Prediction of Solid Propellant Characteristic Signal Based on Improved BP Network

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Abstract. The hidden layer node self-generating and adjusting method combining the improved BP neural network model is used to predict the solid propellant characteristic signal, the simulation result declares this method can overcome the "over-fitting" shortcoming.

Introduction

The experimental design is an important design method of solid propellant and formula optimization performance, some network experiment based on simulation application of neural computing literature also in the field of related research and achieved certain results, but for the simulation of solid propellant characteristic signal prediction has been seen publicly reported. The reference [1] used BP neural network simulation of combustion performance of composite solid propellant. The reference [2] introduced the neural network model, multi model composite flame combustion model and evaluation of the advantages and disadvantages. The reference [3] used genetic neural network NEPE high to simulate high pressure solid propellant combustion performance. The reference [4] used different neural network model in the burning temperature and burning rate prediction calculation analysis.

The generation process of solid propellant characteristic signal involves multiphase and complex physical and chemical reactions. There are no definite theoretical calculation models for prediction of some characteristic signals, the prediction of solid propellant characteristic signal by using experimental design simply takes a long time and costs a lot. In particular, the error back propagation (BP) algorithm is applied to the prediction of the characteristic signal of solid propellant. The adjustment method and the hidden layer nodes self-generation method combining weights is used to overcome these shortcomings, realize the simulation calculation of solid propellant characteristic signal prediction.

Establishment and Verification of Improved BP Neural Network Prediction Model

The Kosmogorov theorem shows that for a three layer BP neural network, as long as the structure is reasonable and the weight is appropriate, any continuous function can be approximated with any precision. But when the number of hidden neurons over time, in the process of training network, too many memories of training sample set in detail, the network error is very small, the sample data for the validation set error will be very big, the lack of predictive power, over-fitting.

Algorithm Improvement

The basic idea of the adjustment method is to adjust the error function by adding the weight value and the mean square item of the threshold value, such as formula (1).

\[ E = \alpha \cdot E_s + (1 - \alpha) \cdot E_u \]  

In the equation,
In the equation, \( E \) is the error function for the network, \( E_r \) is mean square error, \( E_n \) is mean square value of the threshold, \( \alpha \) is ratio coefficient, \( i \) is the expected output value for the calculation of the output neurons, \( o_i \) is the value is the number of neurons, \( N \) is the neurons number in the corresponding layer, \( w_i \) is the weight of the network, \( b_j \) is the network threshold, \( n_w \) is the weight number, \( n_b \) is threshold number, \( \text{rand1}, \text{rand2}, \cdots, \text{rand}_{n_w+n_b} \) are random numbers.

The equation (1) makes the network get smaller weights and thresholds, making the network more smooth and overcoming the goal of over-fitting. The choice is more critical. The larger the network is over fitting phenomenon, the smaller the network is, it cannot train normally, so this paper takes the average of multiple random numbers as a proportional coefficient.

The basic idea of hidden node self-generating: firstly, with only one hidden layer neuron network; in the training process, when the error rate is less than a threshold, and the error of the validation sample reaches the minimum when the network increases a neuron; minimum when the error of the validation sample increase in neurons after reduction instead of increasing, stop training or network error function value reaches the target error, and save the current best network structure.

In this paper, we combine the adjustment method with the hidden layer node self-generation method to improve the BP neural network. The error function in the adjustment method is used to replace the error function in the hidden layer node self-generation method.

Figure 1. The flow chart of establishment and training of network model.

The general steps are as follows:
Step1: set the network parameters and normalize all the input data.
Step2: the normalized sample data is divided into training sample data and validation sample data.
Step3: the hidden node self-generating set and training network, as shown in figure 1;
Step4: the obtained neural network model is preserved, and the sample data is normalized to verify the prediction ability and the accuracy of the solution.
Step5: apply to the actual problem forecast, carry on the forecast result analysis;
Model Establishment and Verification

The [5] gives the experimental data of 7 groups of a formula of solid propellant and 4 band maximum infrared radiation energy, propellant composition: aluminum content is 1%~18%, oxidant concentration is 70%~87%, the burning rate of mass fraction of catalyst is 0~1.7%, explosive mass fraction of 0~10.2%, as the 4 input parameters network, maximum infrared radiation band can select the 1.29~2.0 value as the output parameter of the network, and then using the method of BP neural network model is established between the groups and the MATLAB formula based on infrared radiation.

The model is established and its prediction ability and accuracy are verified. This paper selects the BP network, hidden layer node self-generating BP network, BP network adjustment method and the method proposed in this paper for comparison, verify it’s in overcoming the problem of over-fitting and improve the predictive ability of the advantages of network. In order to avoid accidental, the sample data of 4 independent networks were trained 20 times with the training set, every time after the training, all save 4 network models, each computing network training sample mean square error and mean square error validation sample and record the operation time, table 1 gives 4 kinds of network training 20 training sample mean square error, the mean operation time mean and validation sample mean square error mean, mean operation time. The input data of 7 sets of experimental data are input into the BP neural network model established by this method to calculate the maximum infrared radiation energy of the output, compared with the experimental data of the corresponding maximum infrared radiation energy value, and the relative error of the network simulation calculation value is calculated, as shown in Figure 2.

Table 1. The validation of network predictive ability.

<table>
<thead>
<tr>
<th>algorithm</th>
<th>approximation of training sample</th>
<th>prediction of validation sample</th>
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<tbody>
<tr>
<td></td>
<td>mean value of mean square error</td>
<td>mean value of mean square error</td>
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<tr>
<td>presented method</td>
<td>5.70</td>
<td>5.73</td>
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<tr>
<td>adjustment method</td>
<td>5.72</td>
<td>6.23</td>
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<tr>
<td>self generating method of hidden node</td>
<td>5.78</td>
<td>6.58</td>
</tr>
<tr>
<td>BP model</td>
<td>5.63</td>
<td>15.59</td>
</tr>
</tbody>
</table>

Table 1 shows the 4 network approximation to the training sample level roughly the same, however for the verification of these samples did not participate in the training of the new sample, the BP neural network with the maximum mean square error, and the training sample is large, have a great deviation, there is a clear "over-fitting" phenomenon, this method compared with the mean minimum mean square error, and the training samples are basically the same, with predictive ability, overcomes the problem of over-fitting, but its running time than the other 3 networks are large, which is caused by the network structure and the operation process of the complex, if this method is extended to have more experimental data and more complex performance prediction, the time cost is likely to be more significant.

Figure 2. The simulation results vs experimental data.
From Figure 2, we can see that the simulation data of 7 sets of data input samples are closer to the experimental data, and the relative errors are within 10%, which meet the requirements of the maximum permissible error. The BP neural network model established in this paper can be used to predict the change rule of propellant characteristic signals.

**Prediction of Characteristic Signal of Solid Propellant**

The BP neural network model established in this paper is used to simulate the infrared radiation characteristics and microwave attenuation characteristics of propellants respectively, and predict its variation with the mass fraction of propellant formula, as shown in Figure 3 and Figure 4. When the microwave attenuation law is estimated, the theoretical value obtained by its theoretical formula is compared with the simulated calculation value of the method in this paper, such as formula (2).

\[ A_{w} = 0.1748 \cdot e^{0.309 \cdot x_{Al}} \]  

(2)

Among them, \( A_{w} \) is the microwave attenuation value, \( x_{Al} \) is the mass fraction of aluminum powder.

Figure 3. The effect of the composition of a certain solid propellant on infrared radiation.

Figure 3 (a) is the effect of aluminum powder on infrared radiation under the condition of different oxidizing agents. The burning rate catalyst and explosive concentration was 0, when the mass fraction of oxidant is certain, the maximum infrared radiation energy with the aluminum content increased and decreased when the aluminum content when the mass fraction of oxidant is larger, the maximum infrared radiation value is bigger. Under certain conditions, the greater the ratio of the mass fraction of the oxidant to the mass fraction of the aluminum powder, the more the generation and the more the molecules, and the more the more the molecules are. The sum is the main source of infrared radiation. No more consideration is given to post combustion phenomenon of plumes. The more neutralization of combustion products, the stronger infrared radiation. Figure 3(b) is the influence of burning rate catalyst on infrared radiation. The mass fraction of aluminum powder is 1%, the oxidizer mass fraction is 70%, and the explosive mass fraction is 0. When the burning rate catalyst mass fraction increases, the maximum infrared radiation energy will increase. Figure 3(c) is the influence of explosives on infrared radiation. The mass fraction of aluminum powder is 1%, the mass fraction of oxidant is 70%, and the mass fraction of burning rate catalyst is 0. When the mass fraction of explosive increases, the maximum infrared radiation energy increases.

Figure 4. The effect of aluminum powder on microwave attenuation in polyether/NE/RDX/AP/Al.
From Figure 4, we can see that the simulated value of microwave attenuation of propellant is approximately the same as the theoretical value of formula (2), and it increases exponentially with the increase of mass fraction of aluminum powder.

Conclusion

(1) Combined with the predictive ability this method is better than the BP network model. BP network model for single hidden layer node self-generating and adjustment method of the BP neural network model, which combines the hidden layer node self-generating and adjusting method of BP neural network model for simulation of data input is closer to the experimental data, the relative errors are less than 10%, so it can be used for prediction of solid propellant characteristic signal.

(2) The combination of hidden node self-establishing BP neural network model method and adjustment method of the infrared radiation characteristics of solid propellant and microwave attenuation characteristics were estimated, the results of numerical simulation theory and the theoretical value is consistent, demonstrate the feasibility of this method.

(3) The use of powerful nonlinear mapping ability of BP neural network prediction of propellant composition directly influences on the characteristics of the signal, avoiding the complex mechanism and process characteristic analysis of signal generation, to a certain extent, improve the efficiency, but because of the small sample and the uneven distribution, there is a big gap between the simulation results of characteristic signal with the true value, the next step is to further design and experimental adjustment algorithm.

Reference


