Research on the material fire risk index based on the GA-BP neural network

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Abstract. To improve the material fire risk index (IFHI) forecast precision and accuracy, we raise a way that the prediction model consists of the genetic algorithm (GA) and BP neural network. There are many merits in this model. For example, the weights and thresholds of BP neural networks can be improved by the advantages that the genetic algorithm can reach the peak of the forecasting accuracy of the whole situation. And we pose MSE, MAE, and MAPE to measure the effectiveness. The result of MSE, MAE, and MAPE is 0.005843, 0.0183, 1.08158. The experimental results show that the IFHI of the polymer can be accurately predicted by GA-BP neural networks.

Keywords: IFHI of the polymer, GA-BP hybrid algorithm, prediction model.

1. Introduction
The fire risk index is an important index to measure the fire risk of materials. Prediction of IFHI of different types of materials is an important means to improve the fire safety of buildings. In the book, Fire Risk of Polymer Materials written by Xu Xiaonan, Shu Zhongjun, et al. The IFHI value of polymers [1] is calculated by constructing a matrix. Parameter of the matrix can be get by small-scale experiments. In the book, the numerical value, meaning, and analysis of each parameter of IFHI are introduced in detail. First, the method of analytic hierarchy process (AHP) is that compare each parameter, get the important index of the parameter, and then build a judgment matrix, calculate the weight of each parameter, vector bias value, and finally get IFHI. There are many disadvantages When we construct the judgment matrix in the way of analytic hierarchy such as complex methods to obtain eigenvalues and eigenvectors, too many measurement indexes, large data statistics, and the difficult way of getting weight. Therefore, the process of IFHI calculation is complicated and cumbersome. BP neural network [2] is a kind similar to the neurons in the brain of the nonlinear uncertainty in intelligent learning model, the learning way is that passing the nonlinear function of multilayer feedforward neural network and error backpropagation adjust method of multiple parameters of network internal network model, and the minimum mean square error (MSE) into the target continuously modify the network weights and threshold, finally construct the target data accuracy prediction. BP neural network has good adaptive learning ability and is able to reach specific accuracy in approximate nonlinear functions. But there is a difficulty in seeking the optional solution when predicting the IFHI by the BP neural network. When BP neural network is faced with a large search space, the algorithm will fall into the local minimum point, which will affect the accuracy and speed of prediction.
Genetic algorithm (GA) [3] draws on Darwin's biological evolution theory and is an adaptive optimization method that the principle is biological evolution in nature. Through the calculation of fitness function, the genetic algorithm selects, crosses, and mutates the population to improve the way of search direction. Genetic algorithms can also show a good data fitting effect when the population size is large. The GA can reach the best position in multiple regions of the global space, and overcome the shortcoming of local search of BP neural network. In this paper, the GA-BP algorithm is composed of background propagation and Genetic algorithm. When the neural network is initialized, the weight and threshold will be in the best position by the way of genetic algorithm. Finally, the optimal neural network is used to train and predict the IFHI sequence.

2. GA-BP algorithm process

2.1. BP neural network

The model of BP neural network based on background propagation algorithm and multi-layer perceptron to construct neural network. self-organizing learning ability and nonlinear mapping between input data and output data are the base of BP neural network. The disjunct layers are composed of input layer, hidden layer, and output layer. But the layer interacts each other by the function of mapping. Input layers and the dimension of the parameter are closed related. [4]. In practice, the parameters that affect the IFHI value can be divided into thermal hazard parameters and flue gas hazard parameters. Thermal risk parameters are divided into light time (TTI, from material surface heat to the surface used during combustion in duration), heat release rate (HRR, the material is lit, the heat release rate per unit area), effective heat of combustion (EHC, measured by the ratio of the heat release rate and mass loss rate), mass loss rate (MLR, burning sample quality over time and the rate of change in the process of combustion). Smoke hazard parameters include the Yield of carbon monoxide and carbon dioxide (CO Yield, CO2 Yield) and specific extinction area (SEA, smoke produced by volatile unit mass material). So, we adopt 8 nodes as the input layer nodes and 1 node as the output layer node in this paper. BP neural network’s process is bifurcated. The one is input signal forward propagation. Another is error signal backpropagation to achieve training fitting. The first process is the samples from the input layer through to the output layer through all the hidden layers. The second step is the output layer on the comparison to the current input and expected output if meet the requirement of error. finally, if not satisfied in the process of backpropagation: backpropagation, returns the error signal, and each layer of the weights and threshold of each neuron modification are adjusted. The neural network topology structure predicted by IFHI is shown in Figure1.

![BP neural network model](image)

**Figure 1. IFHI prediction neural network topology.**

However, strong robustness and fault tolerance are features of BP neural network. Method of BP neural network model is the conjugate gradient steepest descent method and takes the error square as the objective function, so the following problems [5] inevitably are falling into the local minimum value, the slow convergence speed. To avoid the above problems when BP neural network is predicting IFHI
data, in the article, the method of GA-BP hybrid algorithm is adapted. When GA-BP neural networks are constructed, the input data parameter predicts IFHI.

2.2. The GA algorithm
Genetic algorithm (GA) is based on the evolutionary theory of nature's "survival of the fittest" principle. The optimization of the population is achieved after the selection, crossover, and mutation of the population. Individuals with a good gene have a high probability of being survived, whereas individuals with a poor gene have difficulties surviving. The crossover results in a new generation of individuals who not only inherit the information of the previous generation but are also a better fit than the previous generation. In this way, after several generations of cycles, the individual finally produced meets the conditions of approaching the optimal solution. The genetic algorithm mainly includes three steps: selection, crossover, and mutation.

2.3. GA-BP algorithm model construction
BP neural network searches for the best point in contrast to the whole, but the characteristic of the genetic algorithm is global search. So, when constructing the model, seek the optimal solution range at the beginning of the initial weight and threshold of the matrix-vector by the genetic algorithm first, and then search the local optimal solution by BP neural network algorithm [6]. The calculated process of the GA-BP hybrid algorithm is as follows: 1. Expression of the chromosome, namely coding. 2. Solving individual fitness. 3. Genetic operation.

3. Experimental testing

3.1. Evaluation criteria
To measure the prediction effect of the GA-BP neural network model on IFHI value, three error measurement functions, MSE, MAE, and MAPE are used to represent the degree of dispersion between the predicted value and actual value. MSE is the network mean error between the predicted value and actual value. MAE represents the absolute error between two sets of data, reflecting the difference between the predicted data and the actual value; MAPE represents the average absolute percentage error between data, which can measure the degree of superiority of a model. When the result of MAPE is greater than 100%, it proves that the model is poor. The closer it is to zero, the better the prediction effect of the model is. The calculation functions of the three evaluations are 1, 2, and 3, respectively. In the formula N represents the total number of groups; \( \hat{y} = \{\hat{y}_1, \hat{y}_2, ..., \hat{y}_N\} \) represents the forecast sequence, the column \( \hat{y}_N \) representative prediction of N sets of data; \( y = \{y_1, y_2, ..., y_N\} \) represents the actual sequence, and \( y_N \) represents the actual NTH group of data.

\[
MSE = \frac{1}{N} \sum_{t=1}^{N} (\hat{y}_t - y_t)^2 \tag{1}
\]

\[
MAE = \frac{1}{N} \sum_{t=1}^{N} |\hat{y}_t - y_t| \tag{2}
\]

\[
MAPE = \frac{100}{N} \sum_{t=1}^{N} \left| \frac{\hat{y}_t - y_t}{y_t} \right| \tag{3}
\]
3.2. Prediction Simulation

Seven materials are included in the 78 groups of IFHI characteristic data selected in this experiment. According to the construction and prediction principle of the neural network, the IFHI characteristic data of 6 substances (a total of 72 groups) were selected as the training data of GA-BP neural network construction, and the characteristic data of the remaining group of substances were used as the prediction data (a total of 6 groups). The GA-BP neural network was constructed by multiple simulation training, and the parameters of the GA-BP neural network were shown in Table 1.

| Neural network algorithm | Number of training data sets | Number of predicted data sets | Chromosome coding length | Evolutionary algebra | Number of training iterations | Hidden layer number | The learning efficiency | The training error |
|--------------------------|-----------------------------|-------------------------------|--------------------------|---------------------|----------------------------|---------------------|----------------------|-------------------|
| GA-BP                    | 72                          | 6                             | 151                      | 100                 | 5000                       | 15                  | 0.01                 | 0.0001             |

The GA-BP neural network model is designed with a three-layer network structure, and the Map-Minmax function is adapted to standard the data. The population size of the GA algorithm species is 50, and the code length of the GA algorithm is 151 by initializing the fit population. The comparison diagram and fitting curve of actual data and predicted data in the training process are shown in Figure 2.

![Figure 2. Contrast prediction and reality for constructing.](image)

3.3. Analysis of experimental results

The GA-BP neural network model was used to predict IFHI by 8 experimental parameters. The predicted value was compared with the actual value and the error data table was calculated. Three index functions are used to show the quality of the actual prediction effect and the degree of the model. MSE, MAE, and MAPE of the model were calculated by the predicted values, and the results were MSE=0.005843, MAE=0.0183, and MAPE=1.08158. These three indicators indicate that the predicted effect is close to
the test results. At the same time, the closer MAPE is to 0, the more perfect the model is, while the more than 100 indicates that the model is inferior. Therefore, according to MSE, MAE, and MAPE, it can be seen that this model is close to the perfect model, which can perfectly predict the IFHI of the polymer. Figure 3 is a comparison of the predicted and actual values of the model graph. The predicted value, actual value, and error percentage are shown in Table 2.

![Figure 3](image-url)  
**Figure 3.** Contrast prediction and reality for the test.

| Number | Test data | Predict data | Absolute error | Percentage error |
|--------|-----------|--------------|----------------|------------------|
| 73     | 1.800     | 1.7400       | 0.0600         | 3.333            |
| 74     | 1.800     | 1.7986       | 0.0014         | 0.077            |
| 75     | 1.800     | 1.7997       | 0.0003         | 0.018            |
| 76     | 1.400     | 1.4009       | 0.0009         | 0.065            |
| 77     | 1.500     | 1.4527       | 0.0473         | 3.154            |
| 78     | 1.800     | 1.8001       | 0.0001         | 0.0004           |

**4. Conclusions**

In the article, the GA-BP hybrid algorithm and network model are constructed to solve the problem of the lack of optimization in the BP neural network model. GA algorithm is adopted to optimize the network weight and threshold of the matrix in the BP neural network. By the way of initializing the population, the GA algorithm carries out genetic coding, hybridization, and evolution on the data of the BP neural network to strengthen the local random searchability of the BP neural network and avoid the trap of local minimum value. The results of IFHI prediction and three evaluation indexes (MSE, MAE, MAPE) of the IFHI test show that GA-BP neural network model can calculate the IFHI value of polymer well, with low prediction error and high accuracy.

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