Study on Wood Defect Detection Based on Artificial Neural Network

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***Abstract*—Contrasting to the original method of identifying the types of wood defects which requires the experienced technical staff with good discrimination to consider the characteristics of wood defects in the image, this paper presents a new method which can identify the types of internal wood defects rapidly and accurately by BP neural network which can analyse the visual characteristics parameters of wood defects extracted from the wood digital image. It analyses the results that different network structure and network parameters impact the capability of wood defects classification, presents the best parameters of BP neural networks which is used to identify the types of wood defects. This paper presents the way of extracting the wood defect characteristics and the way of processing the wood digital image in which has the visual flaw such as noise and low contrast.**

***Keywords*—Artificial neural network, wood defects, detection, and image processing**

I. Introduction

In the wood processing industry, identifying the types of wood defects correctly is necessary for fully and rationally using of wood resources and choosing the reasonable wood material. Wood productions can be determined the right quality rating based on the types of wood defects for maximizing the economic value of wood, and can be rationally used in accordance with the different wood defects, which is not only Conducive to industrial production, but also beneficial to the environment.

There are many methods which were used to detect the internal defects of wood, such as appearance judgment, hammer percussion, X-ray detection method, gamma-ray detection method, ultrasonic detection, microwave detection, nuclear magnetic resonance, acoustic method, pulse resistance method, and so on. X-ray detection method can be use to see internal physical structure of wood by eyes, and have lower cost.

Different Wood defects have their specific physical structure. The types of wood defects can be determined based on the physical characteristic of the area, girth, length width ratio of wood defects which was revealed by the X-ray images of wood reflects. For example, the wood knot in the wood image has lower gray level value, because which has greater density can absorb more X-ray dose than the natural part of wood, it seems to have lower brightness. The wood hollow in the wood image has higher gray level value because which has hollow site without wood structure can hardly absorb X-ray dose. The gray values of wood rot in the image of wood is between the gray values of wood knot and wood hollow, because its density is between the density of wood burl and wood hollow. Although the wood crack has no distinctive features on the gray compared with other defects, but its types can be determined based on its shape, the longer length, and other factors.

Classification by watching X-ray images of wood defect is feasible, but it requires experienced technical staff with good discrimination through comprehensive consideration wood defects in the image to carry out the work. Because of the lower contrast in the X-ray image it is difficult to see the wood internal defects. It is not conducive to improving the efficiency of classification and achieving good classification results because of the lower automation degree and the constraints of man-induced factors.

Artificial neural network technology because of its inherent advantages is a hot technology used in many study areas in recent years. It is ascendant to be applied to pattern recognition. It can find the complex nonlinear relationship between the eigenvalue and the patterns because of its powerful capabilities of self-learning, self-adaptation and nonlinear analysis. It is possible to achieve pattern classification through analyzing comprehensive characteristics data which looks complex and unrelated. For Example, BP network can identify the types of terrain by analyzing the gray level values of specific wave band satellite image of the region; it can identify the flight target whether it is enemy by analyzing the characteristics of airspace site, electronic jamming, target group characteristics, radar response, and so on. BP network also can identify base pile defects by analyzing measured wavelet feature vector of base pile. In a word, there are many successful identified examples using BP network which has the nonlinear mapping ability. This paper presents a new method which can identify the types of internal wood defects rapidly and accurately by BP neural network which can analyze the visual characteristics parameters of wood defects extracted from the wood digital image. it analyzes the result that different network structure and network parameters on the network impact the capability of wood defects classification, presents the best parameters of BP network networks which is used to identify the types of wood defects. This paper presents the way of extracting the wood defect characteristics and the way of processing the wood digital image which has the visual flaw such as noise and low contrast.

II. Materials and Methods

A. Back-Propagation Network

Artificial neural networks (ANN), also known as neural networks (NN), are the networks which interconnect the large number of processing elements. It is the abstract of the human brain, Simulates the human brain, and reflects the fundamental characteristics of the human brain. Artificial neural networks research the human intelligence behavior from the aspect of the physiological structure of the human brain, simulates the functions of information processing of the human brain. It is a technology which roots in neural science, mathematics, statistics, physics, computer science and engineering. It has the highly parallel processing capabilities, a high degree of nonlinear global effect, a good fault-tolerant and associative memory functions, as well as highly adaptive self-learning function, because artificial neural networks learn the many advantages of biologic neural networks.

The whole name of BP network is error back-propagation algorithm multilayer feed-forward network model. 1985 by the PDP group, It is an artificial neural network model that was the most widely used, and was presented by the PDP group in 1985. It adopts the multi-storey mapping between inputs and outputs. Only the nodes of adjacent layers are directly linked to one another transferring information. Each training example spreads twice in the network, the one spreads from the input layer, forward every layer. The different transfer functions are selected in accordance with the actual professional requirements. Output layer can give a result. Actual output and the desired output will be between a certain error, back-propagation adjusts the weights and thresholds of layers using gradient descent methods from the output layer to the input layer against the error vector, and it is repeated until that the error meet the required precision.

A neuron is a basic processing unit of artificial neural networks, and it is a multiple-input and multiple-output nonlinear device. Fig. 1 shows the structure of a neuron. The input of a transfer function f is the sum of the product of each input and the weight, together with the corresponding threshold value. Any differentiable function can be used as the transfer function of the neurons in Back-propagation networks. Fig. 2 shows a kind of partially connected neural network.

Back-propagation networks are widely used in pattern recognition, image processing, control, forecasting, and other fields. Actually a back-propagation networks model transfers a set of sample input and output problem into a nonlinear optimization problem, using the optimization algorithms (such as gradient descent method), obtains the weights by iterative calculation corresponding to learning and memory problems, and adjusts the parameters by the method of Joining the hidden layer to obtain optimal solution.

B. Collecting and Processing the Image of Wood Defects

Taking into account the constraint of costs, protective conditions, and experimental conditions, the wood internal defects image can be obtained and processed by the wood detestation system using X-ray method. X-ray is an electromagnetic wave, and has higher frequencies than the visible light. The energy of a single photon is higher than visible light, so it can penetrate objects which look no transparent in our life, and shows the objects on a view.

X-rays will be absorbed partly when it penetrates the objects. According to the formula which is showed in (1), the X-ray energy of which intensity is I_0 is absorbed partly when it penetrates the objects, supposing the thickness of the wood is d. The μ is an absorption coefficient related to the X-ray wavelength, the absorption material types, and the density of the material.

$$I = I_0 e^{-\mu d} \quad (1)$$

Different objects have different degrees on the X-ray absorption, while the different parts of the same object have different degrees on the X-ray absorption because of the different density, composition, and temperature.

Fig. 3 shows image acquisition and processing system for wood non-destructive detections. The log will be placed between the X-ray source and absorption screen which is coated with fluorescent material. X-rays source give off the X-ray which will be absorbed partly by the wood material when it penetrates the objects. Absorption quantity is related to the types and the density of log defects. The attenuation of X-ray in the logs reduces the energy; reflected in different degrees of activating the same fluorescent material on-screen. The

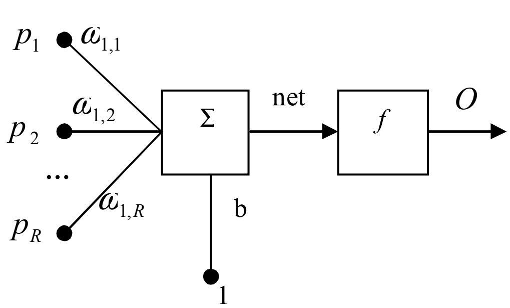

Figure 1. Artificial neural of BP Networks.

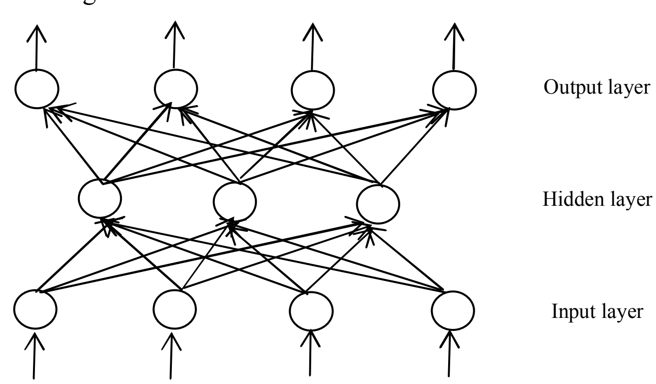

Figure 2. Structure of partially connected one hidden layer BP network.

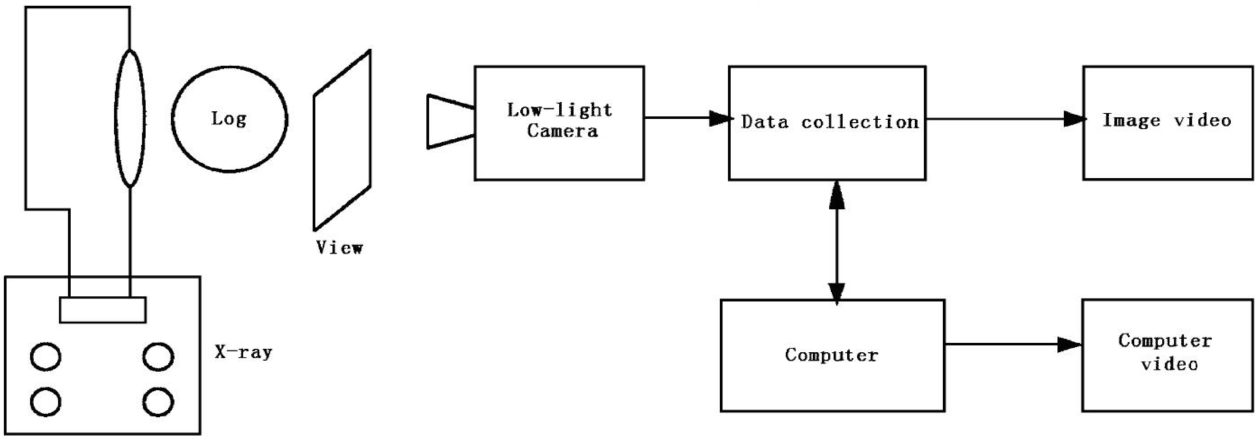

Figure 3. Image acquisition and processing system of log for wood detection.

information of the weak fluorescence on the absorption screen is transmitted to a computer by a video camera. The digital signals transmitted by the A / D converter circuit from the simulation signals are deposited in the image storage system, and are applied in the digital image processing. Fig. 4 shows the original wood defects image which obtained by the collection system.

No accurate eigenvalue will be extracted from original low-definition wood defects image which is obtained by the Low-light-level cameras and digital-simulation converter equipment. The correct samples can not be established, which may lead to the failure in BP network training.

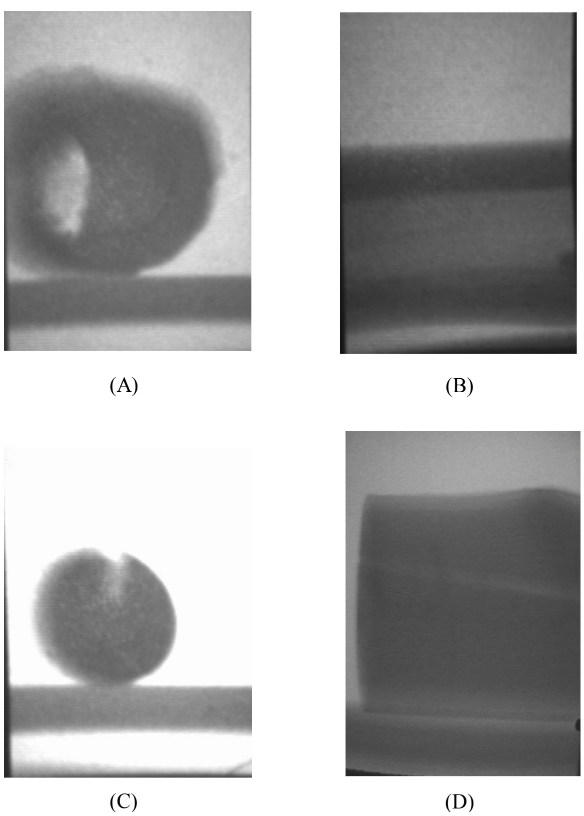

Figure 4. Image of a rot in log (A), image of a hollow in log (B), image of a crack in log (C), image of a crack and a knot in log (D), obtained by X-ray collection system.

In order to accurately extracting the eigenvalue of wood defects from the image, the paper will get rid of the noise of the wood images, enhance the contrast of the wood images. The human eye can easily perceive the spot of which gray level value is largely different from adjacent pixels, such as a bright spot in a dark area in the gray image. This mutation is called the noise in the image. In order to extract accurate defect features, it is necessary to remove or weaken the noise impact on the feature extraction.

A linear smoothing filter is also called an average filter. The coefficients of Mean filter are all positive. For the 3 × 3 template, the simplest operation is that all coefficients are 1, makes the output image still in the gray value area of original image. The product of all the templates and adjacent pixel should be divided by 9. This method is also called neighborhood average.

Median filter is a nonlinear signal processing methods, and can overcome the disadvantage of Linear Filter which makes the image detail fuzzy. Its purpose is to protect the edge of the image when noise is removed. The median filter rand the gray level value of the pixels which are in the area centered by a spot, and the gray level value of the spot is the median gray level value. An average of the two middle values will be the gray level value of the spot when the number of spot in the area is even number.

These two methods can remove the image noise, preserve useful image information effectively. Fig. 5 shows the filtered wood image, and the filter processed image became clear.

C. *Eigenvalues Selecting*

The types of wood internal defects including knot, crack, hollow, and rot can be identified by Back-propagation networks methods in this paper. Each of the four wood defect types has its own physical characteristics. For example, the wood knot in the wood image has lower gray level value, because which has greater density can absorb more X-ray dose than the natural part of wood, it seems to have lower brightness. The wood hollow in the wood image has higher gray level value because which has hollow site without wood

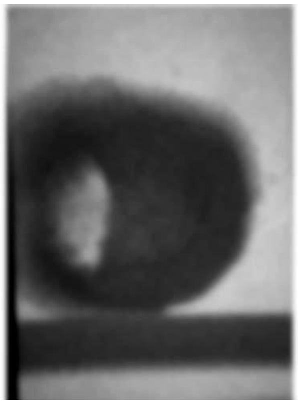

Figure 5. Wood image after filter and then enhance contrast.

structure can hardly absorb X-ray dose. The gray values of wood rot in the image of wood is between the gray values of wood knot and wood hollow, because its density is between the density of wood burl and wood hollow. The crack of wood has no distinctive features on the gray compared with other defects, but it has a narrow and long shape which is different from the other defects.

Considered the characteristics of the four defect types, the area of defect, length of defect edge, the mean gray level value of defect image, and length width ratio of defect will be selected as the input eigenvalue of the ANN.

D. Eigenvalues Extraction

Digital image processing technology is a rapid developing computer technology with rapidly growing high-tech. The four eigenvalues like the area of wood defects, the length of defect edge, the mean gray level value, and the length width ratio are defined according to the characteristics of digital image.

TABLE I. A PART OF THE EIGENVALUE EXTRACTED FROM THE IMAGE OF WOOD DEFECTS

Type of Wood Defect	Binary Coding of Wood Defect	Area	Gray Level Value	Girth	Length Width Ratio
Knot	（0，0）	3719	152	189	1.8063
Knot	（0，0）	1898	181	447	1.6424
Knot	（0，0）	3879	129	766	1.8881
Knot	（0，0）	699	150	232	1.5549
Crack	（1，0）	1033	184	427	5.7505
Crack	（1，0）	1663	132	600	4.0381
Crack	（1，0）	5719	117	1676	37.0412
Crack	（1，0）	8336	108	1647	11.2884

The number of pixels in wood defects is defined as the area (S) of the wood defect. The number of pixels in the defect edge is defined as the girth (L) of the wood defect. Mean gray level value means the average gray level value of the pixels in the defects area. The length width ratio (BI) means the radio between the length of the longest inner diameter and the length of the midperpendicular of the longest inner diameter which also is the inner diameter.

Equation (2) and (3) shows respectively the extraction methods of mean gray level value and the length width ratio. GRAY is the mean gray level value; $G[i][j]$ is the gray level value of the pixel; n is the number of wood defect pixels; $L_{\mathbf{min}}$ and $L_{\mathbf{max}}$ are the maximum coordinates and minimum coordinates in the defect area in vertical direction. $R_{\mathbf{min}}$ and $R_{\mathbf{max}}$ are the maximum coordinates and minimum coordinates in the defect area in horizon direction. $r_{\mathbf{max}}$ is the longest distance between the two spot on the edge of the defect. $r_{\mathbf{min}}$ is the longest distance in the midperpendicular of the $r_{\mathbf{max}}$ between the two spot on the edge of the defects. TABLE I shows a part of the eigenvalue extracted from the image of wood defects.

$$GRAY = \frac{\sum_{i=R_{\min}}^{R_{\max}} \sum_{j=L_{\min}}^{L_{\max}} (G[i][j])}{n} . \quad (2)$$

$$BI = {r_{\max}}/{r_{\min}} . \quad (3)$$

E. Creating and Training the Back-Propagation Networks

The parameters of the network should be set before BP network training. The network parameter settings include the setting of the number of layers in network configuration, the settings of the number of neurons in each layer, transfer function settings in each layer, the settings of learning function and training function, the settings of training Accuracy, and the settings of training steps.

Research shows that a three-layer Back-propagation network with one hidden layer can nonlinearly approximate to the target. Identifying the types of wood defect is realized by a three-layer Back-propagation network. The number of neuron in each layer is signified using N, X, M. This paper extracts four eigenvalues of the wood defects such as the area of wood defect, the girth of wood defect, the mean gray level value, and the length width ratio as the input of Back-propagation network to identify the types of wood defect, so four neurons are set as the inputs, as N=4, are used to receive four input eigenvalues. The output of the network is the types of wood defects, so the network should have four outputs according to the need of identification. In order to simplify network, and enhance efficiency, the output layer is set using two artificial neurons, as M = 2, the output values are 0 and 1. According to the actual needs of identification, four types of wood defects will be transferred by binary coding, that is, the output (0,0) represents wood knot; the output (1,0) represents wood crack; (the output (0,1) represents wood hollow; the output (1,1) represents wood rot. As ANN is inexact, the output value may not be either 0 or

1, but the approximation of 0 or 1. They will be transferred into 0 or 1 according with the way of half adjust.

Current theory can not give the best number of neurons in the hidden layer, while the best number of neurons in the hidden layer can be given by experience and practical application. In this paper, the different networks including different number of neurons in the hidden layer will be tested to identify the types of wood defects. The network that has the optimal performance will be confirmed as the ultimate application.

The S-type tangent function is chosen as the transfer function of neurons in the hidden layer. The S-type logarithmic function is chosen as the transfer function of neurons in output layer, and it is two-valued, meets the requirements of this experiment. The training function of network is trainlm. The function has a high operating speed, and is more suitable for large and medium-sized networks. The learning function of network is learngdm. Performance function is the mean square error (mse). The largest number of training steps is 1000. The training error set at 10^{-8}.

The eigenvalues extracted from the images are different in unit and magnitude. In order to balance the impact ability of various eigenvalues, the eigenvalues need to be transferred into the data which are close in impact ability. In this paper, training samples and test samples are transferred using a logarithmic function. Equation (4) shows the transfer formula, where p is the input eigenvalues of the original matrix, Pn is the input eigenvalues of the transferred matrix. TABLE II shows a part of the processed eigenvalue extracted from the image of wood defects.

$$Pn = \log 10(p). \quad (4)$$

TABLE II. A PART OF THE PROCESSED EIGENVALUE EXTRACTED FROM THE IMAGE OF WOOD DEFECTS

Type of Wood Defect	Binary Coding of Wood Defect	Area	Gray Level Value	Girth	Length Width Ratio
Knot	（0，0）	3.5704	2.1818	2.2765	0.2568
Knot	（0，0）	3.2783	2.2577	2.6503	0.2155
Knot	（0，0）	3.5887	2.1106	2.8842	0.2760
Knot	（0，0）	2.8445	2.1761	2.3655	0.1917
Crack	（1，0）	3.0141	2.2648	2.6304	0.7597
Crack	（1，0）	3.2209	2.1206	2.7782	0.6062
Crack	（1，0）	3.7573	2.0682	3.2243	1.5687
Crack	（1，0）	3.9210	2.0334	3.2167	1.0526

III. RESULTS AND DISCUSSION

The number of neurons in the hidden layer has a greater impact on the performance of the network. In this study, the nine types of Back-propagation networks will be created, which all have four input neurons and two output neurons. They are different in the number of neurons in the hidden layer. The number of neurons in the hidden layer of each network is 4, 6, 8, 10, 12, 14, 16, 18, and 20. Each type of network is trained fifty times, and is tested the success rate of training and the performance in identifying the types of wood defects. TABLE III shows the test results.

The success rate of training networks is low when the number of neurons in the hidden layer is four, as the rate is 60 percent and the network is easy to trap into local minimum points. The success rate of training networks is about 78 percent when the number of neurons in the hidden layer is 6, 8, 10, 12, and 14. The success rate of training networks is high when the number of neurons in the hidden layer is above 18; the rate is about 90 percent. A high success rate of network training does not mean that the network has a outstanding performance in identifying the types of wood defects, only means that the network is not easy to trap into local minimum points. However, due to the higher complexity of the network structure, it will also cause the loss of network generalization.Therefore, the number of hidden layer neurons should not be too much or too small, should choose in the rank of 6 to 14.

TABLE III. THE TEST RESULTS OF BACK-PROPAGATION NETWORKS

The Number of the Hidden Layers	The Number of Neurons in the Hidden Layer	The Success Rate of Training (%)	The Number of Steps for Achieving the Training Aim	Error Number/ The Number of Testing Samples
	4	60	24	0/32
			39	3/32
			24	1/32
	6	78	20	0/32
			52	5/32
			23	0/32
	8	80	30	4/32
			22	2/32
			35	1/32
	10	78	16	0/32
			20	0/32
			26	0/32
	12	78	30	0/32
1			298	1/32
			90	1/32
	14	78	22	1/32
			57	3/32
			305	0/32
	16	92	24	2/32
			46	6/32
			486	0/32
	18	90	35	1/32
			50	0/32
			977	1/32
	20	90	38	2/32
			36	0/32
			363	3/32

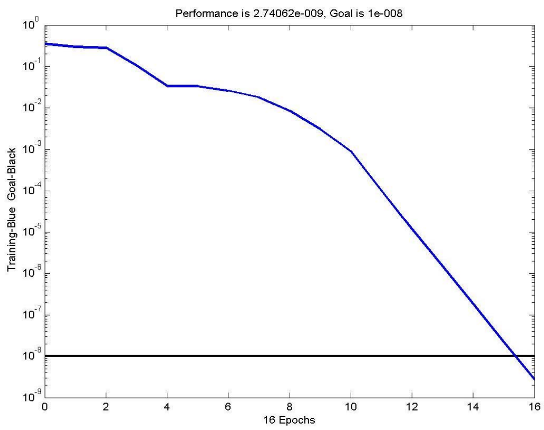

Figure 6. Changing process of error with the training steps.

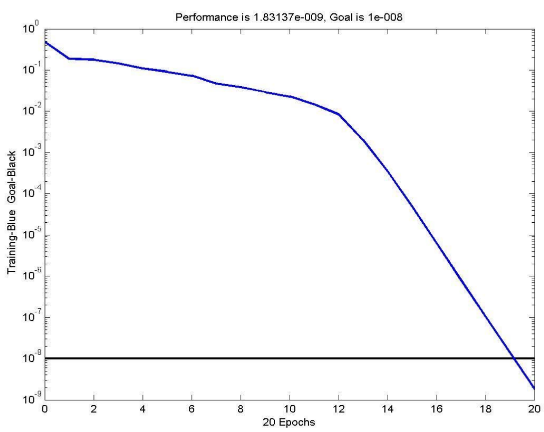

Figure 7. Changing process of error with the training steps.

Experiment shows that when the number of hidden layer neurons is 10, the training success rate is 78 percent. In the three training, the network gets to required training precision in the 16th step, the 20th step and the 26th step. Fig. 6 and Fig. 7 show the two training processes of Back-propagation which has ten neurons in the hidden layer. We can see the changing process of error with the training steps. After each of the three training, the error identification rate of the Back-propagation network that has ten neurons in the hidden layer is zero by testing the thirty two testing samples. The Back-propagation networks that have other number of neurons in the hidden layer have no such excellent identification performance. This paper presents that the optimal Back-propagation network model used in identifying the types of wood defects is the three-layer Back-propagation network with ten neurons in the hidden layer.

IV. CONCLUSIONS

The types of wood internal defects including knot, crack, hollow, and rot can be identified by Back-propagation networks methods. The purpose of identifying the types of wood defects is realized by analyzing the inputs eigenvalue such as the edge length of area, dimension, length width ratio, and mean gray level value. Wood X-ray image quality and the choice of methods for extracting wood defects eigenvalue is very important to the capability of networks in wood defects classification. Denoising filtering and contrast enhancement are applied in wood image processing. The practice shows the edge of wood defects in the pretreated wood image gets clearer, and get easier to extract it. Research shows that the application of artificial neural network method for detecting wood defect types is feasible. This paper analyzes the results that different network structure and network parameters impact the capability of wood defects classification, and determines the best type of Back-propagation network model for identifying the wood defects is the three layers BP network whose hidden layer contains ten artificial neurons.

REFERENCES

[1] Dawei Qi, “Log with Knot-Hole Image Processing Based on the Discrete Brownian Random Field and Fractal Paremeter,” Scientia Silvae Sinicae, vol. 40, pp. 145-147, July 2004.

[2] Dawei Qi, “A Study on Image Processing System of Non-Destructive Log Detection,” Scientia Silvae Sinicae, vol. 37, pp. 92-96, November 2001.

[3] Lei Yu and Dawei Qi, “Study on Wood Defect Testing by Applying Computed Tomography,” Forest Engineering, vol. 22, pp. 13-44, September 2006.

[4] Hongbo Mu and Dawei Qi, “Application of Artificial Neural Networks in the Testing of Wood Defects,” Forest Engineering, vol. 22, pp. 21-23, January 2006.

[5] Jiani Fan, Zhenlei Wang, and Feng Qian, “Research Progress Structural Design of Hidden Layer in BP Artificial Neural Networks,” Control Engineering of China, vol. 12, pp. 105-109, May 2005.

[6] Cunbin Li and Kecheng Wang, “A New Grey Forecasting Model Based on BP Neural Network and Markov China,” J. Cent. South Univ. Technol, vol. 14, pp.713-718, May 2007.

[7] Yingke Mao, Zhicheng Guan, Liming Wang, and Bo Yue, “Prediction of Leakage Current of Outdoor Insulators Based on BP Artificial Neural Network,” Proceedings of the CSEE, vol. 27, pp. 7-11, September 2007.

[8] Shuling Yin, Ning Shu, and Xinhua Liu, “Classification of Remote Sensing Image Based on Adaptive GA and Improved BP Algorithm,” Geomatics and Information Science of Wuhan University, vol. 32, pp. 201-204, March 2007.

[9] Jie Zhao and Hui Lin, “Target Attribute Identification Simulation Based on BP Neural Network Model,” Journal of System Simulation, vol. 19, pp. 2571-2573, June 2007.

[10] Minggui Liu, Xianghong Yue, Yongbo Yang, and Qi Li, “Intelligent Identification of Pile Defect Based on Sym Wavelet and BP Neural Network,” Chinese Journal of Rock Mechanics and Engineering, vol. 26, pp. 3483-3488, July 2007.

[11] Dongmei Lv and Jing Guo, “Character Identification Based on EMD and Improved BP Algorithm,” Chinese Journal of Electron Device, vol. 30, pp. 1786-1791, October 2007.