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A novel method based upon modified composite spectrum and relative entropy for degradation feature extraction of hydraulic pump

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ABSTRACT

Feature extraction is a key step of Prognostics and Health Management (PHM). To improve the feature performance, a method based upon the modified composite spectrum and relative entropy is proposed. The DCS algorithm is firstly presented by the modification of earlier composite spectrum for making fusion of multi-channel vibration signals. Considering Shannon entropy and Tsallis entropy, the DCS power entropy and singular entropy are initially extracted. According to max relation entropy criterion and gradual fusion strategy, the relative entropy algorithm is built to fuse the initial features into a new one, which is considered to be the degradation feature. Result of the application in hydraulic pump degradation experiment demonstrates that the proposed algorithm is feasible and the fused feature is effective to measure the performance degradation of pump.

1. Introduction

Being the key-point of the Conditional-Based Maintenance, Prognostics and Health Management (PHM) plays a more and more important role, which has been applied in modern weapons, such as F-35 [1–3]. Feature extraction is one of the key steps of fault diagnosis and prognostics. Varied from traditional features, the degradation features require high sensitivity to identify various performance degradation stages [4]. Meanwhile, the degradation experiment costs long time and the vibration signals during the degradation are very complex [5]. Therefore, fewer contributions are made in this filed. Yujing Wang [6] and Van Tungtran [7] extracted features by the analysis of the monitoring signal in time domain to realize the recognition and prognostic of bearing degradation. Zhao [8] and Tong [9] applied the Empirical Mode Decomposition (EMD) and wavelet transform analysis in single signal processing for feature extraction. These methods have achieved some expected purposes. Additionally, in our previous work [10], the vibration signal of hydraulic pump is processed by the Local Characteristic-scale Decomposition (LCD) modified by the high frequency harmonic for obtaining sub-signal with sensitive information. The DCT high order spectral entropies of Shannon and Tsallis are extracted to be the degradation features. However, these features are extracted only based on the single monitoring signal which may lead to information loses. Unlike traditional rolling bearing, hydraulic pump has its own structural characters. Striking from pistons and liquid compressibility and the coupling effect are all the factors for pump failure [11]. Taking the loose slipper for example, it is cause by the wear

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Nomenclature

Acronym

DCT	Discrete Cosine Transform
DCS	DCT – Composite Spectrum
SE	the Shannon Entropy
TE	the Tsallis Entropy
SPE	Shannon DCS Power spectral Entropy
TPE	Tsallis DCS Power spectral Entropy
SSE	Shannon DCS Singular Entropy
TSE	Tsallis DCS Singular Entropy
SVM	Support Vector Machine

Main parameters

$S_{CS}(f_k)$	composite spectrum
$X^r_{CS}(f_k)$	composite spectrum Fourier transform coefficient
$X^{r*}_{CS}(f_k)$	complex conjugate of $X^r_{CS}(f_k)$
B	the number of the sampled signals
M	the number of segments divided for DCT calculation
L	the length of each segment for DCT calculation
Bolt	the Boltzmann constant
Q	the number of system microstates
q	the non-scope parameter
K	the number of frequency bands
U	the reconstruction matrix for singular decomposition
O	the order of U
N	the number of features

between piston and slipper. Strikes of the interaction always transfer to the pump surface in various directions, which form the vibrations [12,13]. The fault information in single signal is too hard to directly achieve. Consequently, an novel method is required to make further and effective analysis on the multi-channel signals.

Normal methods for multiple signals are the weighted algorithm, the Kalman filtering algorithm and the wavelet analysis algorithm [14–16]. However, it seems difficult to select appropriate fusion weights for the weighted fusion algorithm [17]. Kalman filtering algorithm lacks of strict filtering functions for nonlinear systems [18]. During the sampling operation in the wavelet analysis fusion algorithm, some sensitive feature information may be lost. Since the Composite Spectrum (CS) is able to realize information fusion of various signals by calculating the correlative index and mutual power spectrum of neighboring signals [19]. It is also capable of taking advantages of detail information and extracting useful feature information [20]. Influenced by the multiplication of Fourier coefficient and its complex conjugate, it is easy to lose some feature information for CS. To solve this problem, some modification has to be made. As the spread of the Fourier transform, Discrete Cosine Transform (DCT) has the property of energy aggregation [21]. Its coefficients are sensitive enough to the change of energy [22]. Therefore, based upon the replacement of Fourier transform by DCT, the modified Composite Spectrum algorithm is proposed to make fusion of the multi-direction vibration signals of hydraulic pump for extracting sensitive degradation features.

The organization of the article is shown in the following: In Section 2, the modified Composite Spectrum is presented for multi-channel signals fusion. Meanwhile, modified Composite Spectrum power entropy and singular entropy, which are relatively defined in Shannon entropy and Tsallis entropy, are extracted as initial features; in Section 3, features fusion strategy is presented in detail; in Section 4, we simply indicate the hydraulic pump degradation experiment and confirm the results through the application of the proposed method on sampled vibration signals; while in Section 5, we draw some conclusions. In Section 5, some major nomenclatures are displayed.

2. Initial features extraction by the modified composite spectrum

2.1. The modified composite spectrum

Assume that the number of the sampled signals is B. Each signal is equally divided into n_s segments. Fourier transform is conducted on each segment. The CS is defined as [19]:

$$S_{CS}(f_k) = \sum_{r=1}^{n_s} X^r_{CS}(f_k) X^{r*}_{CS}(f_k)/n_s \tag{1}$$