A Beidou + UWB + inertial Navigation Integrated Indoor and Outdoor Multi-Source Information Fusion Positioning System

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Abstract. The article analyses the high-precision indoor and outdoor positioning system and its positioning method based on Beidou/UWB. And analyse the principles and characteristics of UWB technology. The article proposes a sequential filtering fusion algorithm for the ship's integrated navigation system. The basic idea of the algorithm is to use the first-order Markov process to establish the noise model of ship motion, and use the state expansion method to transform the state equation into a basic equation that conforms to the standard Kalman filter. Theoretical research and experimental simulation prove that the filter introduced in the article is matched with the system and has high filtering performance and accuracy.

Key words: Integrated navigation, consistency of filter model, Beidou/UWB, multi-source information fusion, positioning.

1. Introduction
In order to accurately and reliably navigate the moving carrier or target accurately, the navigation system must provide the entire system with sufficiently accurate and reliable position, speed and attitude information. The navigation system must not only provide high-precision navigation parameters such as heading, attitude, angular velocity, linear velocity and timely position, but also have strong fault tolerance and redundant navigation capabilities [1]. In the past few decades, the navigation system has developed from a single sensor type system to an integrated navigation system. Various types of sensors have been optimized and their performance complemented each other, so that the accuracy and reliability of the system have been greatly improved. The positioning system can be applied to many industries, greatly saving human resources, greatly reducing construction costs, and significantly speeding up the process.

The integrated navigation system is conducive to making full use of the advantages of each navigation system for information complementation and information fusion, and has become the development direction of the navigation system. The integrated navigation system uses two or more navigation devices to provide multiple information, forming a multi-functional, high-precision redundant system. Inertial navigation system has the advantages of autonomy, concealment, strong interference, high manoeuvrability and complete navigation information, but the accumulation of navigation error increases with time, which limits its application. The Global Positioning System (GPS)
is a global, all-weather, high-precision positioning system [2]. The error does not accumulate over time, but it is susceptible to interference, has a low data update rate, and GPS is directly controlled by the US Department of Defence, and its use is restricted. The Beidou navigation system is an important part of the global satellite navigation system that is being built and operated in China and has absolute autonomy. Therefore, the combination of Beidou system (BDS) and UWB for integrated navigation has become an inevitable trend and research hotspot in the development of navigation systems, and has great practical significance for Chinese national defense construction.

Chinese Beidou/UWB positioning system has achieved a great breakthrough. This article discusses the working principle and positioning method of the Beidou/UWB-based high-precision indoor and outdoor positioning system. In this paper, a loose combination method is adopted for the research, and the position and velocity are taken as observations for simulation analysis. The Kalman filter introduces the calculation of the measurement noise covariance (R) of the system and weights it exponentially to effectively suppress the filter divergence [3]. The introduction of the attenuation memory factor can achieve a smaller current signal deviation value. Increasing the influence of new observation data is an effective way to overcome the filtering deviation and reduce the influence of the data collected in the past on the filtering.

2. Ship integrated navigation system model

2.1. Establishment of ship integrated navigation system model

The state equation of ship motion is

$$x(k + 1) = \Phi(k + 1, k)x(k) + w(k)$$  \hspace{1cm} (1)

Among them, \(k\) represents the discrete time mark; \(x(k)\) is the state vector of the target, and \(\Phi(k + 1, k)\) is the state transition matrix. Because the navigation of the ship is affected by the marine environment, it is more realistic to model the noise \(w(k)\) in the motion process of the ship's integrated navigation system with the first-order Markov process, namely

$$w(k) = \theta(k - 1)w(k - 1) + \eta(k - 1)$$  \hspace{1cm} (2)

In the above formula, \(\eta(k)\) is zero-mean Gaussian white noise with \(Q(k)\) variance. The measurement equations of the navigation subsystems (such as GPS, SINS, TNS, CNS, SAR, etc.) on the ship after time and space registration are written as

$$z_i(k) = H_i(k)x(k) + v_i(k), i = 1, 2, \cdots, N$$  \hspace{1cm} (3)

In the above formula, \(N\) is the number of navigation subsystems, and the measurement noise \(v_i(k)\) is an independent zero-mean Gaussian white noise process, and its variance is

$$\text{Var}[v_i(k)] = R_i(k)$$  \hspace{1cm} (4)

2.2. Standardization of ship integrated navigation system model

The integrated navigation model cannot perform standard Kalman filtering. Here, we adopt the need to adopt the state expansion method to standardize the ship integrated navigation system model into a classic Kalman filtering model. The measurement equation standardized by the state expansion method is

$$x^*(k + 1) = \Phi^*(k + 1, k)x^*(k) + w^*(k)$$  \hspace{1cm} (5)

$$z_i^*(k) = H_i^*(k)x^*(k) + v_i(k), i = 1, 2, \cdots, N$$  \hspace{1cm} (6)
\begin{align}
  x'(k) &= \begin{bmatrix} x(k) \\ w(k) \end{bmatrix} \\
  w'(k) &= \begin{bmatrix} 0 \\ \eta(k) \end{bmatrix} \\
  \Phi'(k+1, k) &= \begin{bmatrix} \Phi(k + 1, k) & I \\ 0 & \theta(k) \end{bmatrix} \\
  Q'(k) &= \begin{bmatrix} 0 & 0 \\ 0 & Q(k) \end{bmatrix} \\
  H'(k) &= \begin{bmatrix} H'(k) & 0 \end{bmatrix}
\end{align}

3. Design of high-precision indoor and outdoor positioning system based on Beidou/UWB

As shown in Figure 1, UWB technology can be easily operated and used in addition to accurate algorithms and less human involvement. The extensive use of the CORS network has accelerated the technological revolution and greatly reduced the pressure on the staff. Under this technological revolution, our engineering survey will achieve good results. The CORS network system consists of three parts: the working platform, the communication network and the sensor, which can accurately transmit the received data to various places [4]. Compared with previous technologies, this emerging network technology is excellent in surveying and mapping speed, measuring distance, and measuring accuracy. Moreover, this kind of network technology is simple to operate and can effectively ensure the accuracy of the data.

![Beidou positioning system](image_url)

**Figure 1.** Beidou positioning system
In the design of Beidou/UWB high-precision positioning system, the design idea proposed in this paper is to use Beidou positioning system to determine outdoor measurement point positioning, and use UWB technology to complete indoor positioning measurement. Normally, UWB technology is difficult to analyse from the principle [5]. Elevation measurement can only determine the linear distance between the initial point of measurement and the point to be measured, while the Beidou satellite positioning system has high accuracy in level measurement. After the level measurement is completed, the elevation of the point to be measured is calculated. The design method of the positioning system is as follows:

3.1. Hardware system construction
The positioning principle of the Beidou positioning system is that the ground receiving station monitors multiple navigation satellites at the same time. It realizes the common measurement of various parameters, and determines the spatial coordinates of the point to be measured on this basis. Therefore, in the hardware system fitness, it is necessary to configure a dedicated receiver Station. Another hardware system is the hardware equipment in UWB technology application, including data packet sending station, ZigBee digital chip, data packet acquisition station, etc., to measure the linear distance between the initial point and the point to be measured (Figure 2).

![Figure 2. Beidou positioning system hardware](image)

For the receiving station of the Beidou satellite positioning system, the application of the currently developed special equipment can meet the work requirements, and the UWB technology hardware equipment in the application includes the hardware equipment wireless transmitting chip, the selected model is DW1000, and the theoretical communication distance is 300~500m; CPU, can use single-chip microcomputer to complete data analysis and calculation, and use SPI to complete the reading and writing of DW1000 module. In the hardware installation, it is necessary to consider the convenience of system debugging, stable and effective coverage radius, etc., to ensure that the operating quality of the hardware system can meet the relevant requirements.

3.2. Communication system construction
In the Beidou/UWB technology system constructed in this article, the hardware devices in the system need to be able to complete data transmission, and after completing the data integration, complete the precise positioning of the spatial position of the point to be measured. There are two design ideas for communication systems. One is wired communication technology. This technology relies on the local party-oriented Beidou system signal receiving station. The fixed-point measurement unit gets in touch with the local observation station through the wired network to obtain the satellite system of the point
to be measured. The space coordinates [6]. The advantage of this method is that the accuracy of the satellite positioning system is higher, and the shortcomings are also obvious, that is, the cost of the entire communication system is higher. The second is the wireless communication system. In fact, there are a large number of ground observation stations in the operation of various positioning satellite systems. The common observation stations are those used by transportation equipment. This type of observation station can already meet the accuracy requirements. In the application of wireless communication network, the data of this small observation station can be sent to the data processing and calculation system. In the specific calculation, the application parameters are the linear distance L between the starting point and the point to be measured, Beidou positioning the system obtains the x and y in the space coordinates, and finally completes the calculation of parameters such as elevation. The advantage of this kind of communication system is that the height of the communication system is relatively low, and it can achieve a high degree of integration between the two types of systems. Relying on the positioning system of the wireless communication system, there is no obvious disadvantage from the theoretical analysis.

4. Simulation Analysis

4.1. Simulation analysis of adaptive filter combination algorithm
Aiming at the characteristics of attenuation adaptive memory filtering and noise weighting adaptive filtering, these two algorithms can be combined to achieve complementary advantages, so as to satisfy the complex BDS/INS system with uncertain noise interference to dynamic models. Firstly, the inaccurate integrated system is filtered. Due to the uncertainty of environmental noise, this paper verifies the rationality of this algorithm in the early stage of this paper. The trajectory and error of the traditional Kalman filter and attenuation adaptive Kalman algorithm for the state estimation of the above system are shown in Figure 3.

![Figure 3. Comparison of Kalman and attenuated Kalman errors](image)

It can be seen from the above figure that the attenuation adaptive memory algorithm can improve the accuracy of the filter to a certain extent. When the environmental noise changes, the attenuation adaptive memory algorithm can better adjust the filter noise variance Rk, so that the Kalman gain K adjustment is more sensitive.

4.2. Data fusion based on federated Kalman filtering theory
The observed system is set with a system actual value, and this randomly generated actual value is used as the original data, and then measured by two observation devices, that is, the actual value is
independently added with noise to form two observation results. Then use the federated Kalman filter to fuse the two observations to form the final filtering result. Through experiments, it can be seen that in the case of using the Kalman filter sub-filter, the result of the sub-filter is closer to the actual value. Further use of the Kalman filter for data fusion can further improve the accuracy of the result and further approximate the actual value. Value, as shown in Figure 4.

![Figure 4. The actual operation result of the federated Kalman filter on the Beidou double star positioning system](image)

5. Conclusion

The Beidou satellite system currently has high measurement accuracy in the horizontal position, but the quality of the elevation measurement is average. The UWB technology section realizes rapid data transmission, but it can only complete short-distance positioning and measurement tasks. In the simultaneous application of these two technologies, the Beidou positioning system is first used to complete the plane coordinate measurement of the positioning point, and then the UWB technology is used to obtain the linear distance of the measurement point, and then the elevation calculation is completed on this basis.

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