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Gearbox fault diagnosis using adaptive redundant Lifting Scheme

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Abstract

Vibration signals acquired from a gearbox usually are complex, and it is difficult to detect the symptoms of an inherent fault in a gearbox. In this paper, an adaptive redundant lifting scheme for the fault diagnosis of gearboxes is developed. It adopts data-based optimisation algorithm to lock on to the dominant structure of the signal, and well reveal the transient components of the vibration signal in time domain. Both lifting scheme and adaptive redundant lifting scheme are applied to analyse the experimental signal from a gearbox with wear fault and the practical vibration signal from a large air compressor. The results confirm that adaptive redundant lifting scheme is quite effective in extracting impulse and modulation feature components from the complex background.

Keywords: Adaptive redundant lifting scheme; Optimisation algorithm; Vibration signal; Fault diagnosis

1. Introduction

Gearboxes are key parts in a wide range of mechanical systems. It is very important to detect incipient fault symptoms from gearboxes. Usually, vibration signals are acquired from

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accelerometers mounted on the outer surface of a bearing housing. The signals consist of vibrations from the meshing gears, shafts, bearings, and other components. The useful information is corrupted and it is difficult to diagnose a gearbox from such vibration signals. Wavelet theory is a powerful tool for non-stationary signal analysis, and it has been successfully used in gearbox diagnosis. Boulahbal et al. [1] used the amplitude and phase maps of continuous wavelet transform together to extract fault features of a gearbox and obtained a more positive assessment of a tooth condition. Lin et al. [2,3] utilised the similarity between Morlet wavelet and an impulse shape, and detected tooth crack symptoms of a gearbox immersed in the noise. Loutridis et al. [4] used continuous wavelet transform and Hodlder exponents to classify gear faults and got better performance.

In all the wavelet techniques mentioned above, researchers usually selected an appropriate wavelet function from a library of previously designed wavelet functions to match a specific fault symptom. Different types of mechanical faults have different waveform characteristics, even one wavelet function is selected, and it is not always the best wavelet function to detect a specific fault symptom in a gearbox. New wavelet method is needed to overcome the drawback.

Lifting scheme is a spatial domain construction of biorthogonal wavelets developed by Sweldens [5–7]. It abandons the Fourier transform as design tool for wavelets, wavelets are no longer defined as translates and dilates of one fixed function. Compared with classical wavelet transform, Lifting scheme possesses several advantages, e.g. possibility of adaptive design, in-place calculations, irregular samples and integers-to-integers wavelet transforms. Lifting scheme provides a great deal of flexibility, it can be designed according to the properties of the given signal, and it ensures that the resulting transform is invertible.

In this paper, we develop a new wavelet method called adaptive redundant lifting scheme. It is based on lifting scheme and designed to capture the transient components of the gearbox vibration by adaptive decomposition. In Section 2, the theory of lifting scheme is reviewed briefly. The data-based optimisation algorithm is described in Section 3. The method of adaptive redundant lifting scheme is presented in Section 4. In Section 5, adaptive redundant lifting scheme is applied to analyse the vibration signals of an experimental gearbox and a large compressor gearbox. Comparison with lifting scheme is also shown. Conclusions are given in Section 6.

2. Lifting scheme principle

Lifting scheme is an entirely space domain wavelet construction. A typical lifting scheme procedure consists of three basic steps: split, predict and update [5–7].

Split: Let $x(n)$ be an original data set. In this step, $x(n)$ is divided into two disjoint even subset $x_e(n)$ and odd subset $x_0(n)$, where $x_e(n) = x(2n)$ and $x_0(n) = x(2n+1)$.

Predict: If the original signal has a local correlation structure, then the even and odd subsets are highly correlated. We predict the odd coefficients $x_0(n)$ from the neighbouring even coefficients $x_e(n)$, and the prediction differences $d(n)$ are defined as detail signal

$$d(n) = x_0(n) - P(x_e(n)), \tag{1}$$

Where $P = [p(1), \ldots, p(N)]^T$ is the prediction operator.