Application Research of BP Neural Network Optimization Based on Firefly Algorithm

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Abstract. Aiming at the problems of low prediction accuracy and premature convergence of traditional BP network prediction models, firefly algorithm FA is introduced into BP neural network model to optimize the optimization process of neural network weights and thresholds. This paper presents a BP neural network prediction model based on firefly algorithm. Taking Fujian port throughput data as an example, the application verification and comparative analysis of the improved prediction algorithm are carried out. The experimental results show that the improved FA-BP prediction algorithm has better performance in prediction accuracy and stability.

Keywords: Firefly algorithm, BP neural network, prediction algorithm, weight threshold optimization.

1. Introduction
The structure of BP neural network and the weights and thresholds between neural nodes have a great impact on the prediction performance of neural network, which restricts the accuracy and stability of the prediction model to a certain extent. To solve this problem, scholars at home and abroad put forward a series of optimization methods. Ma Chuang-tao et al. introduced fireworks algorithm into neural network model, they used the mechanism of simultaneous explosion and diffusion of fireworks explosion operator to optimize the optimization process of weight and threshold, and created a prediction model based on Improved BP neural network based on fireworks algorithm [1]. Wang Ying-li et al. proposed a short-term photovoltaic power generation prediction method based on GA-BP neural network based on improved MIV algorithm to analyze the internal and external correlation degree of variables and improve the prediction accuracy [2]. Zong Kai et al. optimized the BP network by using genetic algorithm [3], which greatly reduced the training time and iteration times. Li Huan et al. optimized the input weight and threshold of LM-BP neural network model using mind evolutionary algorithm (MEA) [4], which enhanced the forecast accuracy and a new optimization route is provided. The existing research mainly focuses on using genetic algorithm, swarm intelligence algorithm and other methods to optimize BP neural network.

In this paper, the firefly algorithm (FA) is introduced into the traditional BP neural network model to optimize the weight and threshold value of BP neural network by taking advantage of the advantages of firefly algorithm, such as less parameters and high stability [5], combined with the BP
neural network’s nonlinear fitting ability, a prediction model based on BP neural network optimized by firefly algorithm is constructed to solve the problems of low accuracy and easy to sink into local optimum of traditional BP prediction model.

2. Introduction of BP neural network and firefly algorithm

2.1. BP neural network
Back propagation neural network (BPNN) is a classic neural network that is widely used [6]. Its output adopts forward propagation and error adopts back propagation. The topological structure of the network model generally includes input, hidden and output layers. Neurons between layers are fully linked, but neurons between the same layer are not linked. In BP network, data propagates back layer by layer from input layer through hidden layer. When training the weights of BP network, the connection weights of the network are corrected layer by layer from the output layer through the middle layer along the direction of reducing the error [7]. By constantly updating the weight and threshold to solve the optimization problem, with the continuous learning, the final error is smaller and smaller. BP neural network has the merits of self-learning, self-adaptive, strong robustness and strong nonlinear approximation ability [8].

2.2. Firefly algorithm
Firefly algorithm (FA) is a kind of bionic swarm intelligence optimization algorithm. The main idea of bionic swarm intelligence optimization algorithm is a random search method constructed by studying the social behavior of imitating the life of biological groups in nature [9]. Experimental results show that FA model has higher global optimization success rate and higher efficiency than other intelligent algorithms such as genetic algorithm. The optimization principle of firefly algorithm is as follows: each point in the space is regarded as fireflies, and the population of fireflies is randomly dispersed. Taking advantage of the characteristics that fireflies with large luminosity attract fireflies with small luminosity, in the process of the Firefly with weak luminosity moving to the one with strong luminosity, the updating iteration of position is completed, so as to find the optimal position, that is to say, the process of finding the optimal solution is completed. The parameters involved in the algorithm include population size, iteration times, random step size, attractiveness and light intensity absorption coefficient. The flow of the algorithm is as follows:

(1) Set initial parameters. Set the number of fireflies n and the maximum attraction $\beta_0$, light intensity absorption coefficient $\gamma$, step factor $\alpha$ and maximum iteration number MaxGeneration or search accuracy $\varepsilon$.

(2) The position of the firefly population is initialized, and the random factor is introduced to make it randomly distributed in the solution space. The objective function value of firefly is calculated, and the value obtained is taken as its maximum brightness $I_0$.

(3) The relative brightness $I$ and attraction $\beta$ of the firefly population were calculated.

$$I = I_0 e^{-\gamma r_i} \quad (1)$$

$$\beta(r) = \beta_0 e^{-\gamma r_i} \quad (2)$$

Where: $I_0$ is the objective function values of each individual firefly, that is, the maximum brightness; $r_i$ is the spatial distance between firefly $i$ and firefly $j$; $\gamma$ is the light intensity absorption coefficient; $\beta_0$ is the maximum attraction.

(4) According to the relative brightness, the moving direction of the firefly is determined, the position of the firefly is updated, and the updated position is calculated according to formula (3).
\[ x_i = x_i + \beta(x_j - x_i) + \alpha(\text{rand} - 0.5) \] (3)

Where: \(x_i, x_j\) is the spatial position of firefly \(i\) and \(j\); \(\alpha\) is the step factor and is a constant on \([0,1]\); \(\beta\) has the same meaning as above. \(\text{rand}\) is a random factor, which increases the search range and avoids entering the local optimum in the early stage.

(5) In the updated position, recalculate the brightness of the firefly. When the number of iterations is not reached, the number of searches is accumulated once, and the third step is carried out to move the new position. When the number of iterations is reached, the movement ends and the global extremum and the optimal individual values are output.

3. Design of FA-BP network and construction of prediction model

3.1. Design of BP network based on firefly algorithm

The weights and thresholds of BP neural network are the key factors affecting the prediction performance of BP neural network model. Due to the limitation of the gradient decomposition method in searching the optimal solution, BP model is easily to appear "premature convergence" phenomenon, so it cannot get the global optimal solution. Firefly algorithm is less dependent on parameters, it can better avoid convergence to local optimal solution, and has stronger ability to explore new space [10]. In FA model, the objective function is regarded as the fitness function, and each firefly contains all the weight values and thresholds. The firefly algorithm is used to optimize the weights and thresholds of the general BP neural network, and the optimal initial weights and thresholds are obtained to construct the BP neural network, so as to improve the generalization performance and search accuracy of the neural network. Figure 1 shows the flow chart of the optimization algorithm.

![Flow chart of throughput index prediction based on BP neural network optimized by firefly algorithm.](image)

In this study, \(X = [x_1, x_2, x_d]\) represents a set of parameters to be optimized. The weights and thresholds of the neural network constitute each dimension of the parameters. The number of neurons in each layer of neural network determines the length of individual coding. If \(\text{inputnum}\) is the number of input layer neurons, \(\text{hidddenum}\) is the number of hidden layer neurons, and \(\text{outputnum}\) is the number of output layer neurons, then the individual coding length is \(d = \text{inputnum} \times \text{hidddenum} + \text{hidddenum} + \text{hidddenum} \times \text{outputnum} + \text{outputnum}\).

The objective function is:

\[ \frac{1}{\sum(y_i - y_n)^2} \] (4)
Where: yi is the expected value of data and yn is the actual output value of the network.

When the iteration times meet the set conditions, the FA model outputs the optimal solution x. The optimal solution is used to update the weights and thresholds of the network. The optimal initial threshold weights are assigned to the network prediction by using formulas (5) to (8).

\[
\text{net.iw}(1,1) = \text{reshape}(W1, \text{hidden num}, \text{input num})
\]

\[
\text{net.lw}(2,1) = \text{reshape}(W2, \text{output num}, \text{hidden num})
\]

\[
\text{net.b}(1) = \text{reshape}(B1, \text{hidden num}, 1)
\]

\[
\text{net.b}(2) = B2
\]

Where, W1 and W2 are the weight matrix extracted from the optimal solution x according to the network structure parameters; B1 and B2 are the threshold matrices extracted from the optimal solution x.

3.2. Model construction

In this paper, the prediction model based on FA-BP neural network is adopted, taking MATLAB software as the experimental platform, and taking the cargo throughput of statistical yearbook as an example, a prediction model of port throughput index based on FA-BP algorithm is established. The main procedures are as follows:

(1) Select input and output values. The cargo throughput of Fuzhou port, Xiamen port, Quanzhou port, Ningde port, Meizhou Bay Port and Zhangzhou Port in Fujian Province is taken as the input value of the network prediction model, and the total throughput index is selected as the output value of the network prediction model.

(2) Normalization treatment. The purpose of normalization is to prevent the difference of order of magnitude between each dimension of data, in order to improve model accuracy. In this study, the data were standardized.

\[
X^* = \frac{x_k - \min(X)}{\max(X) - \min(X)}
\]

Where: max (X) is the maximum value in the data set, min (X) is the minimum value in the data set. After standardization, the data is distributed in [0, 1].

(3) Set parameters. The main parameters of BP neural network are assigned. The number of nodes in input layer is set as 6 and the number of nodes in output layer is set as 1. Based on the experience and model testing, this paper selects the number of hidden layer nodes of BP network as 3. The maximum training times is 200, learning rate is 0.1, and the training target value is 0.00001. Secondly, the population number of fireflies is 20, the number of iterations is 50, the step factor is 0.25, and the maximum attraction is 0.2, and the light intensity absorption coefficient is 1.

4. Simulation results and analysis

In order to verify the effectiveness of the BP network model based on the firefly algorithm, according to the statistical yearbook issued by Fujian Provincial Bureau of statistics, the cargo throughput and total throughput index of Fujian coastal ports are selected, and the prediction model based on FA-BP network is tested and compared with the model before optimization.

The experimental data were standardized, and training data group and test data group were set up respectively. The throughput capacity indexes of Fujian Province from 2000 to 2010 in the statistical
yearbook were taken as 11 experimental samples, numbered 1 to 11. The experimental data sets were trained and tested before and after optimization. Before optimization, the traditional BP neural network model was used. After optimization, the BP neural network model based on firefly algorithm was used. 9 to 11 groups of samples were used for the test, and the table below shows the comparison between the predicted values and the experimental values. Table 1 displays the comparison of prediction results between BP algorithm and FA-BP algorithm.

**Table 1. Comparison of prediction results between BP algorithm and FA-BP algorithm.**

| Sample number | Actual value | Predicted value of BP | Predicted value of FA-BP | Absolute error of BP | Absolute error of FA-BP | Relative error of BP ($10^{-5}$) | Relative error of FA-BP ($10^{-5}$) |
|---------------|--------------|-----------------------|-------------------------|----------------------|-------------------------|-----------------------------------|-----------------------------------|
| 9             | 8.1025       | 7.6226                | 8.1030                  | 0.4799               | 0.0005                  | 5922.8633                         | 6.1709                            |
| 10            | 9.1417       | 8.8624                | 9.1424                  | 0.2793               | 0.0007                  | 3055.2304                         | 7.6572                            |
| 11            | 9.7807       | 9.2563                | 9.7812                  | 0.5244               | 0.0005                  | 5361.5794                         | 5.1121                            |

Compared with the absolute error and relative error data in Table 1, it can be seen that the order of magnitude of absolute error of FA-BP combined algorithm is reduced to $10^{-4}$ and the order of magnitude of relative error is reduced to $10^{-5}$, which is far lower than that of using only BP network model. After optimization, the prediction accuracy of the model has been greatly improved.

The comparison images of predicted value and expected value of the prediction model before and after optimization are shown in Fig. 2 and Fig. 3.

![Figure 2. BP model.](image1)

![Figure 3. FA-BP model.](image2)

It can be seen from the above chart that under the same experimental conditions, the FA-BP neural network model has better performance in prediction. Compared with the common BP network algorithm, FA algorithm optimizes the weights and thresholds of BP network, making the prediction value of FA-BP algorithm closer to the expected value, better stability of prediction and less fluctuation of prediction results.

**5. Conclusions**

Aiming at the shortcomings of traditional BP neural network, such as weak generalization ability and easily get stuck at the local optimum, firefly algorithm is introduced to optimize and improve the weights and thresholds of neural network. A BP neural network prediction model based on firefly algorithm (FA) is proposed, and the performance of the prediction model is tested. From the experimental results, we can see that the BP network algorithm based on firefly algorithm improves the prediction accuracy and has better optimization performance. The model and algorithm proposed
in this paper have a certain practical significance in regional economy. In order to further verify the actual accuracy of the prediction model, a large number of case data are needed to train it.

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