Application of RBF Neural Network in Navigation Filtering Algorithm

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Abstract. As a high-precision and widely used navigation method, satellite navigation can provide users with all-weather and all-time services. In recent years, with the improvement of satellite positioning accuracy requirements, using conventional Kalman filter algorithm to solve the problem can not meet the requirements of high accuracy and low cost of satellite navigation. To solve these problems, this paper proposes the RBF Kalman fusion filtering algorithm. The original data without processing is compared with the results of traditional model and RBF Kalman fusion filtering model through the simulation experiment. The results show that the algorithm can better improve the positioning accuracy.

1. Introduction
As a high-precision and widely used navigation method, satellite navigation can provide users with all-weather and all-weather services. In recent years, it has developed rapidly in various fields. In 2012, China initially completed the construction of Beidou satellite navigation system, marking the beginning of Beidou satellite navigation services in the Asia Pacific region. However, at present, the timing accuracy of BDS is 50 nanoseconds, while that of GPS is more than 10 nanoseconds. At the same time, BDS system can only meet the navigation service of China and Asia Pacific region, which is far lower than the service level of GPS global positioning, and far from meeting the goal of high precision and global coverage. In this paper, by combining DR and BDS navigation system and combining RBF neural network with Kalman filtering, a new navigation filtering model is established to solve the precision information. The algorithm can effectively eliminate the error caused by Kalman filter model itself, so as to reduce the influence of the model and the parameters used in the filtering process on the optimal estimation value, and reduce the anti-interference ability of the high model to the external interference of the dynamic environment.

2. DR / BDS integrated navigation system
Because of the short service time of BDS navigation system for region and the variety of receiving environment of mobile devices, the more complex system combination mode will have an inestimable impact on the positioning accuracy of the system. Through analysis and comparison, this paper uses loose combination to build DR / BDS integrated navigation system, and the specific design structure is shown in Fig.1.
Fig.1 DR / BDS integrated navigation system structure

The main structure of Kalman filter is included in the figure. The signal is transmitted to BDS receiver through Beidou satellite, and then the satellite data input through local sensor filtering is imported into the main filter. At the same time, the real-time stored angular rate and odometer information of the DR system are transmitted to the main filter through the local filter, and the global optimal estimation is obtained by comprehensively solving each subsystem in the main filter.

\[ X_m = X_g = P_g (P_1^{-1} \hat{X}_1 + P_2^{-1} \hat{X}_2) \]  

The system consists of two subfilters which respectively process the positioning data on DR and BDS system. The main task of the system is to transmit the corresponding state estimation value to the main filter, then analyze and synthesize all kinds of values, and calculate the estimation value with high accuracy. By integrating the information data, the main filter can update the covariance and the estimated value, and feed them back to the sub filter to ensure the accuracy of the local filter. Corresponding to the information allocation parameters of sub filter and BDS sub-system is \( \beta_1 \). The corresponding Dr subsystem is \( \beta_2 \).

The system designed in this paper consists of several filters. The main task of BDS filter is to process the data information from BDS navigation system. The task of main office filter is to summarize and sort out the information from local filter, to get the best estimate value and output the final data, which is a very important task. If the state equation of each subsystem is the same as the general state equation, then the BDS subsystem state variable \( X_2 \), the North position variable \( n_2 \), and the east position variable \( e_2 \) can be obtained by discretizing the measurement equation.

\[ Z(k) = \begin{bmatrix} e_{ob}(k) \\ n_{ob}(k) \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} * X_1 + \begin{bmatrix} v_e(k) \\ v_n(k) \end{bmatrix} \]  

In this formula, character \( V_e(k) \) represents the noise test result of the east direction position, character \( V_n(k) \) represents the noise test result of the north direction position, which obey the Gauss white noise of \( (0, \sigma_e^2) \), \( (0, \sigma_n^2) \) respectively. Character \( R(k) = diag[\sigma_e^2, \sigma_n^2] \) is used to express the covariance matrix. The main filter contains the following mathematical formula:

\[ \begin{align*} 
  P_g &= (P_1^{-1} + P_2^{-1})^{-1} \\
  Q_g &= (Q_1^{-1} + P_2^{-1})^{-1} \\
  X_g &= P_g (P_1^{-1} \hat{X}_1 + P_2^{-1} \hat{X}_2) \\
end{align*} \]  

\[ \begin{align*} 
  P_1^{-1} &= \beta_1 P_g^{-1} \\
  Q_i^{-1} &= \beta_i Q_g^{-1}, i = 1,2 \\
  \hat{X}_i &= \hat{X}_g \\
end{align*} \]  

\[ \beta_1 + \beta_2 = 1 \]

Where, \( \beta_1, \beta_2 \) is the information allocation factor, and the selection of its parameters will affect the positioning effect of the integrated navigation system. In order to ensure the normal operation of BDS and Dr subsystems, it can be obtained through research and computer simulation \( \beta_1 = \beta_2 = 0.5 \). The
Positioning effect of the integrated navigation system is the best. At this time, the overall output $\hat{X}_g$ also has the best accuracy.

3. RBF kalman fusion filtering model algorithm

3.1. RBF neural network model

RBF neural network has three layers: input layer, hidden layer and output layer. Each layer has its own function. The neuron activation function of the hidden layer consists of radial basis function. There is a central vector in the array operation unit composed of the hidden layer, which has the same dimension as the input parameter vector. When calculating the nonlinear activation function, the Euclidean distance between them should be used, which is specifically defined as $\|x(t) - c_j(t)\|$. Therefore, the output of the hidden layer is a nonlinear activation function as shown in formula (5).

$$h_j(t) = \exp\left(-\frac{\|x(t) - c_j(t)\|^2}{2\sigma^2}\right), \quad j = 1, \cdots, m$$

Where, $\sigma$ is a positive scalar, which represents the width of Gaussian function in formula (5), and $M$ represents the number of hidden nodes in the whole RBF neural network.

For the convenience of calculation, the width of the basis function is defined as 1, so the output approximation function of neural network shown in formula (6) can be obtained.

$$y_i = \sum_{j=1}^{M} \omega_j \phi_j (\|x - c_j\|), \quad j = 1, \cdots, m$$

According to the above RBF neural network, the output voltage of the micro inertial measurement unit under different known attitude conditions measured by the test is used as the training sample for training, so as to realize the numerical correction of different hidden nodes in the neural network.

3.2. RBF Kalman fusion filtering model

In this study, firstly, gyroscopes and accelerometers are used to realize the angular velocity and acceleration of MIMU installed in the process of movement, and magnetometers are used to calibrate the angular velocity and acceleration of measured angular velocity and acceleration. Then three kinds of attitude information are fused by extended Kalman filter to get the attitude information before the RBF neural network calibration. Then the information of the three sensors and the attitude information before calibration are input to the RBF neural network system to realize the training and prediction of the neural network. Fig.2 is the structure diagram of RBF Kalman-fusion-filter.
4. Application of RBF Kalman filter in DR/BDS navigation system

RBF Kalman filter algorithm is actually a linear minimum variance estimation algorithm, which is based on time-domain space, and has time-domain state recursion. This algorithm includes two kinds of algorithms, continuous and discrete, which are suitable for state estimation in multidimensional stochastic process. The algorithm is simple, efficient and easy to implement on the computer. It is a successful example of integrated navigation system. The flow chart of DR/BDS integrated navigation system based on RBF Kalman filter is as follows:

![Flow chart of DR/BDS navigation system](image)

Two navigation systems have their own advantages and disadvantages: as far as DR system is concerned, its own navigation ability is strong, but the positioning accuracy of the displacement sensor of the system is low, which leads to the accumulation of positioning error with time, so the system does not have long-term stability; compared with BDS navigation system, although it has relatively high positioning accuracy, because of the system capacity, it is easy to be affected by the external environment, and some unexpected errors are easy to occur, resulting in positioning errors. Therefore, in order to ensure the positioning accuracy of the navigation system and improve the long-term stability of the system, this paper introduces DR/BDS based on RBF Kalman filter integrated navigation technology can not only correct the error accumulation of DR dead reckoning drift over time, but also effectively modify the error identification of BDS system based on reference points, which greatly improves the stability and accuracy of the dynamic system.

In the RBF Kalman filter model, considering the accuracy of the navigation angle itself, it can meet the needs of the system. Therefore, we only do the DR/BDS integrated navigation system positioning coordinate filtering of Kalman x-axis and y-axis. The equation is as follows:

\[
\begin{align*}
    x_k &= x_{k-1} + \Delta S_{k,k-1} \sin \theta_{k-1} + \Gamma_{(k,k-1)\chi} W_{(k-1)\chi} \ldots (a) \\
    y_k &= y_{k-1} + \Delta S_{k,k-1} \cos \theta_{k-1} + \Gamma_{(k,k-1)\psi} W_{(k-1)\psi} \ldots (b)
\end{align*}
\]  

\[
\begin{align*}
    Z_{x_k} &= x_k + V_{kkx} \ldots (a) \\
    Z_{y_k} &= y_k + V_{kky} \ldots (b)
\end{align*}
\]  

(7)  

(8)
Because the sampling interval time of the two data is very small, usually let $\theta_{k-1} \approx \theta_k$, we use $\theta_{k-1}$ to express the equivalent heading angle in the process of k-1 transition to K state. In the formula, $x_k$ and $y_k$ respectively refer to the coordinates of the target on two coordinate axes; $\theta_{k-1}$ refers to the control amount of k-1 state equivalent to the heading angle; $\Delta S_{kk-1}$ refers to the transfer control parameters in different stages; $W_{(k-1)x}$, $W_{(k-1)y}$ refers to the noise sequence in the course of the dead reckoning; $\Gamma_{(k-1)x}$, $\Gamma_{(k-1)y}$ refers to the noise input parameters in the course of the dead reckoning; $Z_{x_k}$ and $Z_{y_k}$ refer to the equivalent value of the coordinate measurement of the positioning point obtained from the laser ranging operation; $V_{kx}$ and $V_{ky}$ refer to the equivalent value of the noise sequence in the BDS measurement system.

5. Conclusion

At present, BDS navigation system has achieved great development, but it is still in the development stage. Today is the information age, and satellite navigation technology is the research hotspot of all countries in the world. Compared with the GPS system which has been perfected and operated for many years in the United States, the Beidou satellite navigation system in China is still short in appearance, and its service quality and positioning accuracy are not up to the quality and accuracy of the GPS system. How to further optimize the system through integrated navigation and how to select the right one The following aspects can be studied.

(1) The experimental conditions designed in this paper are more ideal, and many interferences are reduced artificially. In the actual use process, it will face the influence of complex weather, disordered electromagnetic environment and other external environment. In the future research, the system design must be more perfect to make the whole system more practical.

(2) From the simulation results, the RBF Kalman algorithm used in this paper can be applied to DR/BDS integrated navigation system, and the filtering accuracy is good, but the algorithm is only a kind of information fusion technology which is more suitable for integrated navigation at present, and its calculation is still large. In the future research, we can further improve the algorithm, reduce the amount of computation or propose a new and more appropriate algorithm to optimize the whole system.

(3) With the development of computer technology, we can also reduce the accumulated error of the system in the operation time and improve the operation speed by replacing the more advanced hardware environment.

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