Denoising Vibration Signals of Rotating Machines Using Probability Density Function, Similarity Measure and Improved Thresholding Function

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ABSTRACT

In this paper, a new method for removing the noise from the vibration signals acquired the rotating machineries for its condition monitoring is presented. Firstly, each signal is decomposed into its modes using the empirical mode decomposition method. Then for distinguishing the noisy modes from the noise-free modes, the similarity measure between the probability density function of the raw signal and its modes is calculated. Finally, the noise-dominate modes are denoised by the improved thresholding function, and the denoised signal is reconstructed. In this study, the proposed method is implemented for denoising the simulated signal and real data corresponding to different bearing conditions. Finally, the kurtosis and the envelope spectrum of the denoised signal are calculated for detecting the fault presence and its type. The results show that the proposed technique is able to improve the quality of the reconstructed signals so that the sensitivity of the kurtosis factor to the defects presence in the inner and outer rings is increased. Also, the defects frequencies appear in the spectrum of the signals denoised, and the fault type can easily be detected. The results indicate that the proposed denoising technique is superior to the conventional empirical mode decomposition-based denoising method.

KEYWORDS

Vibration Signals Denoising, Empirical Mode Decomposition, Probability Density Function, Bearing Fault Diagnosis, Improved Thresholding Function

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1. Introduction

Rotary machines are one of the key components of the industrial equipment. The defects presence in these systems reduces the efficiency and, ultimately, permanently stops the operation of these devices. On the other hand, in most cases, the signals received by the sensors are accompanied by noise. This noise complicates processing the signals and prevents the extraction of useful features from them. Therefore, a method for denoising the signals that can remove unrelated information plays a key role in accurate troubleshooting of machines. Nguyen et al. [1] introduced a denoising technique based on empirical mode decomposition (EMD) method, soft thresholding function and Naïve Bayes classifier [1]. Nezamivand Chegini et al. [2] proposed a new strategy for denoising the vibration signals using empirical wavelet transform (EWT) method, the kurtosis factor and envelope spectrum. In another work [3], the authors have proposed a vibration signal denoising approach using the EWT method with common thresholding techniques. Komaty et al. [4] analyzed the heart-related signal using the EMD and Kullback–Leibler divergence criterion.

In this paper, a new technique is proposed to extract the characteristics that indicate the bearings working conditions. To achieve this goal, a method has been proposed which is based on the EMD, improved thresholding function and probability density function (PDF). For evaluating the proposed approach, this noise cancellation method has been used to troubleshoot the bearings.

2. The Proposed Denoising Approach

The signal *x(t)* which has noise *n(t)* can be considered as Eq. (1). In real-world applications, a noise-free signal *y(t)* is not available, and the goal is to achieve an approach that minimizes *n(t)* noise as much as possible and extract the reconstructed benign signal.

$$x(t) = y(t) + n(t) \tag{1}$$

The implementation steps of the proposed denoising method are as follows:

1- Decompose *x(t)* into its intrinsic mode functions (IMFs) by the EMD and calculate the PDF of the signal and the IMFs.

2- Obtain the distance between the signal PDF and the i^{th} IMF PDF according to the following equations:

$$similarity(i) = distance\big(PDF(x(t)), PDF(IMF_i(t))\big) \tag{2}$$

$$distance(P,Q) = \sqrt{\int_{-\infty}^{\infty} \big(P(Z) - Q(Z)\big)^2 dZ} \tag{3}$$

3- Determine the most appropriate IMF:

$$K_{th} = argmax\{PDF\ similarity(i)\} + 1 \qquad 1 \le i \le c \tag{4}$$

where The K_{th} boundary index corresponds to the IMF number after the maximum IMF. When K_{th} is determined, the first IMF up to the K_{th} are considered as noisy modes and the rest of the IMFs are considered as noise-free modes.

4- Denoise the noisy by the improved thresholding function [4] and reconstruct the signal:

$$\bar{y}(t) = \sum_{i \in \Omega_1} \overline{IMF_j}(t) + \sum_{k \in \Omega_2} IMF_k(t) + r_c(t) \tag{5}$$

where $\bar{y}(t)$ is the reconstructed signal, Ω_1 and Ω_2 are the noisy modes set and noise-free modes set, respectively. Also, $\overline{IMF_j}(t)$ is the j^{th} denoised mode, $IMF_k(t)$ is the k^{th} noise-free mode and $r_c(t)$ is the residual.

5- Calculate the kurtosis and envelope spectrum of the denoised signal for detecting the defect presence and the fault type, respectively.

3. Application of the Proposed Method for Real Data

3.1. Experimental Setup

This section uses data acquired by the CWRU[2] laboratory set [2]. Point defects on the bearing components with SKF 6205-2RS JEM specifications are created by means of the electrical machining methods. The vibration data are obtained with the sampling frequency of 12 kH. The defects created in the bearing components have a depth of 0.2794 mm and are considered in two different diameters of 0.1778 mm and 0.53434 mm. The vibration signals used in this study correspond to two rotational speeds of 1772 rpm and 1750 rpm.

3.2. Result and Discussion

The vibration signals for the defective outer ring are shown in Figure 1. The denoised signals by the proposed approach are illustrated in Figure 2. The appearance of fault impulses and the elimination of noise in the signal indicate the capability of the technique proposed in this paper. The kurtosis value for the noisy signals and denoised signals by the proposed method and the method in [5] is presented in Table 7. As can be seen in this table, the signals denoised by the proposed method have a higher kurtosis value compared to the method presented in [5].

[2] Case Western Reverse University (CWRU)

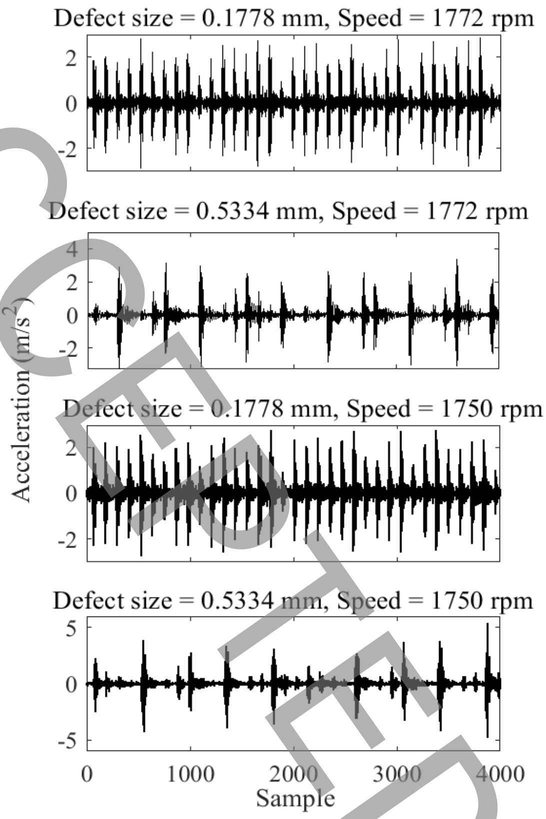

Figure 1. The vibration signals corresponding to the defective outer ring

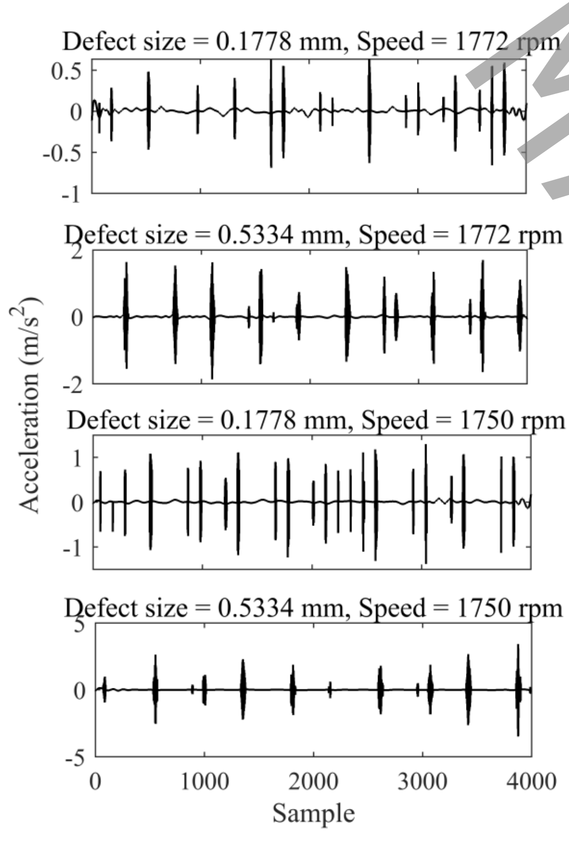

Figure 2. Denoised signals corresponding to the defective outer ring

Table 1. Comparison of the kurtosis value for outer ring vibration signals

Fault size (mm)	Speed (rpm)	Raw signal	Ref. [5]	This study
0.1778	1772	7.64	38.31	40.06
0.1778	1750	7.73	28.22	30.83
0.5334	1772	14.02	28.84	31.35
0.5334	1750	19.32	38.97	39.33

4. Conclusions

In this paper, a new noise removal approach based on empirical mode decomposition method, probability density function and improved thresholding was proposed. Then, this technique has been applied to identify the bearing defect at different rotational speeds. It was observed that the presented technique is able to eliminate the noise in the real data and maintain its useful information. In this paper, the kurtosis factor and spectrum of the denoised signals were used to identify the presence of a defect and its type, respectively. The results showed that this approach is able to distinguish between different bearing defectives.

5. References

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