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Fault Diagnosis using Magnetic Image of PCB

Zhuting Yao
College of Mechanical Engineering and Automatization
North University of China
030051 Taiyuan, Shanxi, China
ztyao713@163.com

Hongxia Pan
College of Mechanical Engineering and Automatization
North University of China
030051 Taiyuan, Shanxi, China
Panhx1015@163.com

Abstract—**With the digital technology and very large scale integrated circuit technology widely used, the structure and function of electronic devices are becoming more and more complex, the defects of contact diagnosis has become increasingly prominent for using the probe or needle bed, it demands people began to in-depth study the diagnostic techniques of PCB non-contact. Based on magnetic image of the PCB fault diagnosis technology is a new non-destructive testing technology of PCB, developed in recent years, it can achieve rapid detection and location of the circuit board failure, improve the reliability of the circuit board. Aimed at the specific PCB, its different failure modes of the magnetic image of the PCB are attained by Ansoft software, are carried out through the magnetic image filtering, image enhancement technology; they are completed on multi-level wavelet decomposition, the construction and extraction of wavelet energy features of the magnetic image. The PCB fault diagnosis based on the magnetic image is completed by using the improved momentum-adaptive rate neural network algorithm. The results show that the magnetic image method is effectively diagnosis method for PCB, and it's a new fault diagnosis approach of PCB.**

Keywords- fault diagnosis；magnetic image；printed circuit boards；wavelet neural network

I. INTRODUCTION

As we all know, the circuit board is in the state of power, the current line and the circuit board components are magnetized, such as resistors, integrated chips will produce electromagnetic radiation, and a particular magnetic field is formed in space [1]. It has one to one relationship between the magnetic field distribution characteristics of the circuit and current distribution characteristics of the circuit. When a component or circuit of the circuit board appears failure, it will cause the change of the current size and direction, and the magnetic field strength at any point in the near-field region of board depends on the size of current and its distribution, it makes nearly magnetic field distribution also undergo corresponding changes. The state of the circuit board is determined by detecting the magnetic field distribution in the circuit or system work, and it will be able to achieve non-contact detection and diagnosis, the fault diagnosis of the magnetic image is based on [2].

During the circuit board fault diagnosis, the first it needs to add excitation source, it makes the circuit board works in the largest working condition, then the magnetic field distribution of the circuit board is detected, and a test data is formed. Comparing the measured magnetic field distribution data of the circuit board with the trouble-free data, if the circuit board presences the fault, both of the magnetic field distribution data must be some difference. According to the difference, the faulty components on the circuit board can be determined and located. If it can not locate to the fault components, it can compress the range of failure, and add power in possible malfunction of the various components, it makes them on the maximum working state, measures the magnetic field distribution, extracts the characteristics vector of test data, based on the correspondence relation between the failure and characteristics vector of the magnetic image, reasoning judge, to determine the fault source, and show the location and types of faults.

II. SYSTEM COMPONENTS AND FUNCTIONS

Based on the magnetic image of PCB fault diagnosis system, the first, it need process the input magnetic image, extract the characteristics information of the magnetic image of board in the work state, and the characteristics information are as neural network inputs, the corresponding fault cause are as network output and network is trained. Until the network training is completed, the magnetic image of the pre-test circuit board is inputted, and the relevant features are extracted, and the board working states can be diagnosed. The fault diagnosis system block diagram is shown in Fig.1.

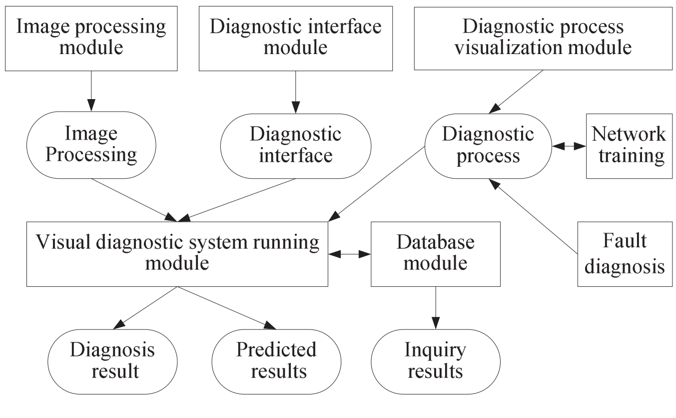


Figure 1. The design frame of system

III. TO OBTAIN THE MAGNETIC IMAGES

Sometimes the magnetic images can be obtained by the EMSCAN devices and software simulation. In this paper, the electromagnetic image in near-field experimental data is indirectly obtained by Ansoft Designer simulation software, and it provides a new diagnostic method for circuit board.

The electromagnetic near-field image of a circuit board by simulating is shown in Fig. 2. As the software simulation from the distribution of near-field magnetic image is color, making image analysis must be conducted before the gray-scale image processing.

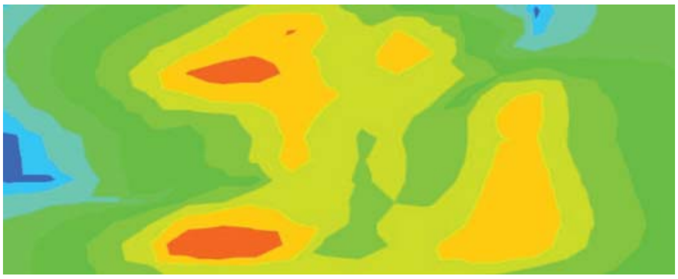


Figure 2. Simulation image of a circuit board magnetic image

IV. THE MAGNETIC IMAGE PROCESSING TECHNIQUES

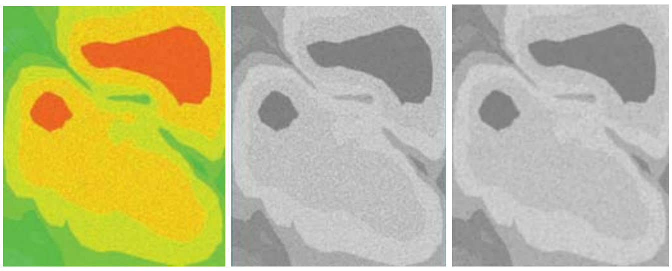
In practice, the magnetic image in the detection process is affected by noise, electromagnetic interference and other external factors, always makes the original image acquires a certain degree of distortion, the images must be digital processing before the magnetic image is analyzed, the images processing in this system includes image filtering, enhancement, and edge sharpening and so on.

A. Gray-scale and filter of the magnetic image

Gray-scale image is the process transforms a color image into grayscale image. The magnetic image is a color image, shown in Fig. 3(a). Color images contain a large number of R, G, B color information, it not only would take a lot of storage space, but also it will require the system to assign a lot of resources in the image application process. As the grayscale images can be the overall reaction and the local color, brightness distribution and characteristics of the whole image. It can save a variety of hardware and software resources when color images convert to grayscale images.

By detecting the magnetic field data to generate the magnetic field grayscale images, it reflects the magnetic field distribution of the circuit board. Image grayscale of the magnetic images generation process includes the magnetic field data acquisition, extracting the maximum and minimum of array data classification and the data is conversed into the magnetic image gray-scale values.

The gray-scale magnetic image is shown in Fig. 3(b). It can be seen from Fig. 3(b), there are some noise points in the image, therefore, median filtering is used in the grayscale image, the point in digital image is replaced by the median value of brightness of each point in a little neighborhood, so that it can protect the edge of the image, and it has good results to the filter pulse interference and scanning image noise [3].



(a)Source image (b)Gray-scale images (c)Median filtered image

Figure 3. The contrast image from source image with gray-scale image and median filtering image

Set the number of groups: $X_1, X_2, \cdots X_n$,If the order is as follows: $X_{i1} \le X_{i2} \le X_{i3} \le \cdots \le X_{in}$, then:

$$Y = Med\{X_1, X_2, \cdots X_n\} = \begin{cases} X_{i[(n+1)/2]} & n \text{ is odd number} \\ \frac{1}{2}\left[X_{i[(n/2]} + X_{i[(n/2+1]}\right] & n \text{ is even number} \end{cases} \quad (1)$$

Y is called the median of $X_1, X_2, \cdots X_n$, and it is extended to two-dimensional, then the median filtering of the output is:

$$Y_i = med\{X_{ij}\} = med\{X_{(i+r)(j+s)}(r,s) \in A, (i,j) \in I^2\} \quad (2)$$

According to the characteristics of the magnetic image, selecting the 5×5 window median filtering method to obtain the magnetic image, it not only can improve the edge characteristics of image signal, and also get faster processing speed and higher accuracy. After filtering the image is shown in Fig.3(c), it can be seen that the noise points in the image are significantly reduced, the smoothness of magnetic image is better, the overall effect is satisfactory.

B. The magnetic image enhancement

Gray value of pixels within the image is an important data of the image, the result of magnetic image gray value is often less than ideal due to testing equipment or filtering effect. Image enhancement can highlight some interesting information or attenuate no interesting information in image, and it is more effective than the original image in the specific application.

Common methods of image enhancement are gray-scale transformation and Histogram Equalization. The histogram equalization method is adopted in this paper. The basic idea of Histogram equalization is to increase the image's pixel gray value dynamic range. The actual processing of histogram correction achieves on the cumulative distribution function transformation. For digital images, the transformation function is set as follow:

$$s_k = T(r_k) = \sum_{j=0}^{k} \frac{n_j}{n} = \sum_{j=0}^{k} p(r_j) \quad (3)$$

Where, $0 \le r_j \le 1, k = 0,1,\cdots,L-1, p(r_j)$ is the gray probability that gray level appears, and $T(r_k)$ is the cumulative distribution function of *r*. In practice, according to meet the actual needs in digital image processing, the conversion result is a real number, also need to re-quantitative, quantitative formula is as follow:

$$\hat{s}_k = INT\left[\frac{s_k - s_{\min}}{1 - s_{\min}}(L-1) + 0.5\right] \tag{4}$$

Fig.4 shows the magnetic image before and after histogram equalization. It can be seen, with the histogram correction, the gray-scale range and gray level intervals of the image histogram are pulled larger, the image become clearer.

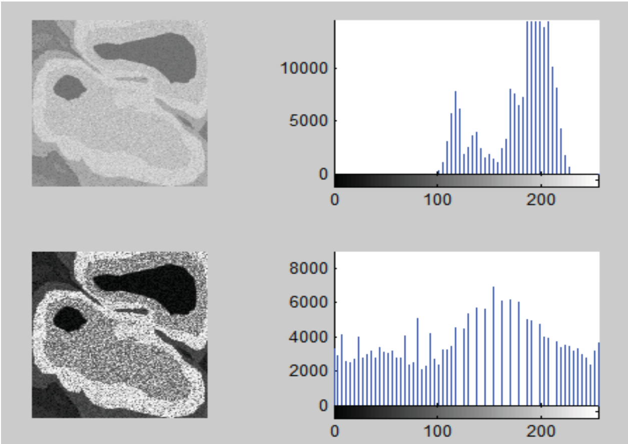


Figure 4. The magnetic image after the Histogram equalization

C. *Sharpen edge of the magnetic image*

In the image smoothing process, it tends to the image boundaries, contours and details become blurred due to image conversion system transfer function attenuation effects on high-frequency components. In order to reduce these impacts, the image enhancement techniques are adopted in various parts of the contour lines and details of more clarity in the image [4].

Laplacian is selected because it has better effect when it is used in edge detection, and it has rotation invariance. Laplacian is a linear quadratic differential operators, it can meet the different sharpening image requirements.

For images $F(x,y)$, the expression for the Laplacian operator is as follow:

$$\nabla^2 F(x,y) = \frac{\partial^2 F(x,y)}{\partial^2 x} + \frac{\partial^2 F(x,y)}{\partial^2 y} \tag{5}$$

Figure 5 shows the magnetic image of PCB after edge sharpening by Laplacian.

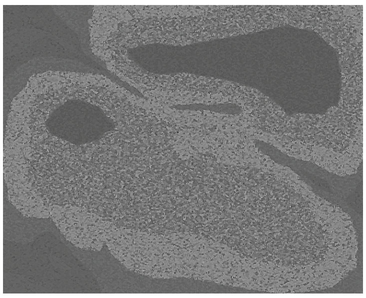


Figure5. Magnetic image of edge sharpening

V. WAVELET ENERGY FEATURE EXTRACTION OF MAGNETIC IMAGE

In practice fault diagnosis, it is always hope to collect a number of samples to train the neural network, and the fault diagnosis is more accurate and reliable. But too much input sample can cause not only the training time is too long, or even obstruct the convergence effects of network, mainly the training accuracy can not arrive, and ultimately affect the circuit board fault diagnosis. Therefore, it requires to extract useful information is a greater contribution to the faults diagnosis from the sample, image feature extraction is to use existing image samples by mapping (or function transformation) to construct a lower dimensional feature space, the original image contains useful information is mapped in a few features.

The two-dimensional discrete wavelet transform (DWT) is adopted because the wavelet transformation has a good effect in the signal weakened or even removed the correlation between the various characteristics by selecting the appropriate filter function, and it has a multi-scale, multi-resolution features. It can be used correlation analysis in the low frequency band by high frequency resolution and low time resolution; at high frequencies, the available low-frequency resolution and high time resolution achieve correlation analysis, and the magnetic image data processing is a two-dimensional gray-scale image data [5].

A. *Two-dimensional discrete wavelet transform*

First, define the scale and translation functions as follow:

$$\varphi_{j,m,n}(x,y) = 2^{j/2}\varphi\left(2^j x - m, 2^j y - n\right) \tag{6}$$

$$\psi^i_{j,m,n}(x,y) = 2^{j/2}\psi^i\left(2^i x - m, 2^j y - n\right), i = \{H,V,D\} \tag{7}$$

Thereinto, $\varphi(x,y)$ represents a two-dimensional scaling function, $\psi^H(x,y)$、$\psi^V(x,y)$、$\psi^D(x,y)$ represent two-dimensional wavelet measurement function, respectively. The properties of $\varphi(x,y)$、$\psi^H(x,y)$、$\psi^V(x,y)$、$\psi^D(x,y)$ are as follow:

$$\varphi(x,y) = \varphi(x)\varphi(y) \tag{8}$$

$$\psi^H(x,y) = \psi(x)\varphi(y) \tag{9}$$

$$\psi^V(x,y) = \varphi(x)\psi(y) \tag{10}$$

$$\psi^D(x,y) = \psi(x)\psi(y) \tag{11}$$

These wavelet measured functions are changed along different directions of the image gray value: ψ^H changes along the image column, ψ^V changes along the line of the image, ψ^D changes along the diagonal direction of the image.

Matrix of size M×N image $f(x,y)$ of the discrete wavelet transformation is as follow:

$$W_\varphi(j_0,m,n) = \frac{1}{\sqrt{MN}}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)\varphi_{j_0,m,n}(x,y) \tag{12}$$

$$W^i_\psi(j_0,m,n) = \frac{1}{\sqrt{MN}}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)\varphi^i_{j,m,n}(x,y), i = \{H,V,D\} \tag{13}$$

j_0 is beginning scale, it can be taken any value, $W_\varphi(j_0,m,n)$ coefficient defined in the scale j_0 factor approximation of $f(x,y)$. $W_\psi^i(j,m,n)$ coefficient will be additional the horizontal, vertical and diagonal details if $j \geq j_0$. In normal circumstances, let $j_0 = 0$, $M = N = 2^j$, $j = 0,1,2,\cdots,J-1, m,n = 0,1,2,\cdots 2^j - 1$, equation (12) and (13) give the value of W_ϕ and W_ψ^i , the original image $f(x,y)$ can be got by inverse discrete wavelet transformation, it expresses as follow:

$$f(x,y) = \frac{1}{\sqrt{MN}} \sum_m \sum_n W_\varphi(j_0,m,n)\varphi_{j_0,m,n}(x,y) + \frac{1}{\sqrt{MN}} \sum_{i=H,V,D} \sum_{j=j_0}^{\infty} \sum_m \sum_n W_\varphi(j_0,m,n)\psi_{j,m,n}^i(x,y) \tag{14}$$

B. The structure and extraction of wavelet energy feature

Set, H_i、V_i and D_i are the details of the image in the i^{th} wavelet decomposition in the horizontal direction, vertical direction and diagonal direction, the wavelet energy of image in different directions of the i^{th} level is defined as[6]:

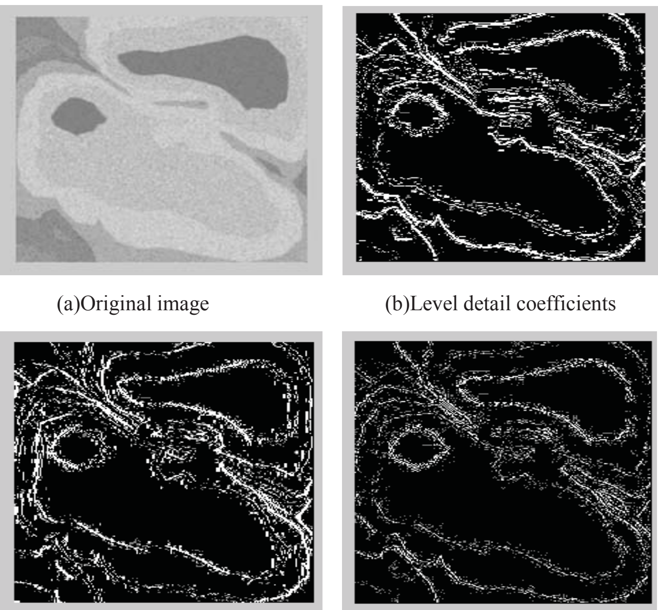
$$E_i^h = \sum_{x=1}^{M} \sum_{y=1}^{N} [H_i(x,y)]^2 \tag{15}$$

$$E_i^v = \sum_{x=1}^{M} \sum_{y=1}^{N} [V_i(x,y)]^2 \tag{16}$$

$$E_i^d = \sum_{x=1}^{M} \sum_{y=1}^{N} [D_i(x,y)]^2 \tag{17}$$

From (15) to (17), they stand for the intensity information of the horizontal, vertical and diagonal directions in the i^{th} level wavelet decomposition of images, respectively.

The wavelet decomposition details image in each direction of the circuit board's magnetic image are shown in Figure 6.



(a)Original image (b)Level detail coefficients

(c) Vertical detail coefficients (d) Diagonal detail coefficients

Figure 6 Image single decomposition

During image wavelet decomposition, the non-oscillating signal wavelet coefficient will increase with the wavelet decomposition series increases, the coefficients of wavelet decomposition level become the maximum when the oscillation signal is corresponding with the oscillation frequency. Therefore, the energy of the non-oscillation of the magnetic image part is concentrated in the large-scale wavelet decomposition detail image, and the energy of the oscillation of the magnetic image part is mainly concentrated in the smaller-scale wavelet decomposition detail image.

The vector of the energy component by wavelet decomposition level is as follow:

$$\left(E_i^h, E_i^v, E_i^d\right)_{1,2,\cdots M} \tag{18}$$

It can reflect the energy distribution of the magnetic image. Where, M is the maximum series number of wavelet decomposition.

Obviously, equation (18) describes the overall information of the magnetic image, and it can not describe some local information of the magnetic image distribution. To solve this problem, the each images details are divided into $S\times S$ disjoint blocks, and the each wavelet energy is calculated. Finally, the local feature vector $\widetilde{V}$ contains many details of the resolution information are composed by the energy of these blocks:

$$\widetilde{V} = \left(\widetilde{V}_{(1)}^1, \widetilde{V}_{(2)}^1, \cdots \widetilde{V}_{(3\times S\times S)}^1, \cdots \widetilde{V}_{(1)}^M, \widetilde{V}_{(2)}^M, \cdots, \widetilde{V}_{(3\times S\times S)}^M\right) \tag{19}$$

Where, M is the total series number of wavelet decomposition, $\widetilde{V}_{(j)}^1 (j = 1,\cdots,3\times S\times S)$ are each images block energy that detail coefficients image H_i、V_i、D_i of the i^{th} level wavelet decomposition is divided into $S\times S$ blocks. Since the wavelet energy feature is a combination of the each level wavelet energy feature, the local features can be reflected the image at different resolutions, different locations, different directions, it can be used as basis to system identification or diagnosis.

Typically, the various samples eigenvalues are required normalized before the image feature value is as the basis for fault diagnosis, it is better identification or diagnosis when the normalized eigenvalues replace the original features.

$$V = \left(V_{(1)}^1, V_{(2)}^1, \cdots V_{(3\times S\times S)}^1, \cdots V_{(1)}^M, V_{(2)}^M, \cdots, V_{(3\times S\times S)}^M\right) \tag{20}$$

$$V_{(j)}^i = \frac{\widetilde{V}_{(j)}^i}{\sum_{k=1}^{M} \sum_{l=1}^{3\times S\times S} \widetilde{V}_{(l)}^k} \quad (i = 1,\cdots,M; j = 1,\cdots,3\times S\times S \tag{21}$$

The feature vector V is the wavelet energy feature.

i^{th} level wavelet energy feature is as follow:

$$V^i = \left(V_{(1)}^i, V_{(2)}^i, \cdots V_{(3\times S\times S)}^i\right) \tag{22}$$

Wavelet energy feature is combined by the wavelet energy levels character, as the magnetic image, the wavelet energy feature of image is combined all levels coefficients of the wavelet energy feature by the wavelet decomposition, and multi-scale wavelet analysis of texture features is obtained, it can reflect the characteristics of the magnetic image distribution.

VI. THE DIAGNOSIS ALGORITHM OF THE MAGNETIC IMAGES

A. *Improved BP Algorithm*

To speed up the learning speed of the network, the improved BP network learning algorithms- Momentum - adaptive learning rate BP algorithm is used when the weights and thresholds are adjusted. The algorithm synthesis the advantage of momentum BP algorithm can avoid training process causes local minima during and adaptive variable learning rate back-propagation (VLBP) algorithm has character of weight adjustment smooth and short training time.

Momentum BP algorithm: when the momentum BP algorithm amend its weight, it not only to consider the error role in the gradient, but also it consider the change trends in the error surface. It adds a proportional the previous weight change value in the each weights change, and according to the back-propagation method to generate a new weight change. Its essence is through a momentum factor to transfer the impacts of weight change in the last time. The weight adjustment formula with additional momentum factor is as follow:

$$mc = \begin{cases} 0 & SSE(k) \succ 1.04 \cdot SSE(k-1) \\ 0.95 & SSE(k) \prec SSE(k-1) \\ mc & \text{other} \end{cases} \tag{23}$$

k is the training times, mc is the momentum factor, it is generally 0.95.

Adaptive Variable Learning Rate Back-propagation, aimed at ensuring the algorithm is stable, the convergence speed of network is faster, and the learning time is short. The learning rate is appropriately adjusted by the error surface. The weight of the correction value is checked whether it really lowers the error function. The adjustment formula of adaptive variable learning rate Back-propagation is as follow:

$$\eta(k+1) = \begin{cases} 1.05\eta(k) & SSE(k) \prec SSE(k-1) \\ 0.7\eta(k) & SSE(k) \succ 1.04 \cdot SSE(k-1) \\ \eta(k) & other \end{cases} \tag{24}$$

The selection of initial learning rate η(0) is very arbitrary.

Figure 7 and Figure 8 respectively show error convergence graph in the normal BP algorithm and improved BP algorithm when the network structure parameters are same.

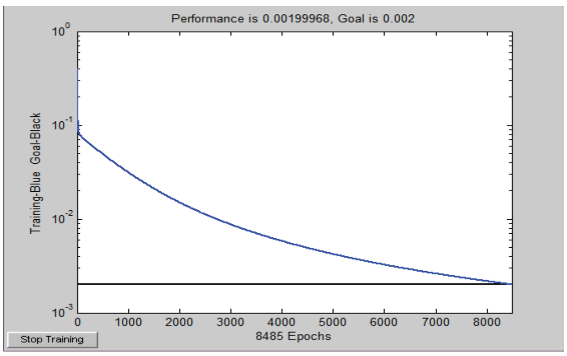


Figure 7. Error convergence graph of ordinary BP algorithm

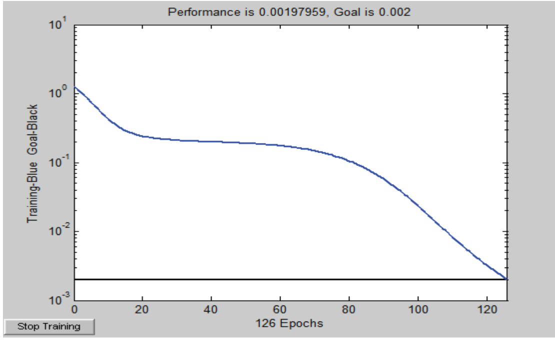


Figure 8. Error convergence graph of improved BP algorithm

It can be seen from Figure 7 and 8, the number of network training improved BP algorithm uses momentum-adaptive learning rate is much less than ordinary BP algorithm, it is the high diagnostic accuracy. It indicates that it is a very effective training method.

B. The integration diagnosis of wavelet analysis and improved BP network

The magnetic image is resolved by wavelet packet analysis method, the wavelet energy eigenvalues are extracted when the corresponding wavelet coefficients are obtained. Wavelet energy features normalized are as neural network input sample, the network is trained by using improved BP neural network algorithm, and circuit board fault diagnosis is achieved. When the circuit board runs, it will inevitably happen one way or another failure, the effective and timely diagnosis of these main failures are effective means to ensure the normal operation of the board. Table 1 shows 5 common component failure modes of the circuit board.

Because of failure modes and failure causes have one to one relationship, that is, a magnetic image sample corresponds to a failed state. In the paper, the magnetic image features in the circuit board failure mode is as the network input, the corresponding failure cause is as the network output to train the neural network.

TABLE I. PCB FAILURE MODE AND FAILURE MECHANISM ANALYSIS

fault symptoms		Fault reason		
failure mode	**fault sample**	**fault symbol**	**failure category name**	**failure category encoding**
x1	I1.jpg	y1	LM8361 fault	00001
x2	I2.jpg	y2	DS-3 U4 fault	00010
x3	I3.jpg	y3	DS-3 U5 fault	00100
x4	I4.jpg	y4	DS-3 U6 fault	01000
x5	I5.jpg	y5	DS-3 U7 fault	10000

Because the pixels of image is too much, and there are many redundant information, magnetic image three layer wavelet energy feature information $X = (x_1, x_2, \cdots, x_9)$ is extracted is as input of neural network, fault causes $Y = (y_1, y_2, \cdots, y_{10})$ is as output, the failure mode is caused different failure is as the training sample and learning, it establishes the corresponding relationship between failure modes and the fault cause. Table 2 is the coefficients energy eigenvalues in different failure modes 3 layer wavelet decomposition of the board magnetic image.

The characteristic values in accordance with equation (21) were normalized. Its failure mode coding is as a neural network corresponding output sample to train the neural network, and the output sample indicates the relative between the input magnetic image information and the component failure. The output samples are shown in Table 3.

Finally, by using the same failure mode of the different magnetic images (non-fault training samples), during the corresponding extracting wavelet energy feature is as the neural network input, judging fault diagnosis, verifying the diagnose ability of network. Test results are shown in Table 4.

TABLE II. THE INPUT SAMPLE OF WAVELET ENERGY EIGENVALUES

Sample	Level 1			Level 2			Level 3		
	Horizontal	vertical	Diagonal	Horizontal	vertical	Diagonal	Horizontal	vertical	Diagonal
1	0.2814	0.0384	-0.0112	0.3507	0.0467	-0.0016	0.2849	0.0031	0.0077
2	0.5094	-0.2391	-0.0350	0.6307	-0.2114	0.0230	0.5435	-0.2151	-0.0058
3	0.4839	-0.1187	-0.0131	0.7172	-0.1456	-0.0034	0.3905	-0.2957	0.0495
4	0.4835	-0.0168	0.0060	0.3353	-0.0107	-0.0281	0.2352	0.0044	-0.0086
5	0.1778	0.0419	0.0120	0.2476	0.2196	-0.0127	0.2437	0.0894	-0.0193

TABLE III. THE DESIRED OUTPUT CHARACTERISTICS OF NEURAL NETWORK

Circuit State	y1	y2	y3	y4	y5
Element 1 failure	0	0	0	0	1
Element 2 failure	0	0	0	1	0
Element 3 failure	0	0	1	0	0
Element 4 failure	0	1	0	0	0
Element 5 failure	1	0	0	0	0

TABLE IV. TEST RESULTS

Input data	y1	y2	y3	y4	y5
Element 1 failure	0.0035	0.0008	0.0072	-0.0013	0.8998
Element 2 failure	0.0008	-0.0016	0.0049	0.9360	0.0003
Element 3 failure	-0.0022	0.0081	0.9221	0.0069	0.0053
Element 4 failure	-0.0034	0.8982	0.0071	-0.0025	-0.0008
Element 5 failure	0.9243	-0.0009	-0.0046	0.0010	0.0106

Test results from Table 4 can be seen, the recognition results of the network is more accurate in given the different components failure mode, and its deviations with network desired outputs are very small, the SSE (sum of prescribing error)between analog output and the desired results are 0.1000. The identify effect is ideal. Network performance is stable and reliable, the network design is successful. The system also shows it is feasible and reliable method based on the magnetic image analyzing the circuit board fault diagnosis.

VII. CONCLUSION

In the circuit board fault diagnosis process, the magnetic detection technology is introduced. The gray, median filtering, gray-scale transformation, histogram equalization and related image processing techniques of the magnetic image are studied when the magnetic image is as the test data. To extract the wavelet energy feature of the magnetic image to determine whether it is a failure occurs in pre-test board or not, the improved BP algorithm is melted into the magnetic image fault diagnosis process, which has an advantage of the weight adjustment smooth and a short training time, so the speed is fast, low cost, high accuracy of fault diagnosis. It can play a larger role, it accords with rapid and quick, intelligent direction trend of the fault diagnosis to the circuit board system debugging, monitoring and diagnosis.

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