

Acoustic Signals Separation of Mechanical Devices Using the ICA with Band-Pass Filters

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Abstract

In this paper, a method of separating the acoustic signals of motors and gears of mechanical devices by using the independent component analysis (ICA) with band-pass filters is proposed. The frequency distribution of a recorded acoustic signal of the operating mechanical device can be divided into three fields, the low-frequency field, which corresponds to the frequency characteristics of the gear, the medium-frequency field, which is mixed with the frequency characteristics of the gear and the motor, and the high-frequency field, which corresponds to the frequency characteristics of the motor. Since only the medium-frequency components are the mixture of acoustic signals of gears and motors, the ICA with band-pass filters is expected to separate the acoustic signals of motors and gears more accurately than the conventional ICA. The simulation and experimental results show that the proposed method can separate the acoustic signals of motors and gears of mechanical devices successfully.

Keywords:

ICA, Signal processing, Neural Networks

Introduction

In the quality evaluation of mechanical devices, it is important to separate the acoustic signals of motors and gears in order to identify the causes of failures. The ICA method, which is developed to solve the cocktail-party problem, can separate two independent acoustic signals from their mixtures by using the information measure of statistically independent properties [1]-[3]. However, many applications in practice denote that the ICA does not perform well in separation by using the observed acoustic signals directly [4]-[5]. In order to separate the independent acoustic signals correctly, additional data processing is necessary before applying the ICA.

By applying the fast fourier transform (FFT) to a recorded acoustic signal of the operating mechanical device, we observe that its frequency distribution can be divided into three fields, the low-frequency field, which corresponds to the frequency characteristics of the gear, the medium-frequency field, which is mixed with the frequency characteristics of the gear and the motor, and the high-frequency field, which corresponds to the frequency characteristics of the motor. Since the frequencies of a

motor may be harmonics of the fundamental frequencies of a gear, which causes the independence assumption of the sources to fail and affects the separation accuracy. Therefore, the mixed acoustic signals with less frequency components are expected to be separated more accurately. In this paper, the ICA with band-pass filters is used to separate the acoustic signals of gears and motors. We first record the acoustic signals of the operating mechanical devices. By applying the band-pass filters, the respective components of low-frequency, medium-frequency and high-frequency can be obtained. Then the medium-frequency components are given to the ICA. After separation, the acoustic signals of gears and motors are recovered by adding the low-frequency and high-frequency components to the separated results, respectively. In this paper, the mixtures of two independent signals are also designed to simulate the separation process of acoustic signals of a gear and a motor. Both the simulation results and the experimental results show that the better separation results can be obtained by using the mixed medium-frequency field than using the whole frequency field.

Simulation Results

Suppose there are two independent signals s_1 and s_2 , their frequency characteristics are illustrated in Figures 1 and 2, respectively where f_1 , f_2 and f_4 are constant and f_3 is variable.

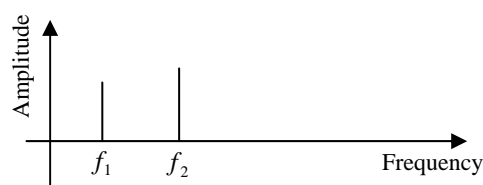


Figure 1 - Frequency characteristic of s_1

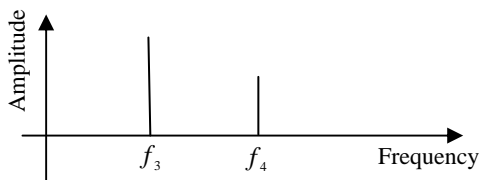


Figure 2 - Frequency characteristic of s_2 .

If we use two microphones to record the acoustic signals, we have two observed signals $x_1(t) = a_{11}s_1 + a_{12}s_2$, $x_2(t) = a_{21}s_1 + a_{22}s_2$. We use the ICA to separate the two independent signals s_1 and s_2 from the observed signals.

Table I shows the separation results where “Y” denotes that the independent signals s_1 and s_2 can be separated correctly and “N” denotes that they cannot be separated correctly. From Table I, it can be seen that sometimes we fail in separating the acoustic signals s_1 and s_2 by using the observed signals x_1 and x_2 directly.

Table I - Separation results of observed signals (unit: Hz)

f_3	30	40	50	60	70	80	90	100	110
Y/N	Y	Y	Y	N	Y	Y	Y	N	Y
f_3	120	130	150	160	170	180	190	200	210
Y/N	N	Y	Y	Y	Y	N	Y	Y	Y
f_3	220	230	$f_1 = 20, f_2 = 140, f_4 = 240$						
Y/N	Y	Y							

However, after filtering the frequency components f_1 and f_4 with a band-pass filter, the frequency components f_2 and f_3 can be separated successfully by using the ICA. Thus, the original acoustic signals s_1 and s_2 can be obtained by adding the frequency components f_1 and f_4 to the separation results of the ICA, respectively. As an example, Figures 3 and 4 show the frequency characteristics of separated signals s_1' and s_2' by using the ICA with band-pass filters, respectively where $f_3 = 100$ Hz. From these figures, it can be seen that the two acoustic signals of s_1 and s_2 are separated correctly.

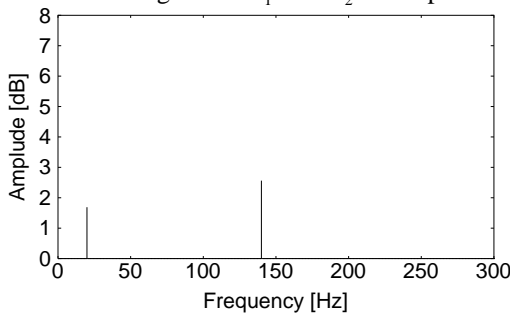


Figure 3 - Frequency characteristic of separated signal s_1' with band-pass filters

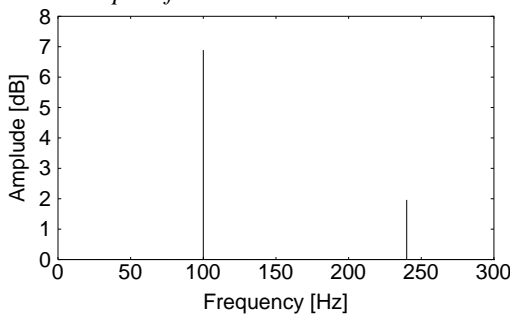


Figure 4 - Frequency characteristic of separated signal s_2' with band-pass filters.

Similarly, other unsuccessful separation experiments of Table I are redone by using the ICA with band-pass filters. The simulation results show that all the signals are separated successfully. And the separation experiments of mixed acoustic signals with multi-frequencies also show that the ICA with band-pass filters performs better than the conventional ICA in acoustic signals separation.

Experimental Results

According to the above simulation results, we separate the acoustic signals of motors and gears of mechanical devices by using the ICA with band-pass filters. The acoustic signals recording system is shown in Figure 5. Two microphones, which are held in different locations, are used to record the acoustic signals of operating mechanical devices. By applying the band-pass filters, we obtain the respective components of low-frequency, medium-frequency and high-frequency. Since only the medium-frequency components are the mixture of acoustic signals of gears and motors, we input the medium-frequency components to the ICA. Then the acoustic signals of gears and motors can be recovered by adding the low-frequency and high-frequency components to the separation results of the ICA, respectively.

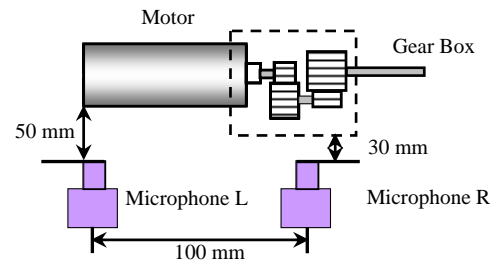


Figure 5 - The acoustic signals recording system

An example of acoustic signals recorded by microphones L and R are shown in Figures 6 and 7, respectively where the sampling rate is 8,000. Their frequency characteristics are shown in Figures 8 and 9.

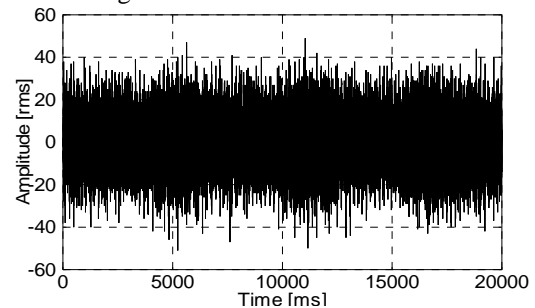


Figure 6 - Acoustic signal recorded by the left microphone

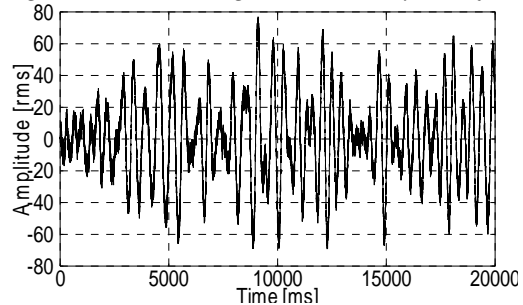


Figure 7 - Acoustic signal recorded by the right microphone

Since the rotational speed of the motor is 3600 rpm and the rotor has 12 poles, the fundamental frequency of the motor is about 360 Hz. Similarly, since the gear ratio is 30:1, the fundamental frequency of the gear is about 12 Hz. Thus, it can be considered that the medium-frequency is the range

of 300 to 2,000 Hz and the relevant band-pass filters are designed.

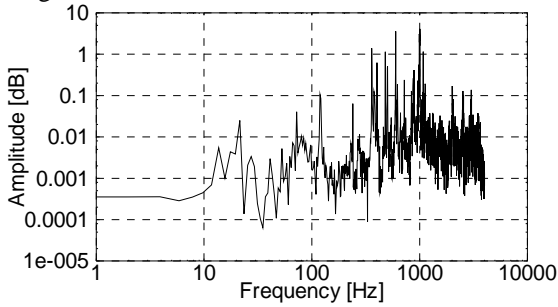


Figure 8 - Spectrum of acoustic signal of left microphone

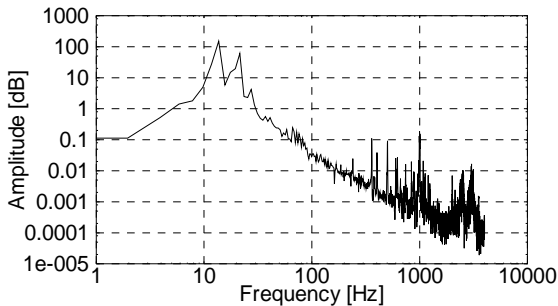


Figure 9 - Spectrum of acoustic signal of right microphone

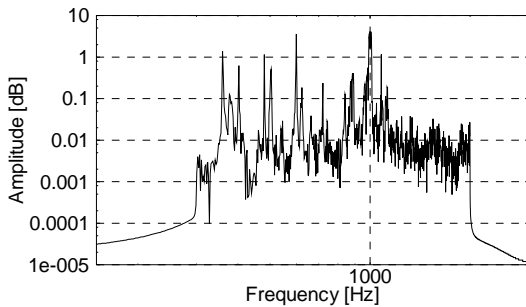


Figure 10 - Spectrum of Figure 8 with a band-pass filter

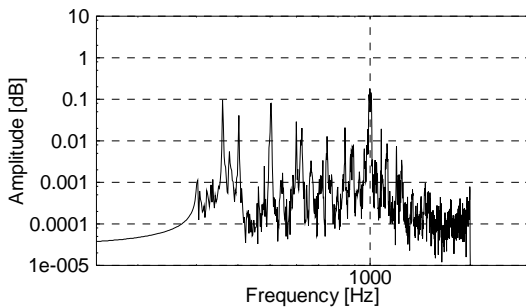


Figure 11 - Spectrum of Figure 9 with a band-pass filter

In Figures 10 and 11, the medium-frequency fields of acoustic signals of left and right microphones with the band-pass filter are given respectively. The filtered signals are used as the input of the ICA. The spectra of the separated acoustic signals are shown in Figures 12 and 13. Since a peak of amplitude nearby 1,000 Hz, which is about 3 times of the fundamental frequency of the motor, can be observed in Figure 12, it is regarded that Figures 12 and 13 show the medium-frequency fields of acoustic signals of the motor and the gear, respectively.

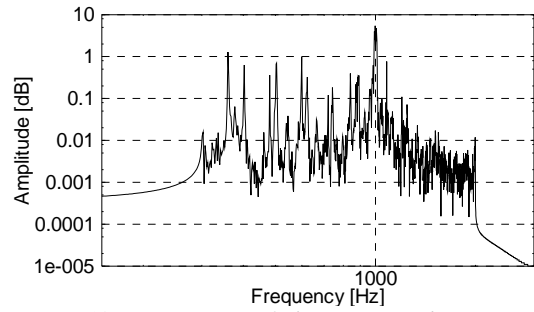


Figure 12 - Spectrum of the separated acoustic signal by using the ICA with a band-pass filter (motor)

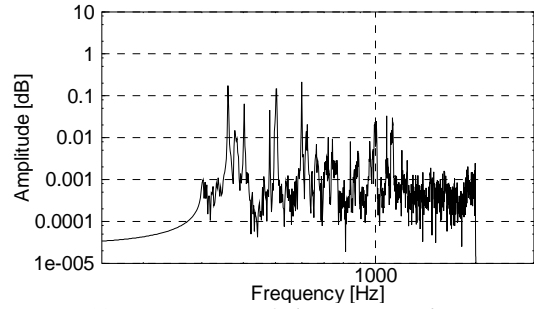


Figure 13 - Spectrum of the separated acoustic signal by using the ICA with a band-pass filter (gear)

To verify the effectiveness of our proposed method, we also give the separation results by applying the recorded acoustic signals of mechanical devices to the ICA directly. The frequency characteristics of the separated acoustic signal are shown in Figures 14 (a) and 15 (a), and the medium-frequency characteristics are shown in Figures 14 (b) and 15 (b). Comparing with Figures 8 and 9, it can be concluded that Figures 14 and 15 show the frequency characteristics of the motor and the gear, respectively.

From the above figures, it can be seen that the ICA with band-pass filters performs better than the conventional ICA in acoustic signals separation. The spectrum of Figure 14 (b) is similar with the one of Figure 15 (b), especially the peaks of amplitudes appeared in both figures, which are located in the multiple of fundamental frequency of the motor, denote that the separation results of acoustic signals of the motor and the gear are not good.

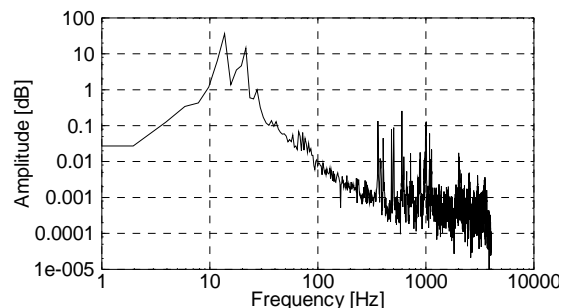


Figure 14 (a) - Frequency characteristics of the separated acoustic signal by using the ICA (motor)

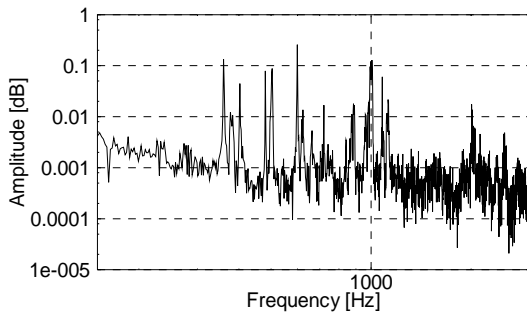


Figure 14 (b) - Medium-frequency characteristics of the separated acoustic signal by using the ICA (motor).

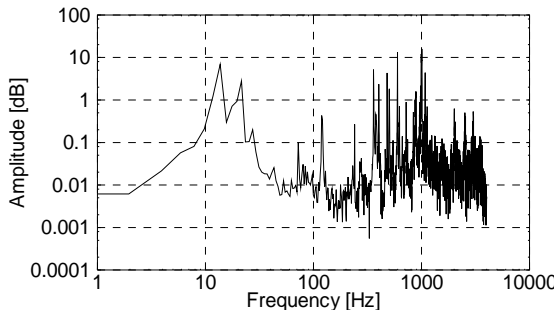


Figure 15 (a) - Frequency characteristics of the separated acoustic signal by using the ICA (gear)

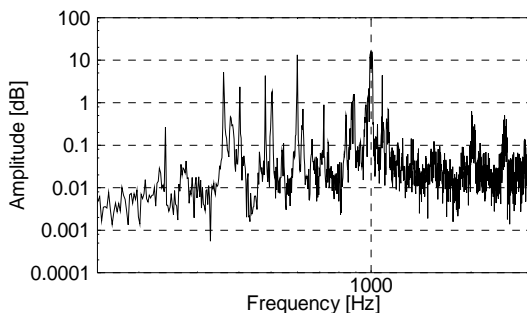


Figure 15 (b) - Medium-frequency characteristics of the separated acoustic signal by using the ICA (gear)

The acoustic signals of the gear and the motor are recovered by adding the low-frequency and high-frequency components to the separation results of Figures 12 and 13, respectively. The spectra of recovered acoustic signals of the gear and the motor are shown in Figures 16 and 17 where the amplitudes of medium-frequency are adjusted according to the amplitudes of low-frequency and high-frequency, respectively. Comparing with the above figures, it can be concluded that the separation results are reasonable. The separated acoustic signals of the gear and the motor are also checked by a technician, the sounds of the motor and the gear denote that the acoustic signals of the gear and the motor are separated successfully by using the ICA with band-pass filters.

Conclusions

In this paper, a method of separating the acoustic signals of gears and motors of mechanical devices by using the ICA with band-pass filter is proposed. The simulation results denote that the mixed acoustic signals with less frequency

components can achieve better separation performance by using the ICA. Therefore, for those independent signals which are mixed only in medium-frequency field, the ICA with band-pass filters can separate the independent original signals more accurately than the conventional ICA. Using the proposed method, we have solved the acoustic signals separation problem of gears and motors of mechanical devices successfully.

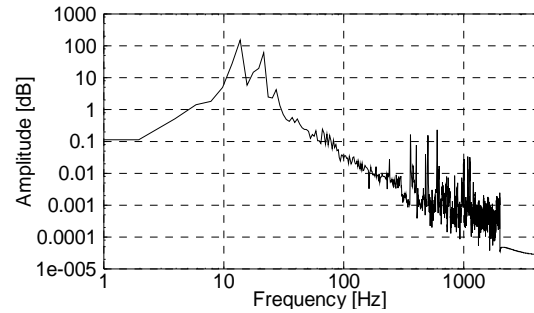


Figure 16 - Spectrum of recovered acoustic signal of the gear

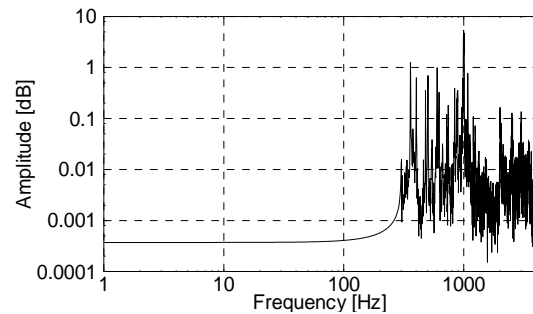


Figure 17 - Spectrum of recovered acoustic signal of the motor

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