

Multi-dimensional neural network and its application in fault diagnosis of analog circuits

Zhao Dezan^a, Xing Jun^{b,*}, Wang Zhisen

(School of Food Science and Technology, Dalian Polytechnic University, Dalian 116034, China)

^a1183489276@qq.com, ^bandeyeluguo@sohu.com

Corresponding Author: Xing Jun

Keywords: Analog circuits fault diagnosis; dimensional neural network; wavelet transform ;principal component analysis

Abstract. When a man classifies an object, he makes a comprehensive judgment after a plurality of feature extraction and classification. Based on the phenomenon and in accordance with the theory of one-dimensional neural network, the concept and theory of multi-dimensional neural network is put forward, which is applied in the field of analog circuit fault diagnosis. Firstly, wavelet is used for feature extraction and principal component analysis is applied for dimension reduction. Then, multi-dimensional neural network is added as a classifier to classify. Finally, a decoder is used for final judging categories. Experimental results show that the proposed network architecture used for fault diagnosis of analog circuits can effectively improve the accuracy of diagnosis.

1. Introduction

The core of the electronic device is electronic circuit which is classified into analog and digital. Due to the characteristic of limited state of the digital circuit, its failure diagnosis is relatively simpler than analog circuit. What's more, the characteristic of tolerance and non-linear of analog circuit components makes the diagnosis problem more complicated. The most commonly used method of analog circuit fault diagnosis consists of approximation method, parameter identification method, fault dictionary method and so on. With the development of the times, wavelet analysis^[1-3], immune genetic algorithm^{[4][5]}, neural networks^{[6][7]}, support vector machines^[8], particle swarm optimization^[9], PCA (principal component analysis) and other smart algorithms have also been introduced into the field. Neural network with vagueness and other characteristics is very suitable for analog circuit fault diagnosis. The traditional structure of the neural network is one-dimensional, whose classification accuracy of fault diagnosis is not high. In real world, when a man classifies an object, he makes a comprehensive judgment after a plurality of feature extraction and classification. For example, when a man wants to recognize another people's face, he makes a comprehensive decision after extracting a plurality of features of ears, nose, mouth, etc. Based on this phenomenon, and according to the traditional one-dimensional neural network architecture, the concept of multi-dimensional neural network is proposed. Experiment results show that the multi-dimensional neural network can be applied to analog circuit fault diagnosis with high accuracy.

2. Principle

2.1 Basic Principle

Based on the characteristics of an object having a plurality of features, the concept of multi-dimensional neural network is proposed, extending the traditional one-dimensional neural networks to multi-dimensional and improving the recognition performance.

Multi-dimensional neural network diagram is shown in Figure 1.

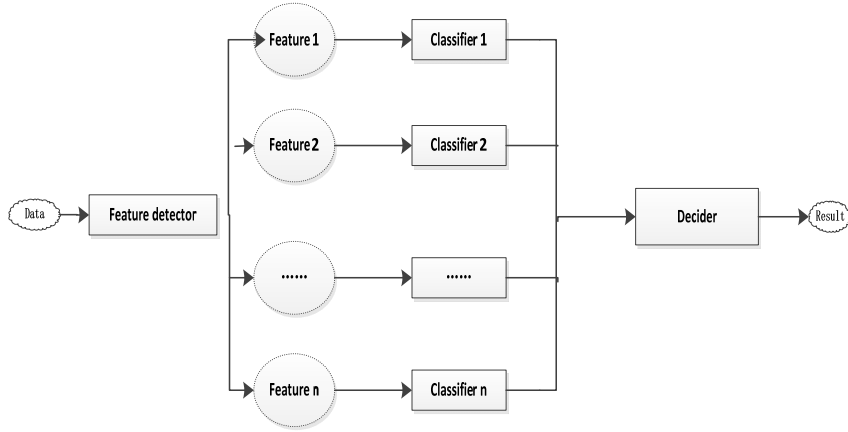


Fig.1 Diagram of multi-dimensional neural network

Specific data processing flow is as follows:

- 1) Get training feature of Training data by feature extractor.
- 2) Classifier is trained by the extracted feature of training data
- 3) Extract feature of test data
- 4) Test the classifier by the extracted feature of test data
- 5) Make result that accounts for a large proportion of results as the final comprehensive judgment result.

In this article, features are extracted by wavelet from different scales and directions, PCA is used for dimensionality reduction, multi-dimensional neural network is used as a classifier for classification, and the final decision is carried out using the decoder. The multi-dimensional neural network is an extension of the traditional one-dimensional network structure.

The traditional one-dimensional neural network is shown in Figure 2.

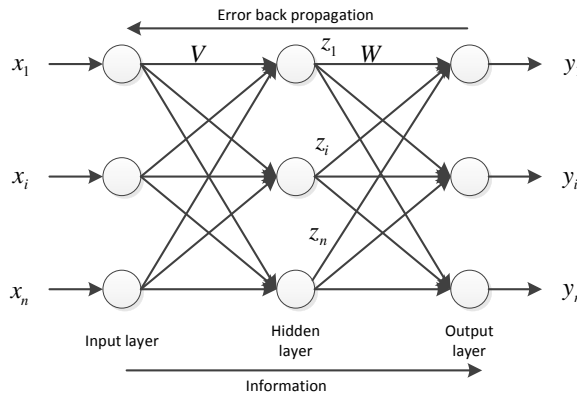


Fig.2 Structure of one-dimensional neural network

Standard formula of weight adjustment is shown in Equation (1):

$$\Delta \omega = \eta \delta y \quad (1)$$

In Formula (1), $\Delta \omega$ is the value of weight adjustment, δ is the local gradient, η is the learning rate, y is the output signal of last layer.

Structure of four-dimensional neural network is shown in Figure 3.

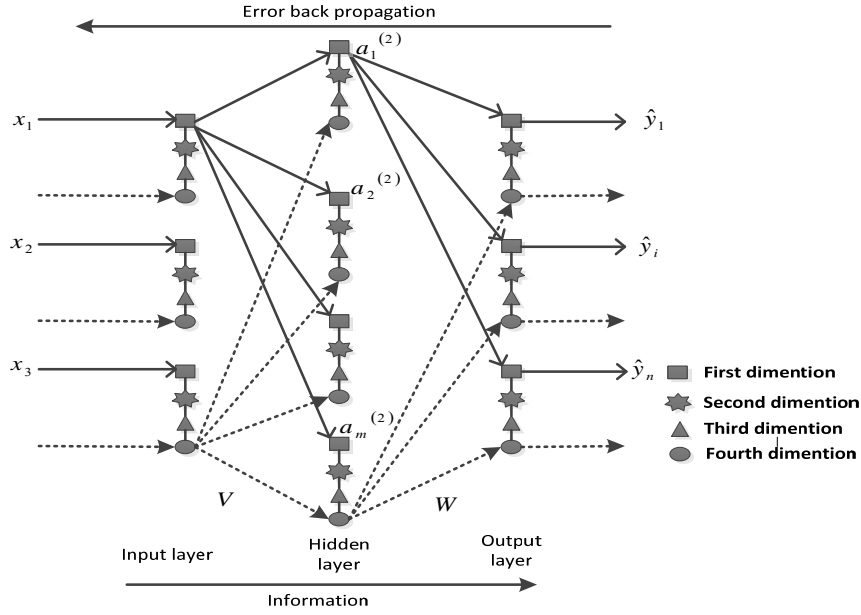


Fig.3 Structure of four-dimensional neural network

As can be seen from Figure 3, the nature of four-dimensional neural network is to combine four parallel one-dimensional neural networks, working with wavelet transform and principal component analysis, making the network have a good capability of parallel data processing.

2.2 Feature extraction by wavelet

Features should be extracted to go on processing the data. Feature extraction have a variety of means, including Gabor transform which is an important tool for feature extraction and is widely used in pattern recognition and image processing. In this paper, Gabor wavelet transform is based on the formula (2) (3) (4) (5).

$$g_{uv}(x, y) = \frac{k^2}{\sigma^2} \exp\left(-\frac{k^2(x^2 + y^2)}{2\sigma^2}\right) \cdot \left[\exp\left(ik \cdot \begin{pmatrix} x \\ y \end{pmatrix}\right) - \exp\left(-\frac{\sigma^2}{2}\right)\right] \quad (2) \quad k = \begin{pmatrix} k_x \\ k_y \end{pmatrix} = \begin{pmatrix} k_v \cos \varphi_u \\ k_v \sin \varphi_u \end{pmatrix} \quad (3)$$

$$k_v = 2^{\frac{v+2}{2}} \pi \quad (4)$$

$$\varphi_u = \mu \frac{\pi}{K} \quad (5)$$

$g_{uv}(x, y)$ is Gabor function while v is the scale of Gabor filter and u is the direction.

2.3 Dimension reduction by PCA

Since the size of feature data is large, the data must be processed by dimension reduction. PCA method is the commonly used for dimension reduction. Assuming a group of data that has m items and n dimensions, the basic dimensionality reduction steps is shown as follows:

- 1) Arrange the raw data by column to compose matrix X of n rows and m columns.
- 2) value of X minus the mean of all the value of the row respectively.
- 3) Find the covariance matrix.
- 4) Find the covariance matrix eigenvectors and corresponding eigenvalues.
- 5) Arrange the feature vector by the corresponding eigenvalues in a matrix by row from top to bottom. take the first k rows as matrix P .
- 6) $Y = PX$ is the final data whose dimensionality is k .

3. Experiment

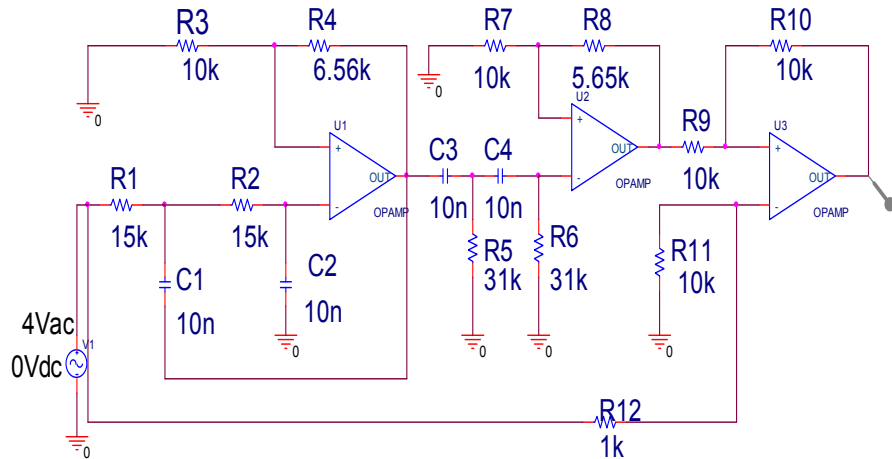


Fig.4 Three order band-elimination filter

Parameter value of each element is shown in Figure 4. The normal tolerance of resistance is 5% and the normal tolerance of capacitance is 10%. The resistor breaks down when the resistance value is between 5% and 50% of normal value while the capacitance value is between 10% and 50%. 3000 Monte-Carlo analysis of this circuit is respectively done by the software PSPICE for ten kinds of fault conditions, normal status, $R2 \uparrow$, $R2 \downarrow$, $R3 \downarrow$, $R6 \downarrow$, $R7 \downarrow$, $R9 \downarrow$, $C2 \downarrow$, $C2 \uparrow$, which is respectively coded as 0 0 0 000001 to 1 0 0 0 0 0 0 0 0.30000 items of data is obtained, and each item has 684 sampling points. 20000 items is used as the training data while 10000 items is used as the test data.

Firstly, each item data is transformed from 30 scales and 20 directions using wavelet. Although the size of each data after processing is still 684, the total data has been changed to the size of $30 * 20 * 684$. The amount of data is large, so dimensionality reduction methods must be used. In this paper, PCA is used to process data for dimension reduction, reducing each dimension of the data to 80, thereby greatly reducing the amount of data. Finally, multi-dimension neural network classifier is used for classification of dimensionality reduction data. The results are shown in Table 1.

Table 1 Comparison of accuracy rates of neural networks with different dimension

| Code | Status | Number of dimensionality | | |
|-------------------|-----------------|--------------------------|-------|-------|
| | | 1 | 2 | 3 |
| 0 0 0 0 0 0 0 0 1 | Normal | 32.4% | 84.3% | 91.4% |
| 0 0 0 0 0 0 0 1 0 | $R2 \uparrow$ | 64.4% | 87.4% | 92.4% |
| 0 0 0 0 0 0 1 0 0 | $R2 \downarrow$ | 85.0% | 80.9% | 94.5% |
| 0 0 0 0 0 1 0 0 0 | $R3 \downarrow$ | 71.6% | 84.3% | 93.5% |
| 0 0 0 0 1 0 0 0 0 | $R6 \downarrow$ | 74.9% | 82.4% | 92.4% |
| 0 0 0 1 0 0 0 0 0 | $R7 \downarrow$ | 60.5% | 81.3% | 93.5% |
| 0 0 1 0 0 0 0 0 0 | $R9 \downarrow$ | 70.7% | 86.7% | 91.8% |
| 0 1 0 0 0 0 0 0 0 | $C2 \downarrow$ | 75.4% | 80.4% | 93.5% |
| 1 0 0 0 0 0 0 0 0 | $C2 \uparrow$ | 72.3% | 86.7% | 90.4% |

It can be seen from Table 1 that the accuracy of identification increases as the dimension becomes higher. When the dimensionality is three, the neural network can accurately determine the fault.

4. Conclusion

This paper proposes the concept of multi-dimensional neural network and applies the theory to analog circuit fault diagnosis. Compared with the traditional one-dimensional neural network, multi-dimensional neural network can improve the accuracy of diagnosis. And the higher the dimension is, the more accurate the diagnosis is. Meanwhile, the structure can also be applied to image recognition, voice recognition and other fields. In other words, this structure has significance of guidance in practical engineering applications.

The experiment also found that the running time increased with increased dimensions. The next work is to improve the program running speed.

Acknowledgments

Project supported by the National Natural Science Foundation of China: 61374154

* Corresponding author

Reference

- [1] Aminian M, Aminian F. A Modular Fault-Diagnostic System for Analog Electronic Circuits Using Neural Networks With Wavelet Transform as a Preprocessor. *IEEE TRANSACTIONS ON instrumentation and measurement*. 2007, 56(5):1546-1554.
- [2] Zhigang Liu, Zhiwei Han, Yang Zhang. Multiwavelet Packet Entropy and its Application in Transmission Line Fault Recognition and Classification. *IEEE Transactions on Neural Networks and Learning Systems*, 2014, 25(11):2043-2052.
- [3] Rajamani, P, Dey D, Chakravorti S. Cross-correlation aided wavelet network for classification of dynamic insulation failures in transformer winding during impulse test. *IEEE Transactions on Dielectrics and Electrical Insulation*, 2011, 18(2):521-532.
- [4] Yanghong Tan, He, Yigang, Chun Cui. A Novel Method for Analog Fault Diagnosis Based on Neural Networks and Genetic Algorithms. *IEEE TRANSACTIONS ON instrumentation and measurement*, 2008, 57(11):2631-2639.
- [5] Mahdiah J, Farhad R. Fault Detection in Analogue Circuit Using Hybrid Evolutionary Algorithm and Neural Network [J]. *Analog Integrated Circuits and Signal Processing*, 2014, 80(3):551-556.
- [6] Weilin Li, Monti A, Ponci F. Fault Detection and Classification in Medium Voltage DC Shipboard Power Systems With Wavelets and Artificial Neural Networks. *IEEE TRANSACTIONS ON instrumentation and measurement*, 2014, 63(11):2651-2665.
- [7] Lifan Yuan, He Yigang, Jiaoying Huang. A New Neural-Network-Based Fault Diagnosis Approach for Analog Circuits by Using Kurtosis and Entropy as a Preprocessor. *IEEE TRANSACTIONS ON instrumentation and measurement*, 2010, 59(3):586-595.
- [8] Fangming Ye, Zhaobo Zhang, Chakrabarty, K. Board-Level Functional Fault Diagnosis Using Multikernel Support Vector Machines and Incremental Learning. *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, 2014, 33(2):279-290.
- [9] Sheikhan M, Shabani, A.A. PSO-optimized modular neural network trained by OWO-HWO algorithm for fault location in analog circuits [J]. *Neural Computing and Applications*, 2013, 23(3):519-530.