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Fault diagnosis of an automotive air-conditioner blower using noise emission signal

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ABSTRACT

This paper presents a neural network system for automotive air-conditioner blower fault diagnosis using noise emission signals. The proposed system consists of three parts: data acquisition, feature extraction, and fault classification. First, the noise emission signals are obtained from a condenser microphone and recorded by a data acquisition system. The signals are split into several wavelet nodes without losing their original properties by wavelet packet decomposition (WPD) by entropy criterion. Meanwhile, the energy values are calculated from these nodes for feature extraction. Finally, the energy features are used as inputs to neural network classifiers for identifying the various fault conditions. The WPD integrated with energy features is an efficient method for feature extraction. The energy features are efficient in reducing the dimensions of feature vectors and in the time consumed for training and classifying. In the experimental work, the probabilistic neural network (PNN) is used to verify the performance and compared with the conventional back-propagation neural network (BPNN) technique. The experimental results demonstrated the proposed technique can achieve powerful capacity for estimating faulty conditions quickly and accurately.

1. Introduction

There is no denying mechanical equipments play an important role in modern life. It is necessary to produce all kinds of equipments for requirements to help us perform tasks in daily life. Therefore, condition monitoring and health evaluation of mechanical systems is an important issue. In recent years, many researches on fault diagnosis have been proposed. For example, vibration signals are extensively utilized as the sources of fault diagnosis in many fields (Lin & Qu, 2000; Nikolaou & Antoniadis, 2002). However, the vibration signals have to be measured by a contact measurement device such as an accelerometer. Some conditions are still not suitable for this kind of contact measurement device. On the contrary, feature extraction based on acoustic emission is an alternate characteristic for fault diagnosis in mechanical systems. In the present study, an application of fault diagnosis in automotive air-conditioner blower using noise emission signals is proposed.

Due to the complex properties of acoustic signals, it is not feasible to tell the feature of fault conditions from the raw acoustic signals. To solve this problem, the fast Fourier transform (FFT) was commonly used (Benbouzid, 2000). This method depends on the variations in frequency to distinguish different faulty conditions. When the signals are transferred to the frequency domain by FFT, these signals lose the original information in the time domain. It is also vulnerable to the interference of background noise (Junsheng, Dejie, & Yu, 2005). Then, short-time Fourier transform (STFT) was developed to overcome above problems. Unfortunately, it is an immovable time–frequency analysis limited to the window lengths for the entire signal. In recent researches, wavelet transform (WT) has been widely applied in signal analysis, such as machine faulty monitoring, classification, and recognition (Peng & Chu, 2004). The main advantage of WT is it belongs to an adjustable window size. Therefore, the WT possesses fine local properties in both the time domain and frequency domain. However, there is a drawback of WT, the traditional WT is able to get good resolution on low frequency but it cannot precisely analyze the features of high frequency. In this paper, an expansion method of WT, wavelet packet decomposition (WPD) is used for signal analysis. The WPD can split the entire time domain and frequency domain. It provides an alternative to analyzing non-stationary signals (Zarei & Poshtan, 2007).

The signals decomposed by WPD will be used as inputs for neural network classifiers. However, the option in the dimension of data is an important subject for training. Redundant data will consume too much time training and classifying. To solve this problem, it is essential to reduce the dimensions of data. There are many conventional recognition methods based on the feature vector distances, but they are not precise enough (Lou & Loparo, 2004). The energy calculation for feature selection and entropy criterion for decomposition are used in this paper. The entropy criterion is used in the procedure of wavelet packet decomposition. The wavelet nodes are obtained for each faulty signal after decomposition.

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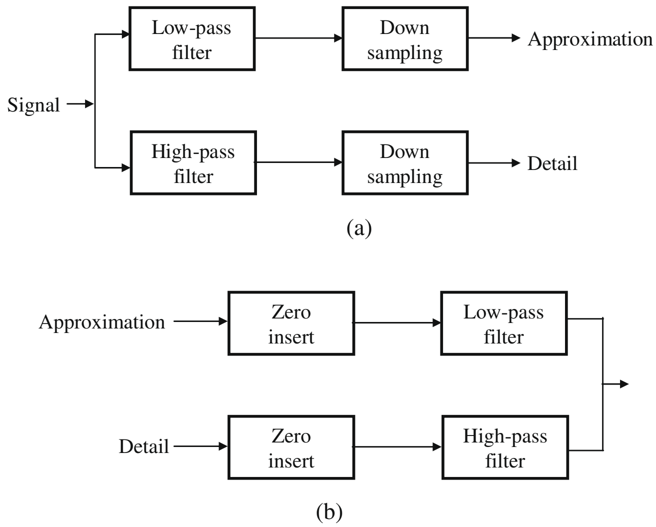

Fig. 1. Basic algorithm of the wavelet packet. (a) decomposition and (b) reconstruction.

The energy values are calculated for each signal separately. The dimensions of data decrease in a striking ratio through this way. Due to the facility and reliability of the energy calculation method, it has been widely adopted as a feature selection method (Ekici, Yildirim, & Poyraz, 2008).

The neural networks applied to recognition have been reported recently. In 1997, neural networks were used for diagnosing ball bearings (Subrahmanyam & Sujatha, 1997). In 2000, motor rolling bearing was diagnosed by the neural network (Li, Chow, Tipsuwan, & Hung, 2000). In 2004, application of the neural network in machine condition monitoring and fault diagnostics was proposed (Peng & Chu, 2004). In recent years, the probabilistic neural network (PNN) has become one of the important approaches in the field of classification, and the results show PNN is effective in classification. In 2008, an expert system for faulty diagnosis in internal combustion engines using PNN was developed. The PNN does not need iteration procedure. It is a major advantage for the PNN algorithm to spend less time on training and classifying (Wu, Chiang, Chang, & Shiao, 2008). In this paper, the PNN is used for training features of various conditions in an experimental automotive air-conditioner blower platform. To verify the performance of the PNN in a faulty diagnosis system, the back-propagation neural network (BPNN) is compared with the proposed PNN method. The principles of wavelet packet and neural network are described in the following sections.

2. Feature extraction of wavelet packet

2.1. Wavelet packet decomposition

The wavelet transform (WT) has been used in various fields, such as mathematics, physics, and engineering. The WT provides an alternative to non-stationary signal processing. In contrast to the fixed window size analysis in the short-time Fourier transform (STFT), the WT provides an adjustable window size. The window size is long for slow frequency variations and short for fast frequency variation. Therefore, the WT can provide better analysis of non-stationary signals.

Wavelet packet decomposition (WPD) is a generalization of orthonormal and compactly supported wavelet (Mallat, 1989). The WPD technique used in the present study is an extension of multi-resolution analysis (MRA). The wavelet packet can be described by the set of functions $\{w_n(x), n = 0, 1, 2, \ldots\}$ obtained from the following dilation equations.

$$w_{2n}(x) = \sqrt{2}\sum_{k=0}^{2N-1} h(k) w_n(2x-k), \tag{1}$$

$$w_{2n+1}(x) = \sqrt{2}\sum_{k=0}^{2N-1} g(k) w_n(2x-k), \tag{2}$$

where $h(k)$ is the low-pass filter, and $g(k)$ indicates the high-pass filter. The index n is the modulation parameter. The wavelet packet functions for $n = 1$ are termed the orthogonal scaling function and mother wavelet function, respectively

$$w_0(x) = \phi(x) \tag{3}$$

$$w_1(x) = \psi(x) \tag{4}$$

Therefore, the wavelet packet including the orthogonal scaling function and mother wavelet function is a set of recursive functions. According to MRA, the basic procedure of WPD algorithm is illustrated in Fig. 1, which can be split into two opposite steps. One is decomposition and the other is reconstruction. In the decomposition step, the given signal is convolved with the low-pass filter and the high-pass filter first, resulting in two coefficients, approximation and detail. Then, the signal filtered is

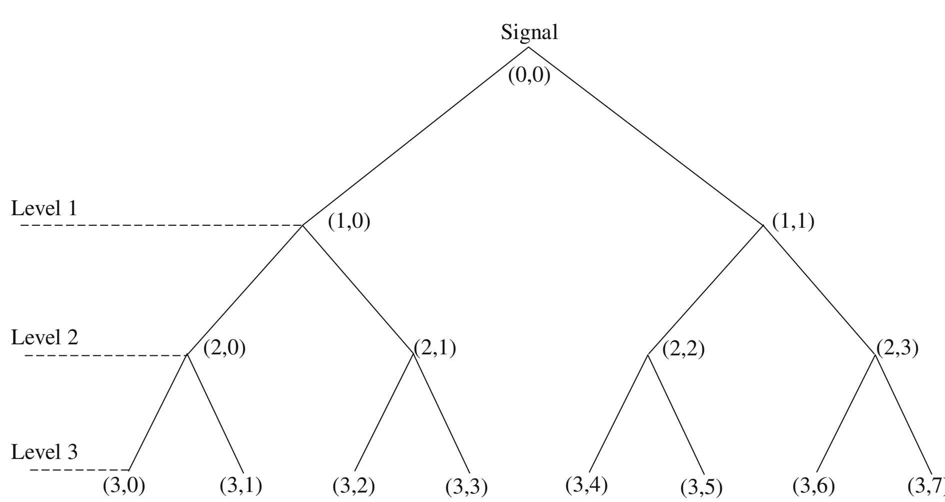

Fig. 2. Full decomposition tree of wavelet packet.