



A novel Pareto-based Bayesian approach on extension of the infogram for extracting repetitive transients



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ABSTRACT

Two most important signatures of repetitive transients in the vibration signals of a faulty rotating machine are impulsiveness and cyclostationarity. In the newly proposed infogram, the time-domain and frequency-domain spectral negentropy were put forward to characterize these two aspects, respectively. However, in extension of the infogram to Bayesian inference based optimal wavelet filtering, only one spectral negentropy was employed in identifying the informative frequency band. To overcome its drawback, a novel Pareto-based Bayesian approach was proposed in this paper. The Pareto optimal solutions which can simultaneously maximize the time-domain and frequency-domain spectral negentropy were utilized in estimating the posterior wavelet parameters distributions. Moreover, the relationship between the impulsive and cyclostationary signatures was established by the domination. It can help balance the contributions due to these two aspects other than simply synthesize by the average weight in the infogram. Three instance studies including simulated and experimental signals were investigated to illustrate the effectiveness of the proposed method by challenging different noises and interferences. In addition, some comparisons with the aforementioned peer methods were also conducted to show its superiority and robustness in extracting the repetitive transients.

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1. Introduction

Vibration-based fault diagnosis of such key components as bearings and gears in rotating machines is always a hot research area in recent decades [1–7]. A localized defect occurred in the contact components can result in impulses in the vibration signal. In addition, these impulses often occur repetitively due to the rotating shaft with loads. However, the fault-induced repetitive transients [8] are generally hidden in heavy noises or along with some inevitable interferences, which makes it difficult to diagnosis. To deal with it, an effective way is to filter the original vibration signal through the resonance frequency band [9] or called as informative frequency band (IFB) [10]. So, the IFB selection is the key issue for the diagnosis of rotating machines.

In recent years, various methods have been devised for the IFB selection, and among them, the spectral kurtosis (SK) technique proposed by Antoni and Randall [11,12] has been found to be the most popular one [13]. In its implementation named fast kurtogram [14], kurtosis of the envelope signal was used to quantitatively depict impulsiveness in the signal. In this sense, a high kurtosis value can indicate the high impulsiveness of the corresponding frequency band. However, there are

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two risks associated with it. One is that a high kurtosis may result from the impulsive noises. The other is that few impulses rather than an impulse train can lead to a higher kurtosis. To overcome the aforementioned shortcomings, Barszcz and Jabłoński [15] gave an alternative approach - protrugram. In locating the optimal frequency band, kurtosis of the envelope spectrum amplitudes was utilized to describe the cyclostationarity [16] of the repetitive transients. But, apparently, both the fast kurtogram and the protrugram are partial solutions in capturing the impulsive or cyclostationary signatures for the diagnostic.

As a breakthrough, Antoni [17] newly proposed the infogram method, in which the negentropy of the squared envelope (SE) was utilized for characterizing the impulsiveness in generating the SE infogram and negentropy of the squared envelope spectrum (SES) was utilized for characterizing the cyclostationarity in generating the SES infogram. Based on the uncertainty principle of entropy, average negentropy of the time-domain and frequency-domain was developed for generating the AVE infogram, which combined these two features of the fault-induced impulses. This interesting work has been widely concerned once published. As an attractive enhancement, Wang [18] extended it to Bayesian inference based optimal wavelet filtering. The SE infogram or the SES infogram was employed to initialize the state space model of wavelet parameters, then the dynamic Bayesian wavelet transform (DBWT) [19] was conducted using the time-domain or frequency-domain spectral negentropy as observation function to extract the repetitive transients. In a word, the fast filtering algorithm was improved to optimal filtering. However, this extension [18] does not fundamentally overcome the existed flaws of the infogram in IFB selection. As discussed in Ref. [20], the time-domain spectral negentropy is not sensitive to the cyclostationary features while the frequency-domain spectral negentropy is not sensitive to the impulsive ones. Correspondingly, the SE infogram is not immune to impulsive noises and the SES infogram is not immune to cyclostationary interferences. Furthermore, their simple average as a compromise cannot balance these two aspects, such as a strong impulsive noise can easily surpass the contribution of the cyclostationary fault features in the AVE infogram [17,20].

Motivated by the above discussion, not only synthesize but also balance the impulsiveness and cyclostationarity is the main principle in extracting the repetitive transients of faulty rotating machines. In other words, there are conflicting requirements in characterizing the fault signatures. The impulsiveness requires a sparse representation [21] in time-domain, whereas, the cyclostationarity requires a sparse representation in frequency-domain. As for this sense, it should be separated as two independent and competitive objectives. In the meanwhile, these objectives should be balanced by a mutual suppression agreement. So that, it can help eliminate the unilateral contributions due to the impulsive or cyclostationary noises in extracting the repetitive transients. Therefore, the IFB selection can be modeled as a bi-objective optimization [22]. Based on this idea, a novel Pareto-based extension of the infogram to optimal wavelet filtering is proposed in this paper. With the non-dominated sorting [23,24], a new Gaussian filtering strategy is given for updating the posterior wavelet parameters distribution. Compared with Wang's extension [18], the Pareto set of these two objectives rather than the optimal solution of one is employed in the dynamic Bayesian inference. Then, the optimal IFB can be identified and envelope analysis is subsequently applied to extract repetitive transients for the diagnosis of rotating machines.

The rest of the paper is organized as bellow. Section 2 briefly reviews the infogram [17] and its extension [18]. Then, a novel Pareto-based Bayesian approach as an enhanced extension of the infogram to DBWT is proposed in Section 3. In Section 4, the addressed method is firstly evaluated by a numerical simulated signal. Followed by, two real fault signals are further investigated in Section 5. At last, some conclusions are drawn in Section 6.

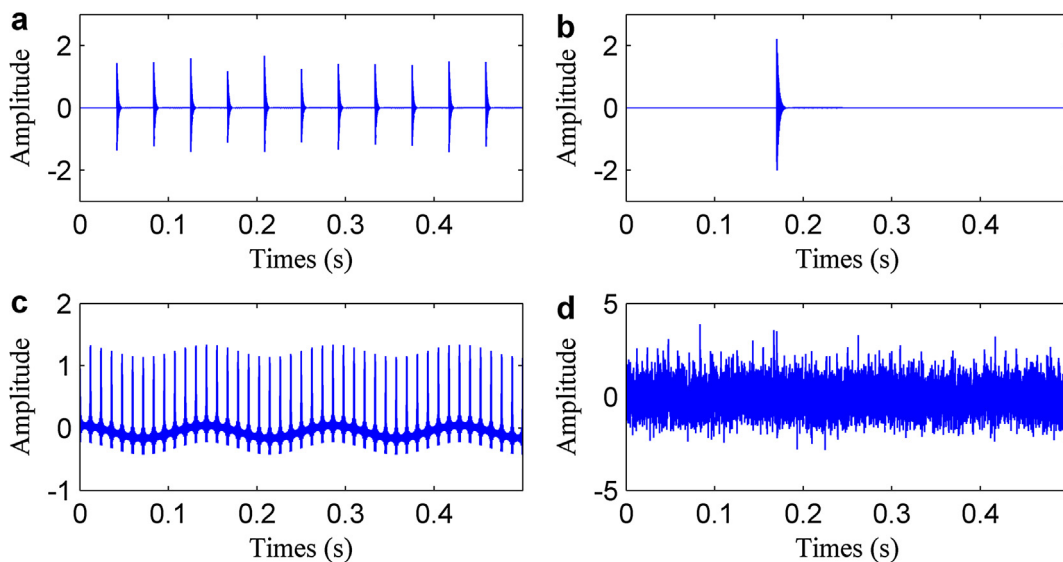


Fig. 1. (a) repetitive transients, (b) an impulsive noise, (c) a cyclostationary noise and (d) the synthesized signal.

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