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Research article

A hybrid intelligent multi-fault detection method for rotating machinery based on RSGWPT, KPCA and Twin SVM

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ABSTRACT

This paper proposes a hybrid intelligent method for multi-fault detection of rotating machinery, in which three methods, i.e. including the redundant second generation wavelet package transform (RSGWPT), the kernel principal component analysis (KPCA) and the twin support vector machine (TWSVM), are combined. Firstly, RSGWPT is used to extract feature vectors from representative statistical characteristics in the decomposition frequency band, and then the KPCA in the feature space is performed to reduce the dimension of features and to extract the dominant features for the following classification. Finally, a novel support vector machine, called twin support vector machine is used to construct a multi-class classifier. Inputting superior features to this classifier, the condition of the monitored machine component can be determined. Experimental results demonstrate that the proposed hybrid method is effective for multi-fault detection of rotating machinery. The TWSVM is also indicated that has better classification performance and faster convergence speed than the normal SVM.

1. Introduction

Rotating machinery is widely used in industry. Its unexpected failure may result in significant economic losses and safety problems [1,2]. At present, because of the vibration signals carry a great deal of information representing mechanical equipment health conditions, the vibration based signal processing technique is one of the principal tools for diagnosing mechanical faults [3,4]. However, fault diagnosis methods only using advanced signal processing techniques require a good deal of expertise to apply them successfully, but most of cases in practical are multi-classed, such as in the rotating machinery classifying. Reliable and fast hybrid intelligent multi-fault detection system which can monitor the working condition of machinery and automatically specify whether it has faults or not and specify the fault type and the fault severity. Therefore, the hybrid intelligent multi-fault detection of machine and its key components (such as bearings and gears) is very important research work and is hotspot and frontier of international and domestic academics [5].The hybrid intelligent multi-fault detection includes three main steps: feature extraction, feature reduction and state classification.

Feature extraction plays an important role in machine fault classification. There are a number of feature extraction methods based vibration signals in the literature. A popular and noted example is the time-frequency analysis method of wavelet transform (WT), which has obtained great success in machine fault diagnostics for its distinct advantages [6]. However, WT cannot split the high frequency band where the modulation information of machine fault always exists. This difficulty can be overcome by wavelet package transform (WPT) which contains complete decomposition at every level. WPT is widely used as a feature extraction tool for machine fault detection and diagnosis [7]. In the case of WT or WPT, it is crucial to select an appropriate wavelet function for a special problem. Engineering experiences also show that the wavelet should be selected according to the fault feature to be detected. The second generation wavelet transform (SGWT) proposed by Sweldens [8] is a new wavelet construction method using lifting scheme in time domain. It abandons the Fourier transform as a design tool for wavelets and is no longer defined as translation and expansion of one fixed function. Compared with the classical wavelet transform, the lifting scheme in SGWT requires less computation cost and allows fast integer-to-integer wavelet transform. In addition, it always satisfies perfect reconstruction no matter what kind of prediction operator and update operator are chosen. Recently, the application of SGWT and

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second generation wavelet packet transform (SGWPT) for condition monitoring and fault diagnosis of rotating machinery has attracted more attention [9,10]. However, one limitation of the SGWT is that it does not have time invariant property. After using this method, the decomposition results of a delayed signal are not the time-shifted version of those of the input signal, and it may lead to the loss of useful faulty information that is critical for feature extraction and fault diagnosis. The redundant lifting scheme possesses time invariant property and overcomes the disadvantage of the lifting scheme by getting rid of the split step and zero padding of the prediction operator and updating operator. The approximation and detailed signals at all levels are of the same length as the input signal in the redundant lifting scheme [11,12]. WPT based on the redundant lifting scheme can not only afford more detailed local time-frequency description of the signal but also inhibit the frequency aliasing components of the analysis result because of the elimination of the split and merge step in the decomposition and reconstruction stage [13]. In this paper, the RSGWPT is used to decompose the vibration signal and then its transform coefficients are used to extract characteristic features for further classification.

However, the extracted characteristic features still have the problem of high-dimensional and excessive redundant information. It is thus necessary to reduce the number of features before classification. Principal components analysis (PCA) is a well-known method applied to dimensionality reduction and feature selection. PCA is the linear dimension reduction method, which assumes a linear relationship between process variables. But the actual equipment monitoring process includes nonlinearity. Kernel principal components analysis (KPCA), a widely used nonlinear feature extraction method, is one type of nonlinear PCA developed by generalizing the kernel method into PCA [14]. Cho et al. [15] have shown the superiority of KCA for fault detection to the linear PCA. Thus, in this paper, the KPCA is used to achieve the selection of the most sensitive features.

There are many methods for mechanical fault pattern recognition, including artificial neural networks (ANN) [16], support vector machine (SVM) [17], Bayesian network-based classifiers [18], hidden Markov models [19], and so on. The recent research has witnessed the evolution of SVM as a powerful paradigm for machine fault classification, for examples, bearing [20], gear [21], rotor [22] and induction motor [23]. But one of main issues with the conventional SVM is to obtain the solution of a complex quadratic programming problem (QPP). The computational complexity of SVM is $O(l^3)$, where l denotes as the total size of training data. It limits the application of SVM to large-scale data.

To solve this problem, Jayadeva et al. [24] introduced a stand-alone nonparallel hyperplane classifier, called twin support vector machine (TWSVM). It seeks two non-parallel proximal hyperplanes such that each hyperplane is closer to one of the two classes and is at least one distance from the other. For this purpose, it solves a pair of relatively smaller QPPs, instead of a large one in the standard SVM. Therefore, the learning speed of TWSVM is faster than that of the standard SVM. The recent research has witnessed the evolution of TWSVM as a powerful paradigm for pattern classification [24–26]. But the TWSVM have not yet been investigated for rotating machinery fault diagnostics. Therefore, the TWSVM is used to establish an intelligent fault classifier in this paper.

Based on above discussion, a hybrid intelligent method for the multi-fault detection of rotating machinery mechanical equipment is proposed in this paper, which combined three advanced signal processing methods, is based on i.e. RSGWPT, KPCA and TWSVM. The flowchart of the proposed method is shown in Fig. 1. In this

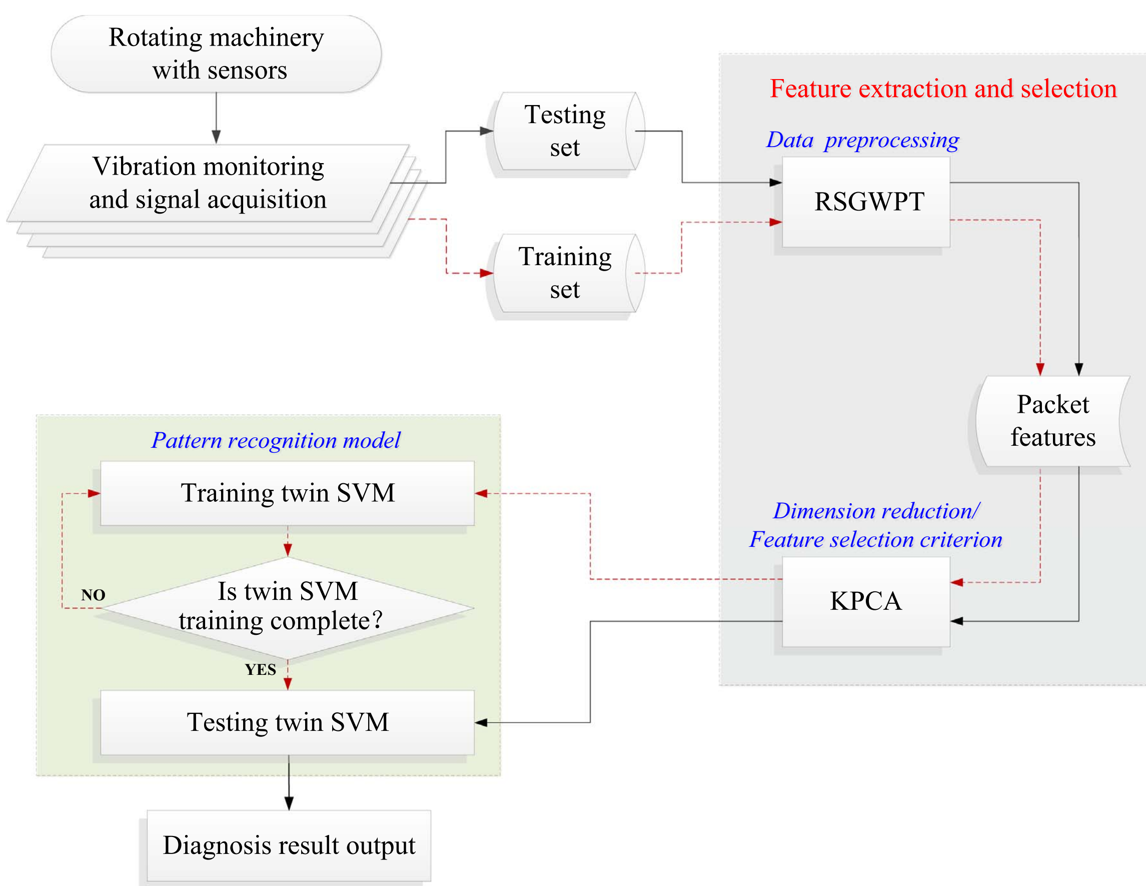

Fig. 1. The flowchart of the learn model for fault identification.