A integrated Navigation Filtering Method Based on Wavelet Neural Network

Zhu Tao1, Saisai Gao2 and Ying Huang3

1Graduate Brigade, Engineering University of the Chinese People's Armed Police Force, Xi'an, China.
Email:375144587@qq.com
2Graduate Brigade, Engineering University of the Chinese People's Armed Police Force, Xi'an, China.
Email:804075883@qq.com
3Graduate Brigade, Engineering University of the Chinese People's Armed Police Force, Xi'an, China.
Email:375144587@qq.com

Abstract. Aiming at the problems of the difficulty to establish the model and the large data dimension for the traditional integrated navigation method, a method of using the wavelet neural network to directly predict the position and velocity error information is proposed. Get rid of the mathematical model establishment, avoid introducing new errors in the model establishment, and adopt multiple parallel networks to reduce the dimensionality of the data, which greatly reduces the amount of calculation. The Kalman filter is used as a reference for simulation experiment. The results show that the proposed method can effectively improve the accuracy and real-time performance of the integrated navigation system, and provides a new feasible path for combined navigation filtering.

1. Introduction

Integrated navigation of satellite and inertial navigation systems is currently the most widely used integrated navigation system[1-2]. The traditional integrated navigation method is to use the optimal estimation method of modern control theory to fuse the navigation parameters of two independent systems and correct the navigation output. The main methods are Kalman filtering as the model framework for various filtering algorithms[1]. These traditional filtering algorithms have problems in establishing mathematical models and the huge amount of computation affecting the real-time navigation.

Wavelet neural network is a research hotspot in recent years. It is a combination of wavelet theory and artificial neural network. It has powerful data analysis and nonlinear mapping functions. The application of wavelet neural network to integrated navigation has been studied, but only as an auxiliary means. The literature[3] uses wavelet neural network to assist in the establishment of Kalman filter model, and the literature [4] uses wavelet neural network to solve the system alignment problem, the literature[5] uses the wavelet analysis theory for noise reduction preprocessing, but can not fundamentally get rid of the problems of the traditional mathematical model.

In this regard, it is proposed to start from the perspective of signal processing, use the nonlinear prediction function of wavelet neural network, and build the wavelet neural network to train the solution data of the integrated navigation system, which can predict and correct the navigation parameter error of the next stage. It can get rid of the flaws of the mathematical model, have strong
nonlinear prediction and fault tolerance, improve the accuracy and timeliness of the navigation system, and can be well applied in integrated navigation.

2. Wavelet Neural Network

Wavelet neural network is a combination of wavelet theory and artificial neural network. It replaces the excitation function of the hidden layer of artificial neural network with the wavelet basis function of wavelet theory, so it has the multi-resolution layering feature of wavelet analysis in time-frequency space. At the same time, it has the powerful nonlinear fitting function of the neural network. Compared with BP neural network, the wavelet neural network has a simple and clear network structure design, and has a clear theoretical basis. The network training can avoid local convergence or non-convergence, which makes the wavelet neural network have a wide range of applications. and its network structure is shown in Figure 1.

![Wavelet neural network model](image)

**Figure 1.** Wavelet neural network model

2.1. Network Parameter Initialization

Assume that the number of input signal samples is \( q(1, 2, \ldots, n) \), the number of input layer nodes is \( I \), the number of hidden layer nodes is \( H \), and the number of output layer nodes is \( M \).

The number of input layer and output layer nodes is determined by the actual input and output. The number of hidden layer nodes of the wavelet neural network can be adaptively determined by experience or formulation.

2.2. Building Wavelet-based Function

Select a mother wavelet function in the Hilbert vector space to satisfy

\[
\int_{R} \left| \phi(w) \right|^2 \, dw < +\infty \quad (\phi(w) \text{ is the Fourier transformed by } \phi(t))
\]

The wavelet function base is generated by the expansion and translation transformation

\[
\phi_{a,b}(x) = \frac{1}{\sqrt{a}} \phi\left( \frac{x-b}{a} \right)
\]

Establish a wavelet neural network activation function and get the network output as

\[
y_k = \sum_{j=1}^{J} w_{2j} \phi\left( \frac{\sum_{i=1}^{I} w_{1i} x_i - b_j}{a_j} \right)
\]
2.3. Predicting Output and Correcting Weights

Input a training sample \( (p_k, t_k), k \in \{1, 2, \cdots N\} \) to the network after initialization, where \( N \) is the number of training samples, \( p_k \) is input signals for the network, \( t_k \) is output expected values for the network, calculate network output \( y_k \), according to

\[
E_k = \frac{1}{2} \sum_{k=1}^{K} (t_k^p - y_k^p)^2
\]

calculate the prediction error.

Wavelet neural networks generally use an improved gradient descent method. During training, the momentum term is added to the correction algorithm of weight and threshold, and the correction value of the previous step is used to smooth the learning path, avoiding falling into local minimum values and speeding up the learning.

3. Filter Method Design

In the design of the combined structure, the position and speed combination in the loose coupling mode is adopted, and the SINS is the main navigation system, the GPS is the auxiliary navigation system. The GPS navigation data is used to correct the SINS navigation parameters in real time.

When selecting the input of the network, the indirect filtering method is adopted, that is, the error amount of the navigation parameters of each subsystem of the integrated navigation system is used as the prediction object.

When using the output of the network, the feedback correction method is adopted, that is, the prediction of the network output is fed into the inertial navigation system, and directly input into the inertial mechanical programming equation to correct the navigation parameters.

In the structural design of the network, according to the required navigation parameters and their dimensions, two parallel wavelet neural networks are used to train the position and velocity error information respectively, and the number of input and output nodes of each network is 3, corresponding to the three dimensions of the data. The hidden layer of the network can satisfy the error condition by adaptively changing the number of cells. The number of hidden layer nodes in the network is 6. The wavelet basis function selects the function \( \psi \), and the expression is \( \psi(x) = \cos(1.75x) \exp(-x^2/2) \). The training algorithm uses an improved gradient descent method, which adds a momentum term to the weight and threshold correction algorithm.

The overall filtering design is shown in Figure 2.

![Figure 2. Scheme structure design](image-url)
In the training phase of the network, the SINS and GPS measured navigation data are first solved, and the position and velocity information of the SINS and GPS are obtained as the training sample set. Taking the difference between SINS and GPS navigation parameters as input, the actual error of SINS output position velocity information is the expected output, and the real output of the network is used as the prediction error of SINS. The mean square error of the output is minimized by a certain number of trainings.

In the prediction stage of the network, the difference between the SINS and the GPS navigation parameters is input to the trained wavelet neural network, and the output of the network is used as the error prediction value of the SINS at that time, and fed back to the mechanical equation of the inertial navigation system to correct the system navigation parameter.

4. Simulation analysis

The simulation experiment uses a nine-axis IMU module and a GPS receiver module. The accuracy of the gyro of the IMU module is 0.05°/s, the accelerometer accuracy is 0.01g, the positioning accuracy of the GPS module is 2.5m, and the speed measurement accuracy is 0.1m/s. Fix the two on the same platform and make a uniform reciprocating motion with a speed of 1m/s and a maximum distance of 0.5m along the east-west direction. The simulation time is 300s. Analyze the data obtained by the experiment, use the first 200s of data as the training sample to train the network according to the design scheme, input the data of the last 100s into the network to predict the SINS parameter error in the time, and feed the error back to the SINS to get the corrected SINS navigation. Parameters and compare them to real trajectories. In order to verify the superiority of the method, a reference experiment using Kalman filtering as a combined navigation filtering method was carried out.

![Figure 3. Comparison of corrected speed error of wavelet neural network](image-url)
Figure 4. Comparison of corrected position error of wavelet neural network

Figure 5. Kalman filter corrected speed error comparison chart
Figure 3 and Figure 4 show the comparison between SINS error and SINS error corrected by wavelet neural network. Figure 5 and Figure 6 show the error comparison between SINS error and Kalman filter combined navigation. According to its own characteristics, the positioning and velocity measurement errors of SINS accumulate over time, and the deviation from the real trajectory is getting larger and larger. However, the error corrected by the wavelet neural network and the error corrected by Kalman filter combined navigation are much smaller with time, and the error is much smaller than the SINS error. Table 1 is a comparison of the results of the position velocity mean square error.

Based on the above results analysis, the following conclusions are drawn:

1. Since the wavelet neural network avoids introducing new errors in the establishment of mathematical models, under the same experimental conditions, the prediction accuracy of wavelet neural networks is higher than that of Kalman filtering. At the same time, wavelet neural networks only target at position and velocity information to Predict, and the use of multiple parallel wavelet neural networks, is equivalent to the dimensionality reduction of the data, greatly reducing the amount of calculation, from the simulation time,witch can improve the real-time navigation.

2. The wavelet neural network can effectively predict and correct the navigation parameters and improve the accuracy of the integrated navigation. However, it can be seen from the simulation results that after the simulation, the corrected error value obviously has an upward trend, because the network is only for the first 200s. The data samples are trained, and their effectiveness decreases as the error of
the navigation parameters increases. Therefore, the method must update the data samples regularly to ensure the navigation accuracy.

5. Conclusion

In this paper, for the traditional integrated navigation method, it is difficult to establish the model and the data dimension is large. A method of nonlinear prediction of the position velocity error information after the solution is proposed by using the wavelet neural network, and multiple parallel networks are adopted. Dimensional processing of data, free from the ambiguity of mathematical models, with strong nonlinear prediction and fault tolerance. The Kalman filter is used as a reference for simulation experiments. The results show that the proposed method can effectively improve the accuracy and real-time performance of the integrated navigation system, and provides a new feasible path for combined navigation filtering. The shortcoming is that there is room for improvement in the learning algorithm of the network, and the update method and update speed of the network training samples need to be further determined.

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