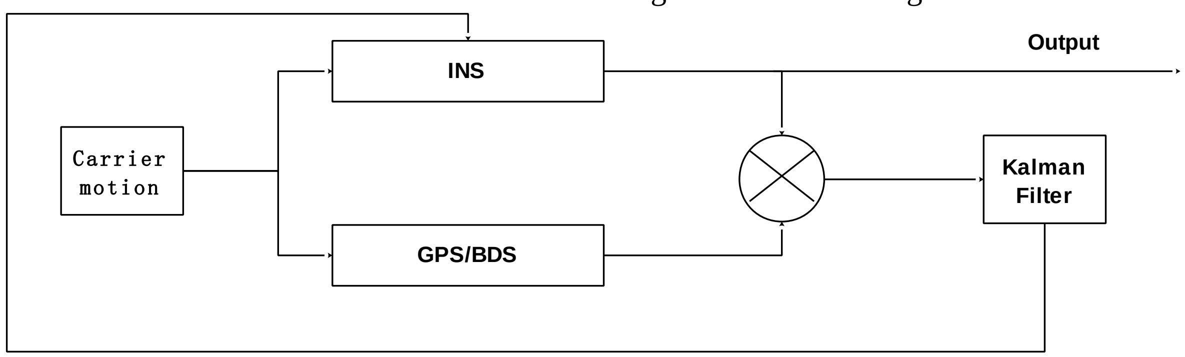

Fig. 3 Navigation system based on Kalman filter

The advantage of this integrated mode is that the integrated structure is relatively simple and easy to realize in engineering, and the two systems can still work independently, which makes navigation information have some redundancy. Kalman filter is a recursive unbiased minimum estimation, which can estimate the real-time optimal output of the noise-contaminated system. According to the above model, the mathematical model of system position and velocity combination mode is deduced.

$$\begin{cases} X(t) = F(t)X(t-1) + G(t)W(t) \\ Z(t) = H(t)X(t) + V(t) \end{cases} \quad (5)$$

The position and velocity information can be obtained iteratively by the above equation.

4. Conclusion

Integrated navigation system has always been a research hotspot. Compared with GPS/INS integrated navigation system, BDS/INS further improves positioning accuracy and reliability on the basis of reflecting the characteristics of integrated navigation system. The design of the integrated navigation system of BDS and INS has a certain reference value for the design direction and method of similar systems at present and in the future. At the same time, the integrated navigation system can be used in the navigation field with high positioning requirements because of the improvement of positioning accuracy and reliability.

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