



## The Application of BP Artificial Neural Network in Fabric Warmth Retention Test

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### Abstract

The fabric warmth retention test is a complex process that is influenced by various factors, so errors often appear in the test. There lies a function relation between the fabric thickness, gram weight and warmth retention rate, CLO value. Artificial neural network BP algorithm was used to simulate the function mapping relation, and realized the automatic mapping from basic performance to warmth retention performance, and exhibited high mapping precision, it could also be used to amend the numerical value and reduce errors. It is demonstrated that the method is of high efficiency.

**Keywords:** Fabric warmth retention test, Artificial neural network, BP algorithm, Function mapping, Error

The data is often influenced by many errors in traditional fabric warmth retention test, especially the CLO value of fabric. CLO values of one fabric might be greatly different when it is tested with the same tool in different seasons or in different places, even the CLO values within a day might be different when it is tested in the morning, at noon or in the evening. These phenomena always confuse the people who are engaged in warmth retention test, so it is urgent to eliminate the errors and ensure the correctness of test result.

Fabric warmth retention rate and CLO value are two important indexes exhibiting the performance of fabric, while the thickness, gram weight, temperature and humidity of the environment directly influence the fabric warmth rate and CLO value.

Hence, if the data and result in the fabric warmth retention test can be simulated and quantified with computer, the influence of errors on test result will be greatly reduced. Neural network can be used to simulate the function of human brain neural cell; it has strong reserving and learning ability and can thoroughly approach to the complex nonlinear relationship. So it is necessary to study and simulate the data and result of fabric warmth retention performance by artificial neural network BP algorithm to reduce the influence of errors on test result and ensure the correctness and accuracy of test result.

### 1. Introduction to artificial neural network algorithm

Artificial neural network is a simulation of microcosmic physiological structure of life form and human neural system, it is a complicated computer network system comprising of interlinked simple processing units. It is indicated that neural network has the basic characteristics of human brain, i.e. learning, memorizing and concluding, it can be used to approach to any complex nonlinear system, so it is studied and applied widely in recent years.

Feed-forward neural network is one of the most important and widely used artificial neural networks. At present, many algorithms are in allusion to feed-forward neural network, EBP (error back propagation) algorithm (briefly as BP algorithm) is one that is widely used and can approach to any nonlinear function. Figure 1 shows the BP structure of feed-forward three-layered neural networks.

It can be seen from figure 1 that the neural network has three layers, input layer, hidden layer and output layer, the hidden layer can be one or more.  $(x_1, x_2, \dots, x_n)$  are input vectors,  $(y_1, y_2, \dots, y_n)$  are output vectors,  $w_1$  is input layer and  $w_2$  is output layer. The hidden layer and the output layer link with the weight value matrix,  $\theta_1$  and  $\theta_2$  are the threshold of hidden layer and output layer.

The learning process of BP algorithm comprises two parts, 1), forward propagation, the input vector, after processed by hidden layer, will be propagated to the output layer, the state of one layer only influences that of the next layer. The input layer unit is numbered by  $i$ , the hidden layer unit is numbered by  $j$ , and the output layer unit is numbered by  $k$ , accordingly, the output of hidden layer is  $O_j = f\{\sum w_{1ji} O_i + \theta_{1j}\}$  ( $O_i$  is the input vector). Similarly, the output of output layer is  $O_k = f\{\sum w_{2kj} O_j + \theta_{2k}\}$ , of which  $f$  is activation function, usually, Sigmoid function  $f(x) = 1/(1 + e^{-x})$  is used. 2) Reverse propagation of error, the error signal will be returned along the original neural network, during the returning, each weight value will be modified, so as to make the sum of squares error ( $E$ ) between actual output of network and supposed output be the least, in light of gradient descent method, educe the adjusted value of weighting coefficient.

$$E = \frac{1}{2} \sum_p \sum_k (y_{pk} - O_{pk})^2$$

( $p$ , the number of sample)

Reverse propagation of error

$$\delta_k = (y_k - O_k) f\left\{\sum_j w_{1kj} O_j + \theta_{2k}\right\} \Rightarrow$$

$$\delta_k = (y_k - O_k) O_k (1 - O_k)$$

(Output layer)

$$\delta_j = O_j (1 - O_j) \sum_k \delta_k w_{2kj}$$

(Hidden layer)

Weight value modification

$$\Delta w_{1ji}(t+1) = \eta \delta_j O_i + \alpha \Delta w_{1ji}(t)$$

$$\Delta w_{2kj}(t+1) = \eta \delta_k O_j + \alpha \Delta w_{2kj}(t)$$

Threshold value modification

$$\Delta \theta_{1j}(t+1) = \eta \delta_j + \alpha \Delta \theta_{1j}(t)$$

$$\Delta \theta_{2k}(t+1) = \eta \delta_k + \alpha \Delta \theta_{2k}(t)$$

$\eta$  means learning rate, if  $\eta$  is larger, the change of weight value will be larger, the training process of network will be accelerated, but the result might surge. In order to increase learning rate but produce no surge, momentum item is usually added to the weight value modification and threshold value modification as follows:

$$\alpha \Delta w_{1ji}(t), \alpha \Delta w_{2kj}(t), \alpha \Delta \theta_{1j}(t), \alpha \Delta \theta_{2k}(t).$$

$\alpha$  is momentum constant, it determines the influence of the past weight variation on the present weight variation. After training, when the  $E$  meets the need, the weight value of each node will be determined, and then the network will be able to be used in relating aspects.

## 2. Fabric warmth retention test based on BP algorithm

### 2.1 The determination of input vector and output vector in BP artificial neural network

The factors that influence the fabric warmth retention performance usually are the temperature and humidity of constant temperature room, gram weight and thickness of fabric, the structure of fabric and the thermal resistance of fiber. It is difficult to quantify the structure of fabric, so we took fabric composed of the same fiber and having the same structure as the test sample, i.e. 100% terylene double-faced polar fleece. The warmth retention rate and CLO value were used to represent the warmth keeping performance of fabric, the data and calculated results were used in BP artificial neural network.

In the BP artificial neural network, input vectors are the temperature and humidity of constant temperature room, the gram weight and thickness of fabric; while the output vectors are warmth retention rate of fabric and the CLO value.

### 2.2 The determination of training sample

The performance of neural network has close relationship with training sample; numerable reliable samples are of great importance. The training sample in this study came from the constant temperature room of Tianjin Polytechnic University and the test was carried out in the constant temperature room of Tianjin Knitting Technology Research

Institute. Firstly, 25 different fabric samples were tested, three tests were done to ensure the accuracy of the data, and then got the warm retention rate and CLO value through weighted average value. The gram weight, thickness, temperature and humidity of 25 samples were taken as the input of neural network, while the warmth retention rate and CLO value were taken as the output of neural network, all of them constituted the training sample of artificial neural network. 20 samples were training sample, and 5 were test sample.

The BP algorithm of neural network takes Sigmoid function as activation function, and the output of Sigmoid function is between 0 and 1, so the output vectors should be normalized. In addition, the units of input vectors are different, so the input vectors should also be normalized. The following two expressions were used to normalize the sample ( $Xp$ ,  $Yp$ ):

$$X(p, i) = (X_{act}(p, i) - X_{min}(i) \times 0.9) / (X_{max}(i) - X_{min}(i)) + 0.05 \quad (1)$$

$$Y(p, i) = (Y_{act}(p, i) - Y_{min}(i) \times 0.9) / (Y_{max}(i) - Y_{min}(i)) + 0.05 \quad (2)$$

Of which,  $X(p, i)$ ,  $Y(p, i)$  are the training sample value,  $X_{act}(p, i)$ ,  $Y_{act}(p, i)$  are the actual sample value,  $X_{min}(i)$ ,  $Y_{min}(i)$  are the minimum of training sample in  $i$  node,  $X_{max}(i)$ ,  $Y_{max}(i)$  are the maximum of training sample in  $i$  node. After testing in the neural network, the test sample will be changed to the actual value by expression (1) and (2).

### 3. Experiment and result analysis

#### 3.1 Parameters of the model

The network as shown in figure 1 was used, the node numbers of input layer and output layer were 11 and 9 respectively, and the node number of hidden layer was 10. According to the expression:  $n1 = \sqrt{n + m + \omega}$  ( $n$ , node number of input layer,  $m$ , node number of output layer,  $\omega$  is a constant between 0 and 10), learning rate  $\eta$  is 0.19, momentum constant  $\alpha$  is 0.17, the initial value of weight value  $w1$  and  $w2$ , threshold value  $\theta1$  and  $\theta2$  is a random number between [-1, 1].

#### 3.2 Results and analysis

The results of neural network training are shown in figure 2 and figure 3.

In table 1, the tested CLO value was the expected CLO value, the temperature, humidity, gram weight and thickness were the inputs of neural network, CLO value and warmth retention rate were the output of neural network. As we can see from figure 3 that the artificial neural network basically met the actual need, the method in the experiment was feasible.

### 4. Conclusion

Using the artificial neural network BP algorithm model to study and simulate the objective function mapping relationship between factors influencing fabric warmth retention rate and tested results, realized the computer test of tested data and results, the unvalued data would be taken out so as to reduce the influence of errors on results and guarantee the objectiveness and accuracy of fabric warmth retention performance test. The study indicates that the method is of high efficiency and accuracy; more scientific training data can be modified by this method.

### References

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Table 1. Part of the tested results of samples

Sample number	Temperature	Humidity	Gram weight	Thickness	Tested CLO value	CLO value output	Warmth retention rate
1#	21.4°C	65.1%	198g/m <sup>2</sup>	4.3mm	0.833	0.813	53.12%
2#	21.1°C	64.3%	203g/m <sup>2</sup>	4.6mm	0.912	0.914	55.41%
3#	20.5°C	64.9%	188g/m <sup>2</sup>	3.3mm	0.675	0.715	48.63%
4#	22.1°C	63.5%	267g/m <sup>2</sup>	4.8mm	1.345	1.356	58.46%
5#	21.6°C	65.4%	253g/m <sup>2</sup>	5.1mm	1.324	1.319	57.37%
6#	20.9°C	63.1%	389g/m <sup>2</sup>	7.4mm	2.225	2.145	77.05%
7#	22.6°C	64.6%	413g/m <sup>2</sup>	7.6mm	2.653	2.456	79.31%
8#	21.6°C	65.4%	311.6g/m <sup>2</sup>	6.2mm	2.154	2.316	76.32%

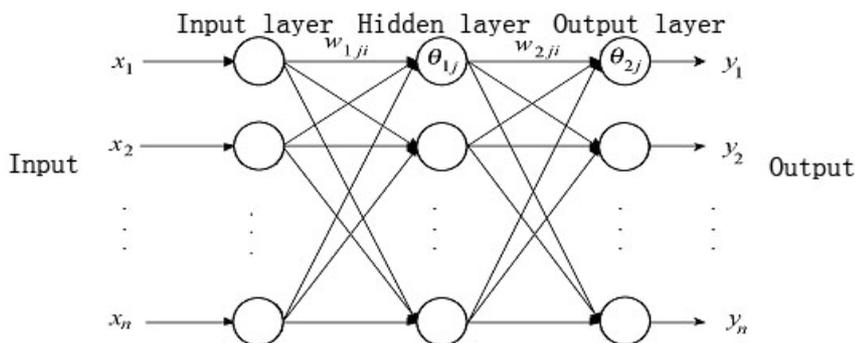


Figure 1. Structure of three layer feed forward neural network

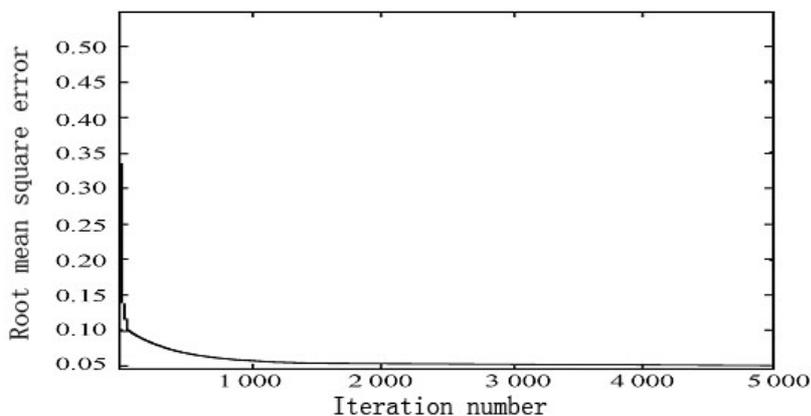


Figure 2. Error curve for network training

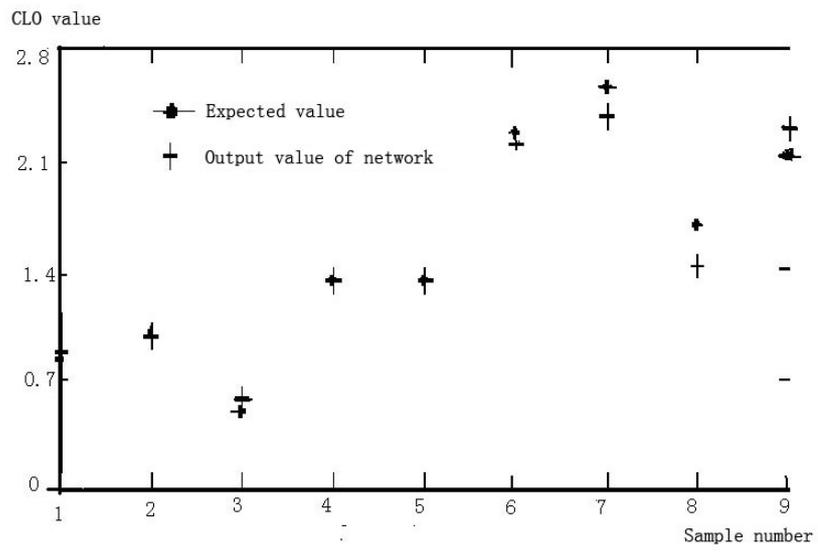


Figure 3. The compare of actual output and expected output of CLO value