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Multiple-teeth defect localization in geared systems using filtered acoustic spectrogram

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ABSTRACT

Contactless health monitoring of machines is highly desirable in industrial setups where the environment inherently imposes restrictions on contact-based data acquisition. This motivates the use of acoustic signal as an effective alternative for condition monitoring of equipments located in such inaccessible environments. However, condition monitoring and fault diagnosis by processing acoustic signals still remains a challenge for researchers. The aim of the proposed work is to establish a robust technique of acoustic signal processing for detection and localization of multiple teeth defect in geared systems. Towards this, the present work proposes the use of time marginal integration (TMI) of the continuous wavelet transform (CWT) coefficients of the decomposed signal derived from an undecimated wavelet transform (UWT) of the raw acoustic signal. UWT, owing to its well established translation invariant property, is implemented on the raw data to extract the de-noised signal for further processing with CWT. The time-axis of the TMI graph is finally correlated to the angular displacement of the driver gear in order to locate the defective teeth and measure their relative positions. An artificial neural network (ANN) model using signal statistical parameters as neurons is proposed as a pre-check to identify the presence of any defect in the gears. In addition, the efficiency of UWT as a de-noising tool is reestablished through the accuracy improvement in ANN based identification. A synthetic signal is simulated to conceptualize and evaluate the effectiveness of the proposed method. Synthetic signal analysis also offers vital clues about the suitability of the biorthogonal 3.1 wavelet over Daubechies and Symlet wavelets in the proposed algorithm. The experimental validation of the proposed method is presented using a customized gear drive test setup by introducing gears with seeded defects in one or more of their teeth. Measurement of the angles between two or more damaged teeth with a high level of accuracy is shown to be possible using the proposed algorithm. Experiments reveal that acoustic signal analysis can be used as a suitable contactless alternative for precise gear defect identification and gear health monitoring.

1. Introduction

Defect detection and measurement in the geared systems using acoustic and vibration signal processing have contributed significantly in prevention of catastrophic failures of rotating machines. In comparison to the most widely used technique of vibration measurement, condition monitoring of rotating machinery using acoustic signal has been a more challenging and relatively less visited area of research. Acoustic emission (AE) measurement has an advantage due to the non-contact nature of sensing technology. On the other hand, the disadvantage with acoustic measurement crops in due to higher possibility of ambient noise interference. This increases the difficulty of processing the signal and extracting the hidden information about the defect. During the last few years, however, a significant progress in the field of acoustic instrumentation and in the related signal processing techniques has made it possible to extract useful diagnostic information even from noisy acoustic signals.

In existing literature one can find the conventional time and frequency domain parameters, such as kurtosis, crest factor, signal to noise ratio (SNR), and power spectral density (PSD), that are well established in defect detection [1,2]. Eftekharnejad and Mba [3], with help of such parameters, established the relationship between volume of removed material from a helical gear tooth and the corresponding AE. However, this technique is not suitable for spur gears as reported by Toutountzakis et al. [4].

In recent years, another aspect of condition monitoring captured the interest of researchers in this field. This aspect deals with automatic defect identification and classification which primarily aims to realize online machine health monitoring systems. Hajnayeb et al. [5] have proposed an artificial neural network

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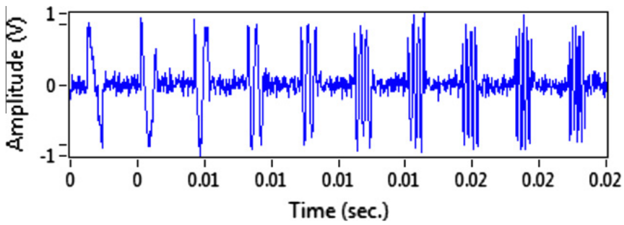

Fig. 1. Synthetic signal used for the performance analysis of the proposed method.

(ANN) based classification technique to identify gear fault from vibration signals. This technique provides an accuracy of 99.98% in defect identification but does not perform satisfactorily in case of noisy acoustics signals as described in a subsequent section.

In addition to detection, defect localization in case of multiple defects is equally important in order to understand the nature and severity of defect. Towards this, many researchers have implemented and reported effectiveness of many variations of joint time–frequency analysis (JTFA) such as wavelet transform (WT) and Wigner-Ville Transform. JTFA based fault detection practice usually relies on visual observation of various time–frequency contour plots. In order to exploit the strength of this technique, Baydar and Ball [6] implemented a smoothed pseudo Wigner-Ville distribution (SPWVD) on acoustic signal to identify gear defect. Their method hinges on the visibility of sharp signal bursts due to faulty gear-tooth impact and its periodicity. During the same time, Sung et al. [7] reported the effectiveness of continuous wavelet transform (CWT) over short term Fourier transform (STFT) in identifying gear defect using vibration signal. They also have used visual inspection of CWT detail parts. In a subsequent work, Baydar and Ball [8] also have demonstrated the efficiency of acoustic signal processing over vibration signal for early fault detection using wavelet transform. In an attempt to eliminate the limitation of visual inspection of time frequency spectrum, Haase and Widjajakusuma [9] proposed a method of damage identification in structures by generating maxima lines and ridges of wavelet transform of non-stationary vibration signals. Belsak and Flasker [10] estab-

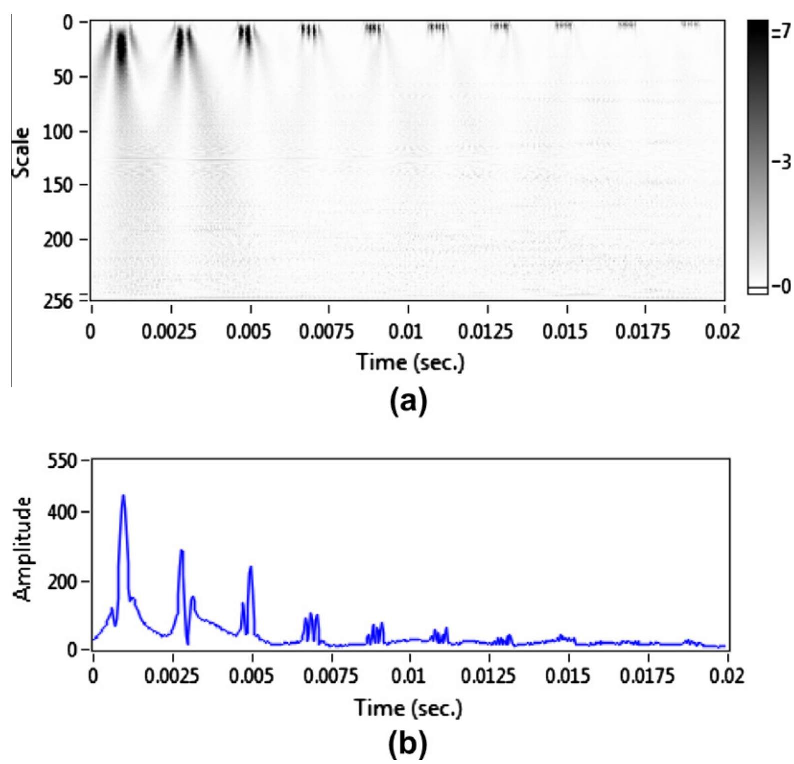

Fig. 2. Time-scale analysis of the raw synthetic signal; (a) CWT scalogram and (b) time marginal integration (TMI) of the CWT scalogram.

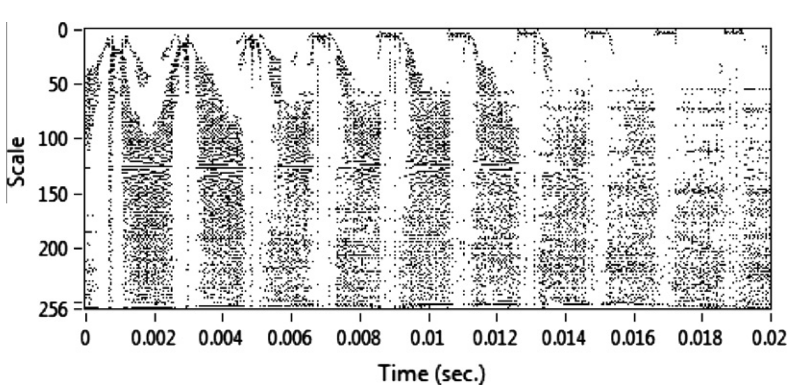

Fig. 3. The ridge spectrum from CWT scalogram of synthetic signal.