Image Recognition Technology in Rotating Machinery Fault Diagnosis

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Abstract: A new diagnostic method for rotating machinery is presented based on image recognition technology. This method focuses on the vibration state parameter image. 3-D spectrum is created with raw vibrating signals, then, smoothing, filtering, and feature extracting are applied by using Wavelet Packet transformation to extract and mine feature information in the state parameter image of rotating machinery. Fault diagnosis of rotating machinery is realized by using artificial immune recognition algorithm. This new method can improve accurate rate and automatic diagnosis level of fault diagnosis for rotating machinery. Furthermore, this method also can be applied in other diagnosis fields.

Keywords: fault diagnosis; technology of image recognition; artificial immune

1 Introduction

Rotating machinery is essential equipment in industries like petrochemical, metallurgy, electric power, aviation, spaceflight, etc. Once the fault happens, it will result in massive loss and safety things. Therefore, the research of fault diagnose for rotating machinery is important and urgent.

Ordinary diagnosis technique for rotating machinery including: the diagnosis method based on probability statistics time series model[1,2], the pattern recognition method based on Bayesian decision rules[3], the signal processing method based on Wavelet Packet analytic fractal geometry[4], and intelligence diagnosis method based on neural network or artificial immune[5-7], etc. All of above methods are based on signal processing technology, not utilized with plenty of state image in the process of rotating machinery starting and stopping, like3-D spectrum, axis orbit image, trend image, amplitude-frequency characteristics curve, phase-frequency characteristics curve, and so on. However, in former fault diagnosis it is more convenient to extract information from time waveform, spectrum map and wavelet packet image. Compared with those some kinds of information especially in the multi-dimension image is hard to be automatically extracted and described with knowledge language. Most of information in multi-dimension images is not utilized sufficiently except that some in 2-D axis orbit feature recognition is finitely utilized. Therefore, diagnosis result is greatly affection; application and spreading of diagnosis techniques are limited.

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According to the limitation of feature extraction method for multi-dimensions image information, application of those information is absent in fault diagnosis for rotating machinery, leading to the descent of diagnosis result and spreading of diagnosis techniques. This method focuses on the vibration state parameter image. First of all, 3-D spectrum is created with raw vibrating signals, then, smoothing, filtering, denoise, and feature extracting are applied using Wavelet Packet transformation to directly extract and mine feature information in the state parameter image of rotating machinery. Fault diagnosis of rotating machinery is realized by use of artificial immune recognition algorithm. A real case of 600MW modulated gas-turbine is studied, including various faults, like unbalance, misalignment, flow-induced vibration and bearing pedestal looseness. It's demonstrated that this new method is able to improve significantly accurate rate and automatic diagnosis level of fault diagnosis for rotating machinery. Also, this method can be applied in diagnosis for other device..

2 Feature extraction

Image recognition technology isn't better utilized in rotating machinery fault diagnosis. One of the primary reasons is that it is difficult to extract image feature. The main fault of the most rotating machinery can be diagnosed through vibration image recognition method. But fault feature in the image can not be inefficiently extracted by use of traditional feature extraction method. The accurate rate of fault diagnosis is very low. Wavelet Packet transformation [10,11] is a more meticulous time-frequency analysis means which can efficiently extract all kinds of fault information in rotating machinery vibration image and which is an efficient method for fault feature extraction of image. Machinery fault state is shown by every frequency composition energy change in vibration image. From this point, Based on wavelet packet decomposition coefficient single-branch recon-

struction, the method that each frequency composition signal's energy is used to build machinery fault feature vector is presented in this paper. Each frequency composition energy' change is directly used to show machinery fault state in this method which doesn't need systematic model structure.

3 Wavelet packet transformation

Wavelet Packet transformation is a time-frequency analysis method of signal. It has merit of multi-resolution analysis and has the capacity of expressing signal local feature in time field and frequency field. Wavelet Packet decomposition can divide frequency band into many layers and further decompose high frequency part which isn't detailed divided in multi-resolution analysis. According to analyzed signal characteristic relative frequency band is elected in self-adapting, which makes Wavelet Packet decomposition match with signal spectrum. Therefore, Wavelet Packet decomposition can detect instantaneous abnormal phenomenon in normal signal and show its composition. When inputting a signal containing abundant frequency composition, owing to Wavelet Packet has different function of restraint and strength for different frequency composition of signal, some frequency composition is restrained and others is strengthened, which makes signal energy to be reduced in some frequency band and to be enhanced in other frequency band. Therefore, energy differentia of each frequency composition can be used to analyze signal differentia [12].

Image structure and texture are shown respectively in different frequency band. Contour information is mainly presented in the part of relative and lower frequency. Meanwhile, texture details information and all kinds of noises are shown in the part of relative higher frequency. When image texture is clear, the gray scale obviously changes and the contrast becomes high in some image fields, it indicates that some feature frequency component is more abundant in frequency field. On the other hand, when image texture is fuzzy, the gray scale unobvious changes and the contrast becomes low, and opposite feature frequency component is little. Therefore, Wavelet Packet decomposition can be used to obtain relative information which each frequency band contains in image and to analyze image texture feature.

4 Computing total energy of every frequency band

After decomposing original image by three layers wavelet packet, its wavelet packet coefficients is a two-dimension signal, low frequency coefficients show image texture information, high frequency coefficients show noise. Different articulation of image show different energy in wavelet packet coefficients. If $S_{2,j}(j=0,1,2,\ldots 15)$is supposed, corresponding energy is $E_{2,j}$ (j=0,1,2, …,15) which is given by:

$$E_{2,j}=\sqrt{\sum_{k=1}^{n}\sum_{l=1}^{m}a_{j,k,l}^{2}} \tag{1}$$

In the formula, $a_{j,k,l}$(j =0,1, …,15,k=1, 2, …,n, l=1, 2,…,m) show gray scale of discrete point reconstruction of image. The image size is $n\times m$.

Feature vector which shows image feature is constructed by elements which are energy of reconstructed signal which is decomposed by image Wavelet Packet. Feature vector X as follows:

$$X=[E_{2,0},E_{2,1},E_{2,2},E_{2,3},E_{2,4},E_{2,5},E_{2,6},E_{2,7},E_{2,8},E_{2,9},E_{2,10},E_{2,11},E_{2,12},E_{2,13},E_{2,14},E_{2,15}]$$

$$E=\left(\sum_{j=0}^{15}\left|E_{2,j}\right|^{2}\right)^{1/2} \tag{2}$$

$$X=\left\lfloor E_{2,0}/E,\quad E_{2,1}/E,\quad \cdots\quad E_{2,15}/E\right\rfloor \tag{3}$$

Vector X is the normalization feature vector.

5 Image Recognition Technology

The usual methods are Distance function method, Bayesian classification method, fault tree method and so on in fault feature recognition. With the development of theory of fuzzy set, neural network technology and the deepening of relative field, such as computer technology and so on. Fault recognition technology is increasingly intellectualized. At present, the research field in artificial immune system is relative fewer because of its complication. Through learning about outside material's natural withstanding mechanism technology, developed artificial immune based on immune mechanism provides evolutionary learning mechanisms of unsupervised learning, self-organizing, etc, and combines with some merits of learning system such as classifier, neural network and so on. It has strong capacity of processing robustness information, and provides a new capacity of solving complex problem. Artificial immune system has successfully been used in some fields such as image recognition, etc. For example, David F. McCoy [10] firstly took negative selection algorithm method to be successfully used in segmentation of remote sensing image in 1997. De Castro [11] presented clone selection algorithm which has function of continual learning and memory. The algorithm is successfully used in engineering practical problem of character recognition, Multiple Objective Optimization and traveler in 2000. In 2001, Srividhya Sathyanath [13] took immune genetic algorithm to be successfully used in colour image classification, and improved classification accurate rate compared with directly matched algorithm. It took a good foundation for that artificial immune system is successfully used in recognition of rotating machinery state parameter image.

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6 Fault diagnosis instance analysis

System consists of HP and IP cylinder rotor, low- pressure cylinder rotor1, low-pressure cylinder rotor2, motor rotor, exciter rotor. There are nine bearing and five-spans. The power installation of this test-bed uses 55KW variable-frequency motor to output rotating speed and power through PRENIC inverter, and uses HG0G-C2 type gearbox. Lubrication system of test-bed supplies oil to every bearing with independence oil supply system. The type of BENTLY3000XL8mm eddy current sensor is stalled on every bearing seat. Output of 1 mm is 7.87v. In the process of test, the sampling frequency is thirty two times as rotating speed. The sample time is 0.64s. The highest working rotating speed of rotor is 3200 rounds per minute. The collected signals are input into computer by A/D card, which are prepared for data analysis. Otherwise, it installs the type of WP401B oil film pressure sensor and the type of WB2PK-184M3 integration temperature sensor to monitor pressure and temperature of oil film in this place bearing.

In order to testify this method is effective, four states are tested on rotor-bearing system test-bed of 600MW supercritical steam unit turbine. Four states are normal state of rotor, rotor unbalanced fault, rotor misalignment fault and bearing loose fault. The component contains five parts which are 600MW supercritical steam unit turbine rotor-bearing system, power system, lubrication system, steam supply system, signal acquisition and analysis system.

7 Conclusion

A new diagnostic method for rotating machinery is presented based on image recognition technology. This method focuses on the vibration state parameter image. 3-D spectrum is created with raw vibrating signals, then, smoothing, filtering, and feature extracting are applied by using Wavelet Packet transformation to extract and mine feature information in the state parameter image of rotating machinery. Fault diagnosis of rotating machinery is realized by using artificial immune recognition algorithm. This new method can improve accurate rate and automatic diagnosis level of fault diagnosis for rotating machinery. Furthermore, this method also can be applied in other diagnosis fields.

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Reference

[1] Zhu Dachang.Image recognition technology in rotating machinery fault diagnosis based on artificial immune. Smart Structure and System, Vol.5, no.3,pp209-221,May,2009.

[2] Wang Tao, Liu Nian, Xie Chi, Sun Kejin. Study of fault diagnosis in brushless machines based on artificial immune algorithm. IEEE 2006 International Symposium on Industrial Electronics, Vol. 3, pp: 1779-1782, 9-13 July,2006.

[3] Elhadet M, Das S, Nayak A. A novel artificial-immune-based approach for system-level fault diagnosis. The First International Conference on Availability, Reliability and Security, 2006.

[4] Wei Dou, Zhan-sheng Liu, Xiaowei Wang. Application of image recognition based on artificial immune in rotating machinery fault diagnosis. The First International Conference on Bioinformatics and Biomedical Engineering, pp: 1047-1052, 6-8 July, 2007.

[5] Caslellini P, Scalise A, Scalise L. A 3-D measurement system for the extraction of diagnostic parameters in suspected skin nevoid lesions. IEEE Transactions on Instrumentation and Measurement, Vol. 49, no. 5, pp: 924-928, 2000.

[6] Ortiz E, Syrmos V. Support vector machines and wavelet packet analysis for fault detection and indentification. International Joint Conference on Neural Networks, pp: 3449-3456, 16-21 July, 2006.

[7] Shen M, Sun L, Chan F.H.Y.. Method for extracting time-varying rhythms of electroencephalography via wavelet packet analysis. IEE Proceedings of Science, Measurement and Technology, Vol. 148, no. 1, pp: 23-27, 2001.

[8] Gao Guohua, Zhu Yu, Duan Guanghuang, Zhang Yongzhong. Intelligent fault identification based on wavelet packet energy analysis and SVM. The 9th International Conference on Control, Automation, Robotics and Vision, pp:1-5, 5-8 Dec, 2006.

[9] McCoy D. F., Devarajan V. Artificial immune systems and aerial image segmentation. 1997 IEEE International Conference on Systems, Man and Cybernetics, Vol. 1, pp: 867-872, 12-15 Oct, 1997.

[10] Dasgupta D, Ji Z, Gonzalez F. Artificial immune system (AIS) research in the last five years. The 2003 Congress on Evolutionary Computation, Vol. 1, pp: 123-130, 8-12 Dec, 2003.

[11] Sathyanath S, Sahin F. An AIS approach to a color image classification problem in a real time industrial application. 2001 IEEE International Conference on Systems, Man and Cybernetics, Vol. 4, pp: 2285-2290, 7-10 Oct, 2001.

[12] Alexander Tarakanov, Dipankar Dasgupta. A formal model of an artificial immune system. Biosystems, Vol. 55, no. 1-3, pp: 151-158, 2000.

[13] Bennett C H,Steck J E,Behrman E C.Quantum information and computation[J].Nature,2000,404(3):247-255.

[14] Kak S C.On quantum neural computing[J].Information Sciences,1995,13(2):143-160.

[15] Karayiannis N B,Purushothaman G.Fuzzy pattern classification using feed forward neural networks with multilevel hidden neurons[J].IEEE International on Neural Networks,1994,5(2):127-132.

[16] Gopathy P,Nicolaos B,Karayiannis N B.Quantum neural networks:Inherently fuzzy feedforward neural networks[J].IEEE Transactions on Neural Networks,1997,8(3):679-693.

[17] Behman E C,Chandrashkar V G,Wang C K.A quantum neural network computes entanglement[J].Physical Review Letters,2002,16(1):152-159.

[18] Narayanan A,Menneer T.Quantum artificial neural network architectures and components[J].Infirmation Sciences,2000,128(3):231-255.

[19] Zhou J,Qing G,Adam Krzyzak.Recognition of handwritten numerals by quantum neural network with fuzzy fea-

tures[J].International Journal on Document Analysis and Recognition,1999,2(1):30-36.

[20] Upadhyaya Belle R, Akorska Malgorzata. A modular approach for the diagnostic analysis of dynamic systems using stochastic time-series models. IEEE Transactions on Systems, Man and Cybernetics, Vol. 12, no. 6, pp: 794-804, 1982.

[21] Zhinong Li, Junjie Sun, Jie Han, et al. Parametric bispectrum analysis of cracked rotor based on blind idendification of time series models. The Sixth World Congress on Intelligent Control and Automation, Vol. 2, no. 21-23, pp: 5729-5733, 2006.

[22] Brandt Y, Jervis B. W, Maidon Y. Circuit multi-fault diagnosis and prediction error estimation using a committee of Bayesian neural networks. IEE Colloquium on Testing Mixed Signal Circuits and Systems, 23 Oct, pp: 7/1-7/7, 1997.

[23] Khan M.A.S.K, Radwan T. S, Rahman M. A. Real-time implementation of Wavelet packet transform-based diagnosis and protection of three-phase induction motors. IEEE Transactions on Energy Conversion, Vol. 22, no. 3, pp: 647-655, 2007.

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