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Time Delay Prediction based on Wavelet Algorithm and Elman Neural Network

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Abstract

Train network control requires accurate control of equipment, so it requires ultra-low delay and ultra-low packet loss rate. Therefore, this paper presents a train network control platform based on wireless control, and forecasts the delay generated in the platform. In view of the high sample entropy and difficult prediction of wireless network delay series, wavelet algorithm is used to decompose the delay series, and the prediction difficulty of each component is greatly reduced compared with the original sequence. Each component is predicted through Elman neural network, and then the predicted values of each component are superimposed to obtain the final prediction result. Comparing the simulation results with other algorithms, this method has high prediction accuracy.

Keywords

Wireless Control; Wavelet Decomposition; Neural Network; Delay Prediction.

1. Introduction

In recent years, wireless network technology has been widely used in many industrial fields. However, the existing wireless network is not designed for new industrial control. For example, the ultra-low delay required for the transmission of core control information in high-speed trains requires that the end-to-end delay in TRDP (train real time data protocol) protocol should be less than 10ms [1], but the existing wireless network is difficult to be fully applicable, The key to the application of wireless network control in these fields lies in the breakthrough of technology or the accurate prediction and compensation of time delay.

As a time series, time series can be processed by time series. At present, the prediction and analysis of time series mainly includes three directions: (1) regression modeling [2], the parameter solution process of the model is complex and is not suitable for the situation with large variation range; (2) Neural network algorithm [3] has the characteristics of nonlinear identification ability and fast operation speed, but it depends on the complexity and correlation of input data; (3) SVM method [4] has unique advantages for nonlinear, small samples and high-dimensional sequences, but the parameters are difficult to determine.

In this paper, a one-step prediction method based on db3 wavelet decomposition and Elman neural network is adopted for the time delay data generated by the train network control platform of wireless communication.

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2. Algorithm Theory

2.1 Mallat Algorithm

At present, the mainstream method of time series decomposition and reconstruction using wavelet function is Mallat algorithm, which is an algorithm proposed by Mallat on the basis of multi-resolution analysis in 1989 to realize the wavelet transform and inverse transform of signals through filter banks. Mallat algorithm adopts the method of two extraction, which shortens the decomposed subsequence to half of the original sequence, greatly reduces the calculation amount of wavelet transform, improves the calculation speed, and is conducive to real-time processing of a large amount of information [5]. The specific principle is: divide the original signal into high-frequency and low-frequency signals, and then decompose the low-frequency signals again to obtain new high-frequency and low-frequency signals, and so on until the requirements are met. The specific decomposition process [6]. is shown , see Fig. 1.

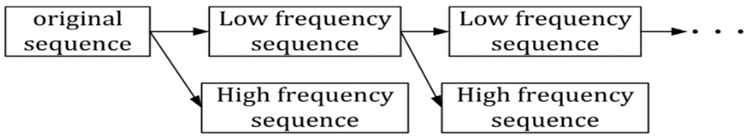

Fig. 1 Mallat algorithm decomposition process

In this prediction model, in order to avoid the cumulative error caused by multi-layer decomposition, three-layer decomposition is adopted in this paper, and the mother wavelet is db3 wavelet. After the signal is decomposed, its approximate component and detail component can be obtained, which can be expressed by formula (1).

$$\begin{cases} a_{j+1} = Ha_j \\ d_{j+1} = Ga_j \end{cases} \tag{1}$$

Where j = 1,2,3, J. H is low pass filter, G is high pass filter, a_ J is the approximate component of the signal decomposed to the j-th layer, D_ J is the detail component of the signal decomposed to layer J, and j represents the maximum number of decomposition layers.

2.2 Elman Neural Network

Elman neural network is an algorithm based on BP neural network structure [7], and compared with BP neural network, Elman neural network has feedback system, which makes Elman neural network have strong adaptability and can approach any function with any precision. The specific structure of Elman neural network is shown, see Fig. 2.

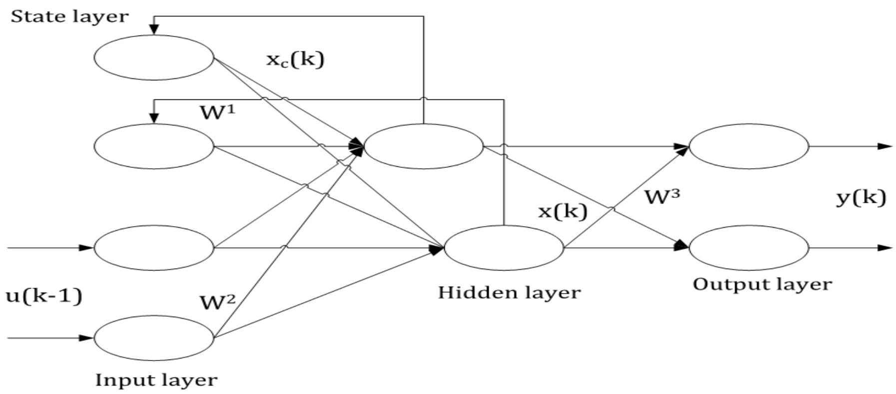

Fig. 2 Elman neural network structure

It can be seen from the structure diagram that Elman neural network is composed of input layer, hidden layer (middle layer), receiving layer and output layer, in which dimensional input vector; Is the dimension output vector; x_ C is the output vector of dimension receiving layer; Output vector for dimension hidden layer; W ^ 1 is the connection weight from the hidden layer to the receiving layer; W ^ 2 is the connection weight from the input layer to the hidden layer; W ^ 3 is the connection weight from the hidden layer to the output layer. The nonlinear state space expression of Elman neural network is shown in formula (2).

$$x(k) = f(w^2 u(k-1) + w^1 x_c(k)) \tag{2}$$

$$x_c(k) = x(k-1) \tag{3}$$

$$y(k) = g(w^3 x(k)) \tag{4}$$

Where, f is the neuron transfer function of the hidden layer, usually s function, and G is the neuron transfer function of the output layer, which is a linear combination of the outputs of the middle layer.

2.3 Proposed Method

In this paper, the network time delay prediction model first decomposes the original time delay sequence by wavelet to reduce the prediction difficulty of the model, then uses Elman neural network to predict each component respectively, and finally synthesizes all components to obtain the final prediction result. In order to reduce the prediction error and improve the operation speed, normalization processing is carried out in the input layer during simulation, The inverse normalization processing is performed in the output layer. The specific delay prediction steps are as follows:

Step 1: input the original time delay sequence, decompose the time delay sequence with db3 wavelet basis through formula (1) to obtain detail components D1, D2, D3 and approximate component A3.

Step 2: divide the data into training set and test set, and normalize the data.

Step 3: determine the structure of Elman neural network model, establish Elman neural network model, input the training set into the model, train according to formula (2) (3) (4), and inverse normalize the output data.

Step 4: input the test set into the trained model for prediction, and overlay the prediction results of each component to obtain the final prediction result.

3. Simulation and Result Analysis

In this paper, the delay data is obtained through the indoor train network control experimental platform based on wireless communication. The platform changes the traditional ECN network to wireless communication, uses the central AP as the etbn, and the terminal equipment is used in conjunction with the client. All equipment in the platform runs at 5.8GHz, and the delay data is obtained through screening by Wireshark packet capturing software. After processing the captured data, 1000 groups of delay data are obtained for simulation, of which the first 900 groups are used for training and the last 100 groups are used for verification. In order to further verify the complexity of the original delay series and each component, this paper uses the sample entropy as the standard to measure the complexity of the time series [8]. The greater the entropy, the higher the complexity of the time series and the greater the difficulty of prediction; The smaller the corresponding entropy, the lower the complexity of the time series and the less difficult the prediction is. After testing, the entropy value of the original time delay sequence is 2.3376, while the entropy values of D1, D2, D3 and A3 after wavelet decomposition are 1.5181, 1.1080, 0.7938 and 0.6681 respectively. Compared

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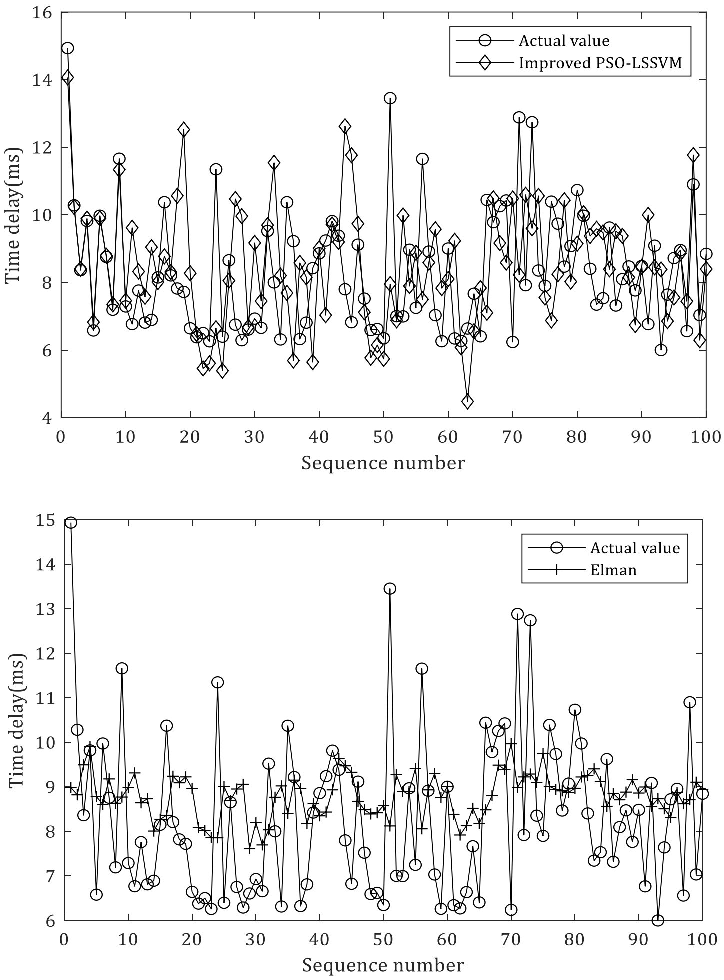
with the original time delay sequence, the entropy value is significantly reduced, so the prediction difficulty of the model after wavelet decomposition is indeed reduced. In Elman neural network training, the time delay of the first 10 times is used to predict the time delay of the next time. Therefore, in this paper, the number of input nodes of the neural network is 10, the number of output nodes is 1, and the number of hidden layer nodes is k = √ (2 & M + n) + X, which is a constant between 1 and 10, then the value range of K is [4,13], and each component is predicted 20 times under different values, After comparison, when the number of hidden layer nodes is 12, the error rate of each component is the lowest. Therefore, set the number of hidden layer nodes to 12, and the number of receiving layer nodes is the same as that of hidden layer, also set to 12 [9]. In this paper, mean square error (MSE) is used as the standard to measure the prediction accuracy. According to the above settings, each component is predicted respectively. The MSEs corresponding to D1, D2, D3 and A3 are 0.4654, 0.0711, 0.0324 and 0.0242 respectively. Compared with the sample entropy, it is consistent with the theory that the lower the entropy value, the less difficult the prediction is.

In order to compare the prediction performance of this method, as a comparison, this paper selects the improved PSO-LSSVM prediction model proposed in reference [10], the population size is set to 30 and the evolutionary algebra is 200; The emd-lssvm model in reference [11] is selected, the embedding dimension is 10, and the LSSVM parameters are automatically selected by particle swarm optimization algorithm when predicting each component; At the same time, Elman model without wavelet decomposition is selected for prediction [12]. The prediction results are shown, see Fig. 3. And the MSE of each method is shown , see Table 1.



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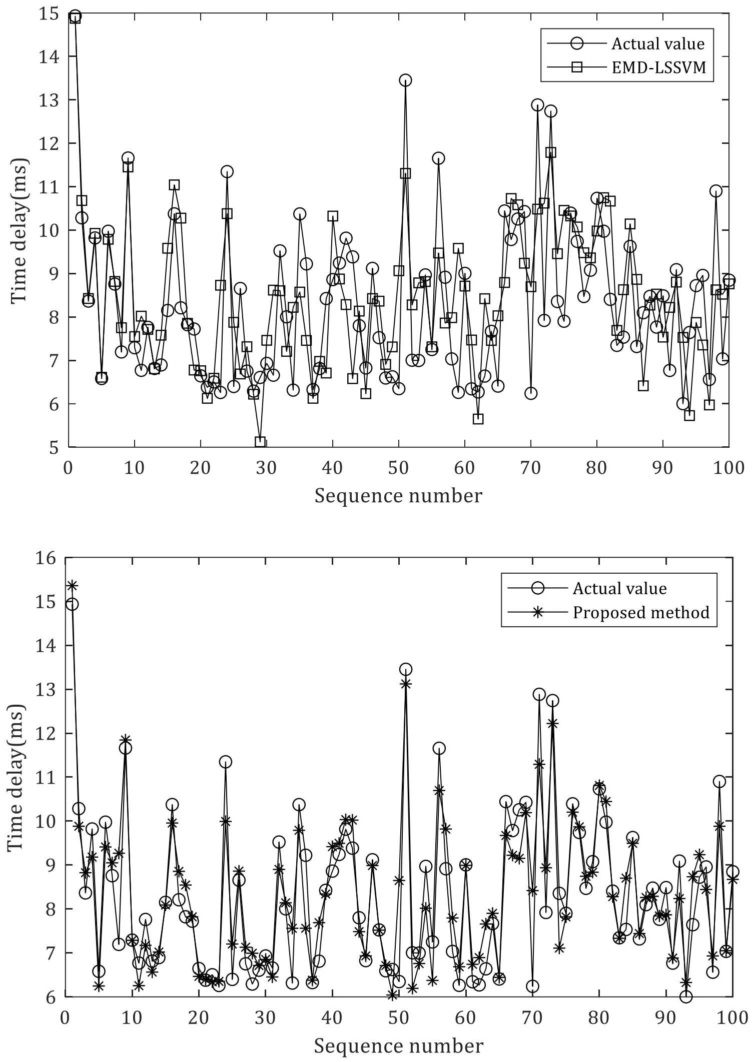

Fig. 3 Comparison between predicted value and actual value of each method

Table 1. MSE comparison of various methods

Prediction method	MSE
Improved PSO-LSSVM	4.4410
Elman	3.6549
EMD-LSSVM	1.6948
Proposed method	0.4835

It can be seen from table 1 that the prediction accuracy of this method is higher than that of other algorithms. It is difficult to fit the data directly for the non decomposed data, whether LSSVM model or Elman neural network model is used, and the sample entropy of the time-delay data is significantly reduced after decomposition, thus reducing the difficulty of sequence prediction. Compared with wavelet decomposition, the sample entropy of high-frequency components after EMD decomposition is still large. Although it can reduce the prediction difficulty to a certain extent, the prediction difficulty of high-frequency components is still large, resulting in low prediction accuracy.

4. Conclusion

For this experimental platform, after wavelet decomposition of the original time delay series, Elman neural network is used to predict each component respectively. Finally, the predicted values of each component are superimposed to obtain the final prediction results, which successfully reduces the difficulty of model prediction. The simulation results show that the prediction accuracy of this prediction method is high.

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