Combination of ICA and time-frequency representations of multichannel vibration data for gearbox fault detection

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Abstract. In the paper a multichannel vibration data processing method is presented in the context of local damage detection in gearboxes. The purpose of the approach is to obtain more reliable information about local damage when using several channels in comparison to results obtained for single channel vibration. The method is a combination of time-frequency representation and Independent Component Analysis (ICA) but applied not to raw time series but to each slice (along to time) from spectrogram. Finally we create new time-frequency map, that after aggregation clearly indicates presence of damage. In the paper we will present details of the method and benefits of using our procedure. We will refer to autocorrelation function of mentioned aggregated new time frequency map (1D signal) or simple spectrum (that might be somehow linked to classical envelope analysis). We believe that results are very convincing – detection of cyclic impulses associated to local damage are clearly identifiable. To validate our method we use real vibration data from heavy duty gearbox used in mining industry.

Keywords: local damage detection, gearbox, belt conveyor, vibration, multichannel data, ICA, time-spectrogram.

1. Introduction

A problem of fault diagnosis in rotating machines attracts attention of researchers for many years. In the literature one can find several comprehensive reviews on damage detection in gears and bearings [1-4]. Classical methods incorporate high-order statistics [5], empirical mode decomposition [6], wavelet transform [7], time-frequency domain analysis [8-10], bi-frequency analysis [1, 11]. Vibration signal from a machinery system is often a mixture of several source signals. For instance, a signal acquired on a bearing operating in a belt conveyor driving station might be contaminated with vibrations of a gearbox located nearby [12-21], vibration signal from a hummer crusher bearing consist of both a signal related to bearing and an impulsive noise related to the crushing process [22]. Another example of a multi-source signal is a gearbox with two faults, each of different nature [17, 23]. In [24] authors analyze a signal from a gas compressor and provide a diagnostic method in case of bearing vibration signal in presence of impulsive noise. In this paper we incorporate independent component analysis (ICA) for local damage detection in a two-stage gearbox operating in a belt conveyor driving station. The vibration data obtained during the experiment represents vibration acceleration of a single gearbox, measured at 3 different locations. ICA is performed on time-frequency representations of the signals. The method proved that integration of vibration signals from several channels provide a more clear damage indication than a single signal does.

The paper is structured as follows. In section 2 a methodology based on both ICA and time-frequency representation is described. Section 3 contains description of the considered machine and results obtained from real data analysis. The last section contains conclusions.

2. Methodology

In this section we present the methodology which we use to real vibration signal from heavy duty gearbox of belt conveyor used in mining industry. The technique consists of few main steps. As it was mentioned, we analyze the multichannel (three dimensional) vibration data. First, the decomposition of input channels into time-frequency maps (spectrograms) is performed. The spectrogram is an absolute value of the short-time Fourier transform (STFT) defined as follows:

$$STFT(t,f) = \sum_{k=0}^{N-1} x_k\, w(t-k) e^{\frac{2j\pi f k}{N}}, \tag{1}$$

where $w(t-\tau)$ is the shifted window and x_k is the input signal. In the next step of our procedure we divide the time-frequency maps into narrow-band slices corresponding to given frequencies. As a result of this step we obtain three dimensional sub-signals for each frequency band. Then for each of three-dimensional sub-signal we apply the Independent Component Analysis (ICA) which returns three independent features. In signal processing, the ICA is a computational method for separating a multivariate signal into additive subcomponents (features). This is done by assuming that the subcomponents are non-Gaussian signals and that they are statistically independent from each other. ICA is a special case of blind source separation [25-33].

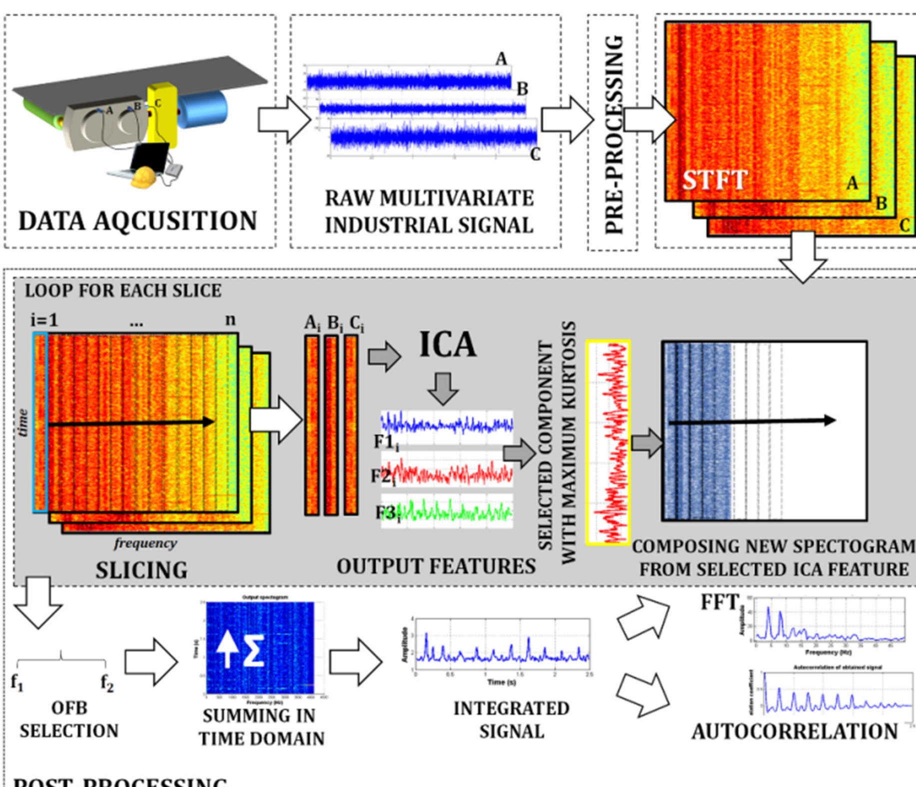


Fig. 1. The scheme of the introduced technique of local damage detection

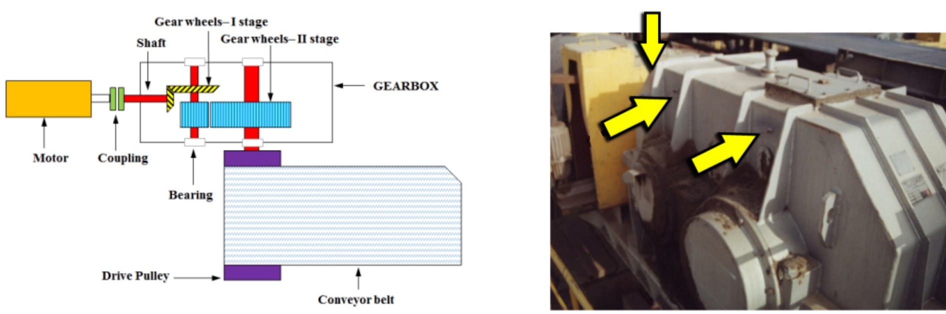
In the next step of our analysis for each three-dimensional sub-signal we select one feature, mainly this with the greatest kurtosis. As a result we obtain the new time-frequency map which contains selected features corresponding to given frequencies. On the basis of this map we can indicate the informative frequency band. At the end we aggregate the new time-frequency map in time domain to extract one-dimensional time series which may contain cyclic components resulting from damage. In order to enhance this cyclic behavior we calculate spectrum of the new time series and/or its autocorrelation function.

The scheme of the presented methodology is shown in Fig. 1.

3. Application to industrial data

3.1. Machine and experiment description

The machine considered here is a two-stage gearbox used in drive system for belt conveyor, see Fig. 2(a). Data used for validation of the method has been measured with using 3 accelerometers mounted on the gearbox housing (Fig. 2(b)) and the Brüel&Kjær Pulse system. Due to high level of noise and presence of high amplitude components related to mesh frequencies informative part of the signal representing damage cannot be seen in the acquired signals. It is known that impulsive signal related to damage in gear-wheel on the middle shaft should be associated to the fault frequency equals to 4.1 Hz.



a) b)

Fig. 2. a) Scheme of the investigated machine, b) location of sensors on gearbox housing

3.2. Diagnostic data – raw multichannel signal

Raw multivariate (3D) signal considered here consists of three 2.5 s time-series representing gearbox vibration under "normal" operation i.e. during transportation of bulk material. Frequency sampling is $f_s = 8192$ Hz. Raw multichannel signal and its spectrogram representation is shown in Figs. 3 and 4, respectively. Both time series and their spectrograms allow to notice some weak impulsive/wideband components but it is impossible to distinguished unambiguously.

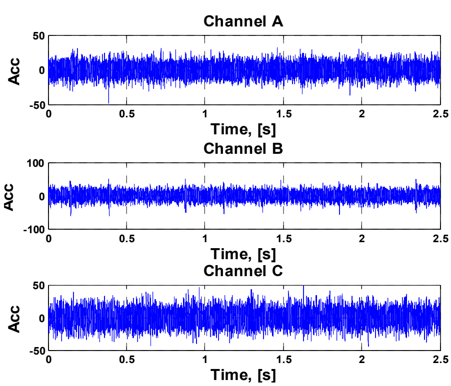


Fig. 3. Multichannel input signal

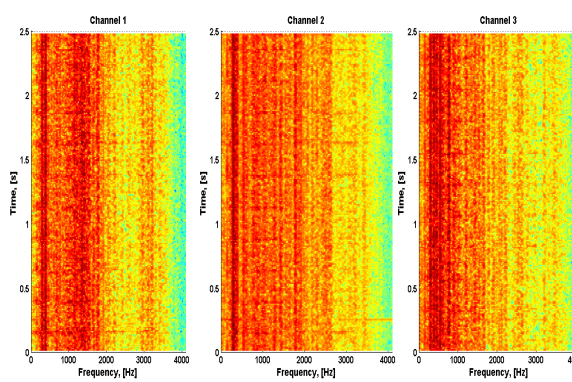
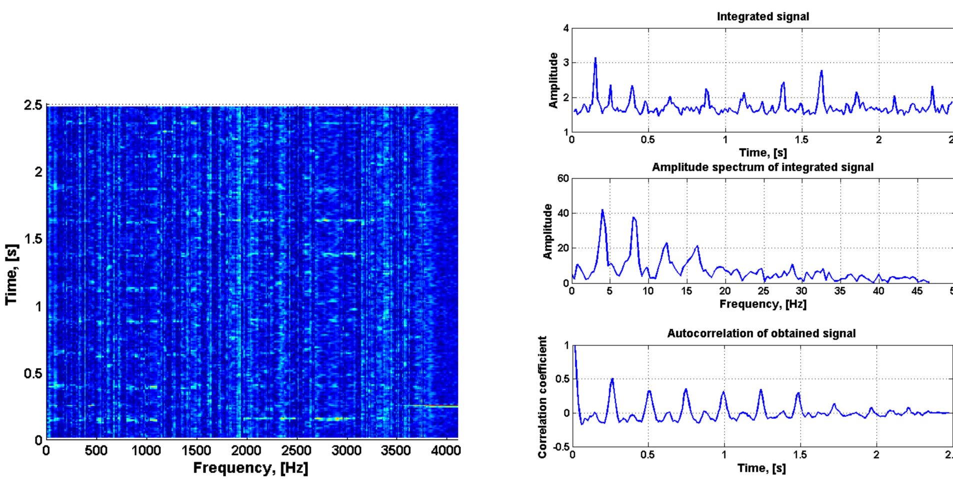


Fig. 4. Spectrograms of the multichannel signal

3.3. Evaluation of algorithm performance with industrial data

In this section we present the obtained results i.e. performance of the algorithm provided with real industrial data. Fig. 5(a) presents output, i.e. new time-frequency map which consists of the features extracted by applying ICA to the sub-signals from the initial spectrograms presented in Fig. 4. As we observe, the impulses (wideband excitations) are visible much clearly than in the spectrograms of multichannel raw signal. Moreover, simple aggregation of 2D map into 1D vector by integration of energy for each time instance shows impulsive nature of energy flow. Using autocorrelation or simple spectrum one might identify period/frequency of impulse repetition that corresponds to fault frequency, see Fig. 5(b).



a) b)

Fig. 5. a) Output spectrogram composed from selected ICA features, b) time series extracted from output spectrogram, spectrum of integrated time series and autocorrelation function of the integrated time series

4. Conclusions

In this paper we have introduced a new method of local damage detection applied to the real vibration signal from heavy duty gearbox used in mining industry. This methodology is based on the analysis of multichannel time series and its representation in time-frequency domain (spectrogram). In order to extract information about the damage we analyze the features obtained by applying the ICA to three-dimensional sub-signals corresponding to given frequencies on the spectrogram. The introduced technique applied to real signal gives much better results than the classical methods based on the analysis of one-dimensional vibration signal. By using the methodology we can easier identify the informative frequency band. Moreover, the cyclic impulses are more visible and distinguishable. We should mention, the proposed algorithm is automatic and can be applied to other vibration signals for which the classical methods do not give the desired results.

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