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Research Article

Intelligent Method for Faults Diagnosis of Rolling Bearings via Chaos Optimized Support Vector Machine

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Abstract: In a transmission system, the faults of rolling bearings occur very frequently. A tiny crack may cause huge damage on the system. Therefore, it is essential to detect the faults of rolling bearings. However, the single fault has been researched extensively while very few works have been done on the multiply faults detection (i.e., simultaneous existence of 2 or more fault types). To deal with this problem, a new method is proposed to diagnosis multi-fault of rolling bearings in this study. The vibration data was analyzed in the time and frequency domains. Then the Support Vector Machine (SVM) was used to recognize the fault patterns. In order to enhance the generalization ability of the SVM diagnosis model, the Chaos algorithm was adopted to optimize the structural parameters of the SVM. Experimental tests have been carried out on a fault simulation setup. The fault detection results show that the proposed method is competent for the multi-fault diagnosis of rolling bearings. The fault detection rate is beyond 90.0%.

Keywords: Chaos optimization, fault diagnosis, rolling bearings, SVM

INTRODUCTION

Rolling bearings are key components in transmission systems. Once failures happen on the rolling bearings, the transmission efficiency of the system will degrade significantly. Hence, it is very crucial to monitor the condition and detect the faults in rolling bearings. As rapid development of automation, the transmission systems become more and more complicated. The failures of rolling bearings become complex and diverse in category. It is very difficult to detect weak faults. However, detecting faults of rolling bearings can prevent the transmission systems from damages and thus prolong their serve life (Li *et al*., 2011a, b, 2012a, b). The fault diagnosis is therefore very important and advanced applied technologies should be proposed to deal with this problem.

In the transmission systems, a crack or a fracture is common fault types for rolling bearings. In practice, there are always multiply faults, such as combined faults of crack and fracture. However, a lot of earlier studies have researched the vibration signals of rolling bearings to detect single fault. The fault diagnosis performance should be implemented for the multiply faults. However, this issue was often ignored in previous study.

In the fault diagnosis it is usually involved with 2 procedures. One is the feature extraction and the other is fault pattern recognition. As for the feature extraction of rolling bearings, the time and frequency domains analysis on the vibration signals is the most useful method. Lots of advanced signal processing algorithms have been establishes to deal with the vibration signal and extract informative fault features for the diagnosis of rolling bearings. These algorithms include Fast Fourier Transform (FFT), wavelet transform and Hilbert Huang transform, etc. As for the fault pattern recognition, the intelligent classifiers have been proposed. The most representative models are the Artificial Neural Network (ANN) and Support Vector Machine (SVM). However, the ANN model often requires a large amount of training. If not enough training is provided the fault detection performance is unsatisfactory. In contrast, the SVM does not need extensive training samples and works well even with a very small amount of samples. Hence, the SVM is very powerful for fault pattern recognition. Li *et al*. (2011) used the QPCA and SVM algorithms to diagnose rolling bearings faults. Their research results suggested that the SVM detection model is very efficient for the bearings fault diagnosis. Du *et al*. (2011) adopted the probability boxes theory and SVM to detect the bearing fault. Experiments verified their method. Sugumaran and Ramachandran (2011) employed the SVM model as a classifier to diagnose roller bearing faults. The experimental results showed high performance of the SVM based fault diagnosis approach. Nevertheless, SVM detection performance is affected by its structural

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parameters. The main reason is that it is difficult to determine the structural parameters of the SVM model (Zhao *et al*., 2011). To address this problem, a new intelligent fault diagnosis method using Chaos optimization and SVM technologies is presented for the rolling bearings in this study. The experiments have been conducted on a simulation set-up. The fault detection results demonstrate high performance of the newly proposed method. The multiply faults of the tested rolling bearings in the experiment rig can be detected correctly.

This study is organized as follows: In Section 2, the proposed faults diagnosis method based on the Chaos-SVM is introduced. The experimental result is presented in Section 3. The performance of the proposed diagnosis method is discussed. Conclusions are drawn in Section 4.

THE PROPOSED FAULT DIAGNOSIS METHOD

Assuming that sample set $S = \{(x_j, y_j) | j = 1,2,\dots,n\} \in R^p \times \{-1,1\}$ is linear separable and exist a hyper plane $\omega^T x + b = 0$ that makes arbitrarysample (x_j, y_j) satisfy the following condition:

$$\begin{cases} \omega^T x_j + b \geq +1 \,(when\ y_j = +1) \\ \omega^T x_j + b \leq -1 \,(when\ y_j = -1) \end{cases} \tag{1}$$

where,
ω : The weight vector
b : A constant

Then the goal of SVM is to find the optimal hyper plane $\omega^T \mathbf{x} + b = 0$ and make (ω, b) subject to the following convex quadratic optimization problem:

$$\begin{cases} \min(\frac{\|\omega\|^2}{2}) \\ s.t.\ y_j(<\omega, x_j> + b) \geq 1 \end{cases} \tag{2}$$

When the sample set S is not linear separable, a slack variable ξ is needed such that Eq. (2) can be rewritten as:

$$\begin{cases} \min(\frac{\|\omega\|^2}{2} + C\sum_{j=1}^{n}\xi_j) \\ s.t.\ y_j(<\omega, x_j> + b) \geq 1 \end{cases} \tag{3}$$

where, C is a constant.

Equation (3) is typical convex quadratic optimization problem. To solve this problem the Lagrange multiplier method as well as kernel trick have been introduced. The RBF kernel is defined as:

$$K(a,b) = \exp(\frac{\|a - b\|^2}{2\sigma^2}) \tag{4}$$

where, σ is a constant.

For the RBF kernel based SVM, the parameters, i.e., parameter C and parameter σ have great influence on the generalization ability of SVM model. Therefore, in order to improve the generalization ability of SVM model, the Chaos algorithm is employed to optimize the SVM parameters in this study. The Chaos algorithm has many special advantages in parameter optimization. Its periodicity is useful for SVM to avoid local minima or precocity. In this study, the Logistic chaos (Zhao *et al*., 2011) optimization is adopted. It firstly maps the parameter C and parameter σ into Logistic chaotic spaces. Then it searches the periodicity and randomicity of chaotic variables. After several iterations, the best SVM parameters can be lastly obtained. The flow chart of the proposed diagnosis method for the rolling bearing is shown in Fig. 1.

EXPERIMENTS AND RESULTS

To verify the effectiveness of the proposed fault diagnosis method, experimental tests have been carried out on a rolling bearings experimental set-up. Two multiply fault types as well as the normal bearings have been investigated. The 2 faults include inner race crack and erosion and outer race crack and erosion. Figure 2 shows the time and frequency spectra of the vibration signals of the rolling bearings under the 3 working conditions. It can be seen that in the figure it is difficult to determine the existence of the faults and distinguish different fault types. Hence, the wavelet packet transform was used to decompose the original signal into 3rd transform was used to decompose the original signal into 3rd level and extract 8 kurtosis

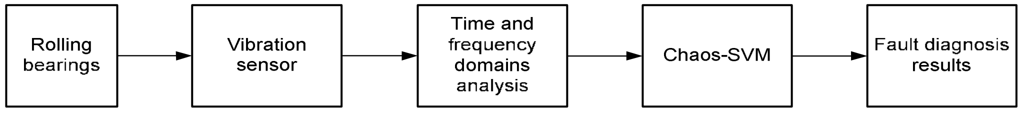

Fig. 1: The process of the proposed diagnosis method

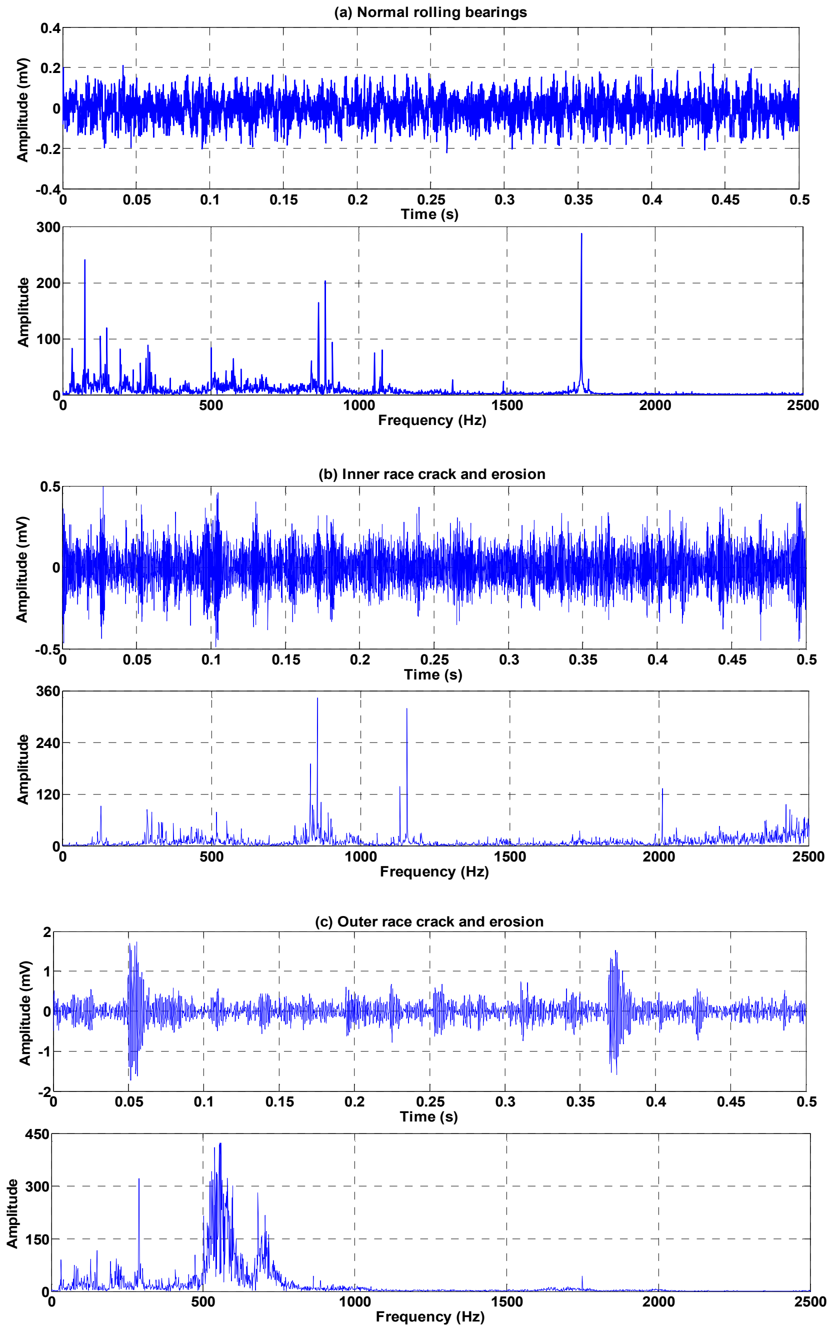

Fig. 2: The time and frequency spectra (a) normal rolling bearings, (b) inner race crack and erosion, (c) outer race crack and erosion

values of the sub-wavelet signals. Then, these 8 kurtosis values were treated as the input of the SVM to recognize the fault patterns of the rolling bearings. Figure 3 shows the SVM performance.

It is noticeable in Fig. 3 that the SVM model can classify the input data into 3 categories. The fault detection rate was 91.0% or better in the experimental analysis. Table 1 compares the performance of SVM and Chaos-SVM. It can be seen that the Chaos-SVM increases the fault detection precision by 2.0% when compared with SVM. Hence, the proposed method is efficient for the fault detection of rolling bearings.

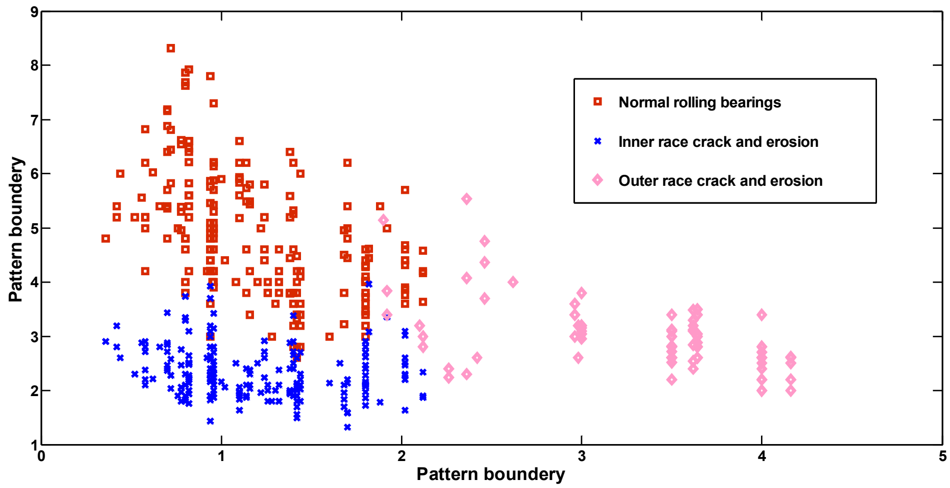

Fig. 3: The SVM fault recognition results

Table 1: The fault diagnosis results

Training		Testing	
SVM	Chaos-SVM	SVM	Chaos-SVM
89.5%	91.5%	89.0%	91.0%

CONCLUSION

Rolling bearings have been used extensively in industrial engineering. To prevent the transmission line from broken-down, a new fault detection method base on the Chaos optimization and Support Vector Machine (SVM) is proposed in this study. The innovation of the new method is that it employed the Chaos algorithm to optimize the structural parameters of the SVM model for multi-fault diagnosis of rolling bearings. A series of experiments have been conducted in a test rig. The detection results show that the proposed method can detect the multi-fault precisely. Future work will evaluate the new method in practice application.

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