

Removal of power line interference of space bearing vibration signal based on the morphological filter and blind source separation

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Abstract. Aiming at the problem that it is difficult to extract the feature information from the space bearing vibration signal because of different noise, for example the running trend information, high-frequency noise and especially the existence of lot of power line interference (50Hz) and its octave ingredients of the running space simulated equipment in the ground. This article proposed a combination method to eliminate them. Firstly, the EMD is used to remove the running trend item information of the signal, the running trend that affect the signal processing accuracy is eliminated. Then the morphological filter is used to eliminate high-frequency noise. Finally, the components and characteristics of the power line interference are researched, based on the characteristics of the interference, the revised blind source separation model is used to remove the power line interferences. Through analysis of simulation and practical application, results suggest that the proposed method can effectively eliminate those noise.

1. Introduction

Bearing is widely used in rotating machinery. In order to eliminate the power line interference, the conventional method of eliminating such interference is through the use of a notch filter, Jacek proposed using the multiple-notch filtering methods to remove the harmonic powerline interference[1-2]. However, the nature of this approach in the time domain is consistent to the notch filter. So, the above method can't effectively eliminate the noise, in order to eliminate the noise, we should know the properties of the noise. Additionally, the exist of the running trend information and the high-frequency noise also affect the feature extraction effect. The EMD method is used to remove the running trend item information in Section 1. The morphological filter is used to eliminate high-frequency noise is described in Section 2. The blind source separation model is used to remove the power line interferences in Section 3. The case study is presented in Section 4, in which the proposed method is validated. Finally, the conclusions are given in Section 5.

2. Removing the running trend item

EMD[3] is defined as upper and the lower envelopes should cover all the data in the time series. The mean of the upper and the lower envelope, $m_1(t)$ is subtracted from the original signal to obtain the first component $h_1(t)$ of the sifting process:



$$h_1(t) = x(t) - m_1(t) \quad (1)$$

Ideally, if $h_1(t)$ is an intrinsic mode function, the sifting process will stop. So, it will shift the signal again in the same way to get another component $h_2(t)$:

$$h_2(t) = h_1(t) - m_2(t) \quad (2)$$

where $m_2(t)$ is the mean of the upper and lower envelopes of $h_1(t)$.

Repeat steps until the residual satisfies some stopping criterion. The signal can be expressed as:

$$x(t) = \sum_{i=1}^n c_i(t) + r_n(t) \quad (3)$$

where n is the number of IMFs, $r_n(t)$ is the residue which is a constant, a monotonic, or a function with only maxima and one minima from which no more IMF can be derived, and $c_i(t)$ denotes IMF.

3. Remove the high-frequency noise

Morphological filter requires less computational time than other traditional filters. Through constantly moving the structure element(SE) to match the signal, the purposes of de-noising can be achieved. The transformation consists of four basic operations: erosion, dilation, opening and closing [4].

The nonlinear filter was constructed in the form:

$$y(x) = \frac{1}{2} [F_{co}(f(x)) + F_{oc}(f(x))] \quad (4)$$

where $y(x)$ is the filtered signal.

While the SE is controlled by its shape and the selected SE should be as close as possible to the signal that been analyzed. [5]. The determination of the SE length depended on distribution of the noise and the sampling frequency. To maintain the probe effect of the SE to the morphological filter function, the SE length should be far less than the filter function (the length equal to the signal been analyzed), and greater than the width of the disturbance pulse. Generally, the pulse width of the vibration signal is very narrow [6]. So the SE length needs not to be selected too long, usually the length of SE selected as the length of several sampling points [7, 8]. One unit represents one sampling point, and the SE length is selected from these four length units.

4. Removing the power line interferences

Independent component analysis(ICA)of observed n -dimensional random vectors X ($X=(x_1, x_2, x_3, \dots, x_n)^T$) is defined as the process of finding an m -dimensional linear transform $S=WX$ ($S=(s_1, s_2, s_3, \dots, s_n)^T$) such that the separation matrix W is a linear transformation and the hidden components s_i are as independent as possible. Usually, the dimension of S is less than that of X ($m \leq n$). In this paper, note that only the case of $m=n$ is considered. Here, the matrix W is assumed to be invertible. FastICA is just such an algorithm, which is based on a fixed-point iteration scheme for finding a maximum nongaussianity of WX . There are different measures of nongaussianity, such as kurtosis(fourth-order cumulant) and negentropy. In this paper, we make use of the kurtosis as the maximum nongaussianity measure (i.e.,the score function),which is defined for a zero-mean random variable s as[9]

$$kurt(s) = E\{s^4\} - 3(E\{s\}^2)^2 \quad (5)$$

Using the natural gradient method under the constraint $\|w_j\|_2 = 1$ (where w_j is the j th column of W), the updating rule of w_j is written as:

$$w_j(t+1) = w_j(t) + u(t)\{v_i(t)[(w_j(t))^T v_i(t)]^3 - 3\|w_j(t)\|^2 w_j(t) + f(\|w_j(t)\|^2)w_j(t)\} \quad (6)$$

where v_i is the i th row of whitened results of observed vectors X , $(w_j(t))^T$ is the transpose of $w_j(t)$, $u(t)$ is the learning rate, and $f(\cdot)$ is a penalty term due to the constraint $\|w_j\|=1$. The learning rule will stop at a fixed point for which $|w_j^T(t) - w_j(t-1)|$ is sufficiently close to unity. The linear combination WX will be one of the required independent components in accordance with the formula of $S=WX$.

5. Validation

In order to verify the effectiveness of the method, the method is used on the actual application. The test rig is shown in Fig.1.



Fig.1 The test rig of the simulated space equipment

The bearings are hosted on the shaft; the shaft is driven by AC motor. The rotation speed is kept at 1000 rpm; a radial load of 3kg is added to the bearing. The acceleration sensor lance LC0135T is selected, the sensor sensitivity is 100 mv/g, frequency response range of 1~12000Hz, range is 50g. The charge amplifier of B & K company 2692-A-OS4 four-channel charge amplifier is selected: Amplifier Gain: 0.1mV/pC to 10 V/pC; calibrated output: attenuator range 100dB, -20 ~ +80 dB one file per 10dB; acceleration frequency range : 0.1Hz to 100kHz; lowpass filter: 0.1, 1, 3, 10, 22.4, 30, or 100kHz; high-pass filter (acceleration): 0.1, 1.0, or 10Hz. For vibration data collection we choice American Ni company collector NI9234, 32-channel, 8-slot USB interface box, 4-channel vibration collector. The data sampling rate is 25.6kHz and the data length is 10,240 points, as shown in Fig.2. Every 2 hours, the vibration data is collected once. The spectrum of the collected signal is shown in Fig. 3, and the refinement spectrum of the collected signals is shown in Fig. 4:

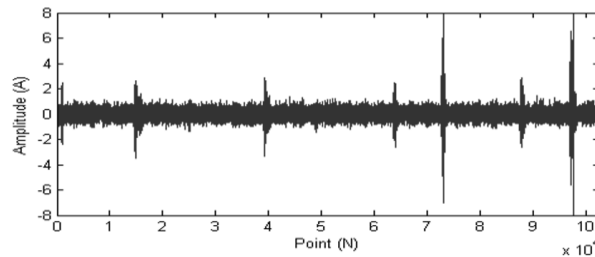


Fig.2 The collected vibration signal

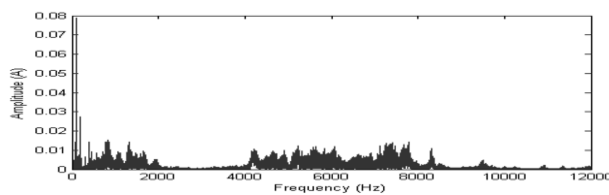


Fig.3 The spectrum of the collected signal

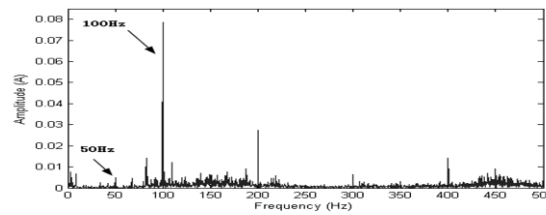


Fig.4 The refinement spectrum of the collected signals

The EMD is used to eliminate the trend term, the morphological filter is used to eliminate high-frequency interference. The length of the structural elements is set to 7, the amplitude of the structural elements is set to 0, the signal which is processed by the EMD is filtered by the morphological filter, the spectrum of the filtered signal is shown in Fig.5:

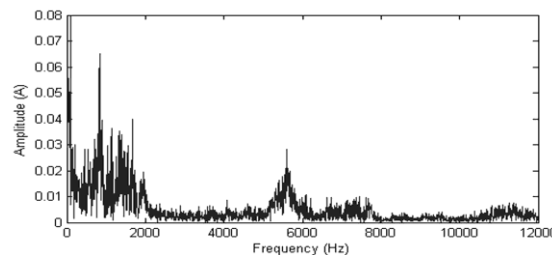


Fig.5 The spectrum of the filtered signal by the multi-scale morphological filter

From Fig.5 we can see that the high frequency components are filtered by the morphological filter, the fault feature information of the bearing is clearly.

Finally, in order to eliminate the power line interference (50Hz) which is caused by the space simulation equipment, the blind source separation algorithms FastICA is selected for signal processing. According to the FastICA theory, we first construct the reference power line interference, since the frequency spectrum of 2 times at 100Hz, 200Hz four times the frequency of the signal is the most serious interference, therefore, we first construct four reference signals $b = \sin 200\pi t$, $c = \cos 200\pi t$, $d = \sin 400\pi t$, $e = \cos 400\pi t$, and merge the 4 signals with the pre-processed vibration signal into the blind source separation model FastICA algorithm. The result for eliminating the power line interference (50Hz), and 2 times, four times is shown in Fig.6

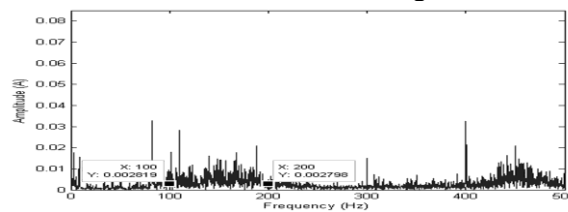


Fig.6 The frequency spectrum after removing the 2 times and the 4 times of the spectrum

As can be seen from Fig.6, the spectrum 100Hz and 200Hz frequency are effectively eliminated, showing effectively of the FastICA blind source separation method. For other obvious ingredients the algorithm can be used to filter out them effectively.

6. Conclusion

Firstly, this research used the EMD method to remove the running trend item information, the FastICA method was used to construct the separation model, this can effectively eliminate the power line interference of 50Hz and multiple frequency of the space simulation equipment in the ground.

Then, although the three method deal with different noise, they together can obtain better noise eliminating effect.

Finally, through the tested signals in the research, the results show the significant efficacy of the proposed method can effectively eliminate the power line interference effect.

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