SELECTION OF INFORMATIVE FREQUENCY BAND BASED ON THE LOCAL MAXIMA METHOD IN APPLICATION TO BEARING DIAGNOSTICS

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Abstract

Raw vibration signal acquired from the rotating machinery operating under industrial conditions usually contains strong contaminations from machines located nearby. Thus, simple methods, e.g. PSD, cannot detect frequencies specific for a particular local damage type and more accurate methods must be used for diagnostic purposes. In this paper we extend the idea of filtering raw vibration signal based on spectral kurtosis – measure of energy dispersion in time for each frequency bin obtained from the short-time Fourier transform. Our approach incorporates the local maxima method for enhancement of time-frequency map. Instead of kurtosis, we calculate weighted average of local maxima occurrence for each slice from spectrogram. The presented methodology is compared to the classical kurtosis. All the analysis are performed on real data from industry - raw vibration signals from bearing housing located nearby planetary gearbox.

1. Introduction

Optimal band selection for diagnostic purposes has been the subject of many previous papers. It has been shown by Ho and Randall [1] that changes of energy related to localized damage may be difficult to identify in the signal. Authors propose several methods of searching for informative signal. Most of them are based on kurtosis. Lin and Zuo [2] used kurtosis as a criterion for Morlet wavelet-based adaptive filtering, Bartelmus and Zimroz [3] proposed similar approach but with the use of simple band pass filter. Recently, the most famous examples are: the spectral kurtosis [4], the fast kurtogram [5, 6], the Protrugram [7] or modulation intensity distribution [8]. We propose an approach to find frequency band where the impulsive character of local damage is best seen. In other words, it is an attempt to express features visible on the time-frequency map in a selector, i.e. set of coefficients that for each frequency band measures its ability to detect wideband excitations. Healthy signal should reveal small coefficients similar for all frequencies. Signal acquired from the unhealthy machine should be identified by high coefficients for some particular frequency bands. Kurtosis based methods sometimes fail, especially when the diagnosed machine is operating under industrial conditions and accidental signals of character similar to fault are measured. Our approach deal with some situations when unwanted behavior of kurtosis is observed.

The paper is organized as follows. Section 2 contains a description of the methodology and its theoretical properties. In Section 3 we present results of our method on real data set from industry. The last section provides conclusions.

2. Methodology

One of the widely-used measures of energy disturbance for each frequency bin of spectrogram is kurtosis – normalized fourth central moment of the signal [9]. Signal from the damaged machine should reveal leptokurtic feature. It is known that kurtosis is very sensitive to single impulses which are expected during the measurement procedure under industrial conditions. Analysis based on kurtosis might result false-positives, e.g. when time-frequency map consists short in time high-energy intervals occurring in a narrow frequency band. This behavior can be noticed when machine is a part of the multistage system.

To deal with these problems we propose a novel measure of wide-band excitations occurrence based on the local maxima method for enhancement of time-frequency map. The enhanced spectrogram defined for the regular one $\{STFT(t, f)\}_{t\in T,\ f\in F}$ at point (t_i, f_j) is defined as follows:

$$ENH(t_i, f_j) = W(t_i)M(t_i, f_j), \tag{1}$$

where $W(t_i) = \frac{1}{\#F}\sum_{f\in F} M(t_i, f)$, $M(t_i, f)$ represents binary valued time series of the local maxima occurrence at t_i for a slice of spectrogram at frequency f, F and T are sets of frequencies and times, respectively, at which STFT is calculated. Because of random character of time series obtained from slices, we assume that local maximum occurs when value at the analyzed point is higher than the other values in its neighborhood of a fixed length. To check which bands are informative, we propose to calculate mean of the enhanced spectrogram slices for each frequency. Formula for our selector is:

$$S(f_i) = \frac{1}{\#T}\sum_{t\in T} ENH(t, f_i). \tag{2}$$

Even if a single wide-band excitation occurs, our selector will not increase as much as kurtosis. In real data analysis very often we observe that the impact of outliers on the first-order statistics is less than the fourth-order statistics. This method is also robust in case of narrow-band temporary increases of energy. This feature will appear on the enhanced spectrogram, but its impact on S will be reduced by the narrow-band character.

3. Real data analysis

In this section we will present results of novel procedure on the real data set – two raw vibration signals acquired on bearing housing. One of these signals represents vibrations of the pulley bearing in healthy condition and the second corresponds to the locally damaged one. Broader description of the data with several approaches tested on it is the subject matter of previous papers [10, 11]. The main reason to use advanced signal processing tools is strong contamination from the gearbox located nearby.

Sampling frequency of the signal is 19200 [Hz] and duration – 2.5 [s]. Parameters of STFT are: FFT length NFFT=512 points and non-overlapping Kaiser windows of length 125 each. Expected frequency fault is 12.69 [Hz] and corresponds to the inner race damage. Combining the STFT window length and the expected period of failure signal we choose the local maxima minimal neighborhood length of 11 adjacent STFT windows.

Regular and enhanced spectrograms which are the basis for kurtosis and the proposed selector are presented on Fig. 1.

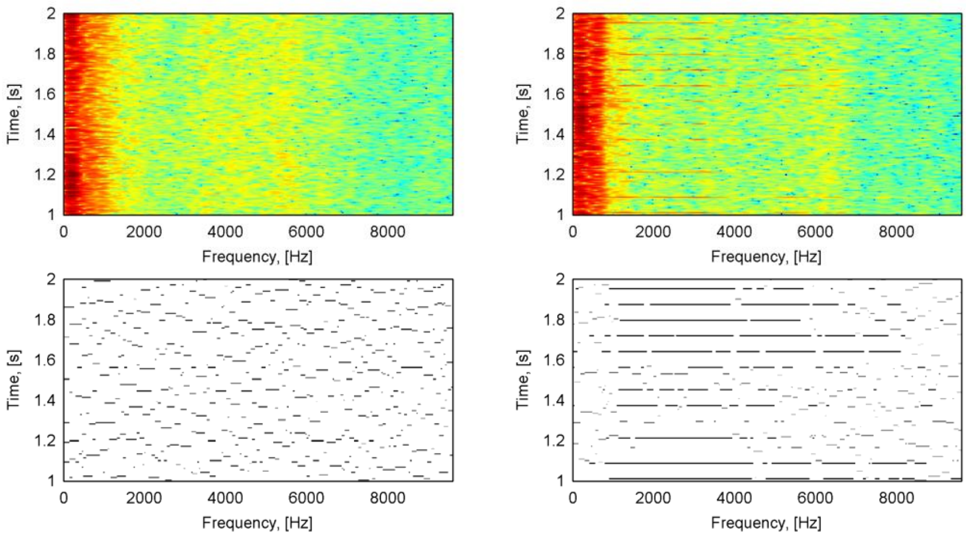

Fig. 1 Regular and enhanced spectrograms (only one second).

The local maxima method produces energy insensitive enhancement of spectrogram – behavior of local maxima in the high and low energy bands is similar.

Fig. 2 shows the normalized values of both analyzed selectors. The novel method reveals greater difference between signals derived from machines in healthy and unhealthy condition. What is more, differences between “healthy” and “unhealthy” signal is still significant at high frequency band, i.e. 6-8 [kHz]. The lowest and highest frequency bands (<1 [kHz] and >8 [kHz]) do not carry significant information about damage. Empirical analysis confirms the theoretical results – kurtosis for “healthy” signal has a false-positive at the frequency close to 1 [kHz]. This singularity is a real problem in the case of determining a threshold of the kurtosis value that separates the healthy and the unhealthy machine. Our novel selector has no significant singularities in the signal representing the machine in good condition. Therefore, to distinguish damaged machine from undamaged is easier.

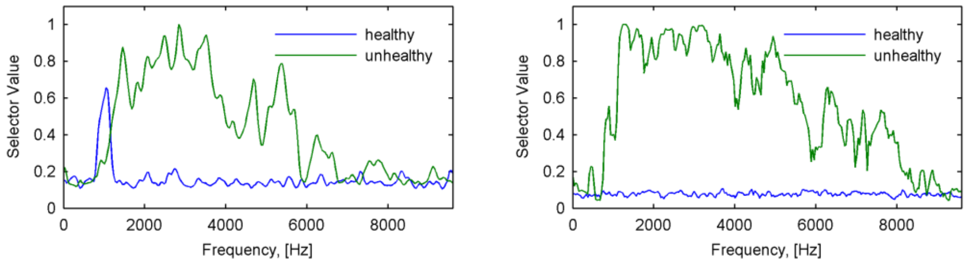

Fig. 2 Normalized selector value. Kurtosis (left panel) and novel selector based on the local maxima method (right panel).

4. Conclusion

In this paper a novel procedure of informative frequency band selection is presented. It can be used to detect local damage in the rotating machinery from the raw vibration signal. The methodology is an extension of previous approaches which incorporate the use of kurtosis for slices of time-frequency map. Instead of kurtosis, we propose to use selector based on the local maxima method. We have shown several theoretical properties of our method that make our method superior to kurtosis in diagnosis of machines operating in the industrial environment. Empirical analysis of the bearing vibration confirmed advantages of the proposed selector.

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