

Research of Gear Fault Detection in Morphological Wavelet Domain

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Abstract. For extracting mutation information from gear fault signal and achieving a valid fault diagnosis, a gear fault diagnosis method based on morphological mean wavelet transform was designed. Morphological mean wavelet transform is a linear wavelet in the framework of morphological wavelet. Decomposing gear fault signal by this morphological mean wavelet transform could produce signal synthesis operators and detailed synthesis operators. For signal synthesis operators, it was just close to original signal, and for detailed synthesis operators, it contained fault impact signal or interference signal and could be caught. The simulation experiment result indicates that, compared with Fourier transform, the morphological mean wavelet transform method can do time-frequency analysis for original signal, effectively catch impact signal appears position; and compared with traditional linear wavelet transform, it has simple structure, easy realization, signal local extremum sensitivity and high denoising ability, so it is more adapted to gear fault real-time detection.

1. Introduction

Running gear, which is the usual transmission component for speed and transmission power, plays an important role on the whole machine operation, but the manufacturing process, work environment, machine wear and other factors existed led to the gear fault easily, and even the subtle fault also can cause the whole machine fault, result in great economic loss. Therefore, the analysis of the gear fault detection has very important significance. Fourier transform and wavelet transform are commonly used analysis methods in time-frequency domain^[1], but the traditional Fourier transform, reflecting the signal overall characteristics only, has significant limitations for non-stationary nonlinear signal because of the lack of refinement function for the details of the signal and especially in the time and frequency mutations; The wavelet analysis with its multi-scale and multi-resolution advantage is more superior to the Fourier analysis, because that the wavelet transform can do signal decomposition in different directions, different scales, and different resolution, and to some extent, it can give more meticulous description on the details of non-stationary signals for the time-frequency information can be effectively extracted from the signal, it has extraordinary significance in the field of signal processing and becoming more and more widely used in gear fault diagnosis^[2-3]. And for the traditional wavelet, based on linear decomposition of frequency, determine gear faults and types by analysis the interval of impact signal in time domain but frequency information of the gear faults feature such as multi-step meshing frequency, side frequency cannot be directly extracted^[4]. In recent years, a new wavelet analysis has become the focus of attention, Morphological Wavelet transform



were more popular, however, the theoretical analysis of new wavelet was still in the early stages of research, lots of advantages in the application has not been approved yet^[5-6].

This paper seeks to take into account a morphological wavelet suite for fault diagnosis and analysis, used in vibration signal analysis of one-dimensional, verify the feasibility and effectiveness of morphological multi-resolution analysis, and inspect the stability in noise interference.

2. Program design

When gears running if there is local damage fault, the fault point and another gear engage each other will produce a shock response, with the continuous transmission, each of the rotation produce a periodic impulse response, i.e., the vibration signal which is a typical non-stationary nonlinear signal, it needs to extracted some information of effective representational gear fault status from signal to analyses and detect the fault of gears. Morphological Wavelet transform is an effective method undoubtedly, and the DTC contains signals analysis operator as low-pass filter and details analysis operator as high-pass filter. The fault signals passe through low-pass filter produce approximation of the original signal retained the basic information on normal running gears. While the detail information by high-pass filter includes vibration and noise, we can extract relevant profiles of gear fault.

Mean filter is one of the more effective means of signal denoising^[7], we consider using morphological mean wavelet transform to detect the fault signal of gear^[8]. Make the mean filter as the low-pass filter of morphological wavelet, so we can get the signal analysis operator and details analysis as follows:

$$\begin{aligned}\psi^{\uparrow}(x)(n) &= \text{mean}(x(2n), x(2n+1)) \\ \omega^{\uparrow}(x)(n) &= x(2n) - x(2n+1)\end{aligned}\quad (1)$$

According to the perfect reconstruction condition, we can get synthesis operators as follows:

$$\begin{aligned}\psi^{\downarrow}(x)(2n) &= \psi^{\downarrow}(x)(2n+1) = x(n) \\ \omega^{\downarrow}(x)(2n) &= 0.5 * \omega(n) \\ \omega^{\downarrow}(x)(2n+1) &= -0.5 * \omega(n)\end{aligned}\quad (2)$$

Then the morphological midpoint wavelet which achieves perfectly reconstruction without redundancy is constructed. Specific steps in gear fault detection as follow:

(1) Morphological mean wavelet transform of the original signal, the gear fault signal is decomposed into signal coefficients and detail coefficients for each layer;

(2) Basic information signal stored in the signal coefficient, but the details of coefficients contains vibrations and most of noise generated by the fault. By thresholding detail coefficients of morphological mean wavelet are processed to eliminate noise;

(3) We observe every detail de-noised layer, comprehensive analysis to determine the fault feature to guide troubleshooting.

3. Experiment

The simulation is completed in two parts, vibration signal without noise and with noise, construction simulation signal generated by the superposition of two parts. Suppose the time-domain waveform of original vibration signals shown in Figure 1(a), the impact signals generate by gear fault signal shown in Figure 1(b), so, the total simulated signal is . As shown in Figure 1(c), the sampling frequencies of 15KHz.

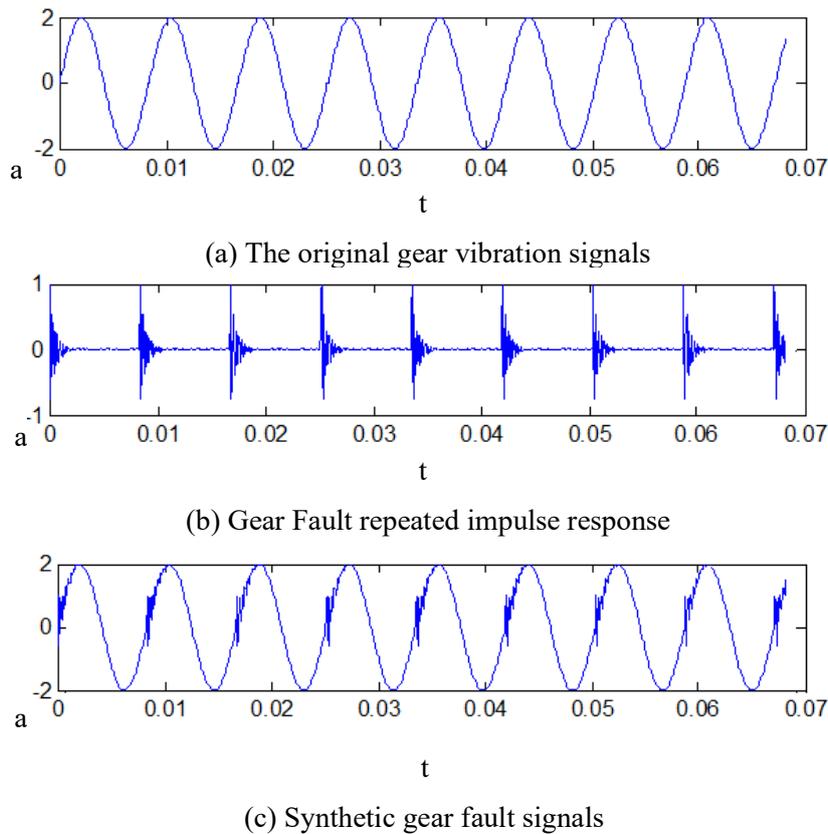


Figure 1. Simulation signals.

A spectrum obtained by Fourier transform of the gear fault simulation signals as shown in Figure 1(c) is shown in Figure 2. It can be seen that the frequency of normal gear vibration signal is captured at 120Hz, however, the fault repeated impact response was not clearly portrayed. Therefore, there has limitations of Fourier transform analysis for non-stationary signals such as gear fault.

Fourier transform of the gear fault simulation signals as shown in Figure 1(c), obtain a spectrum as shown in Figure 2. As can be seen, the frequency of normal gear vibration signals is captured at 120Hz, however, the repeated impact response of fault was not clearly portrayed. Therefore, Fourier transform analysis of non-stationary signals such as gear fault has limitations.

Morphological mean wavelet transform has the characteristics of traditional wavelet transform. It can effectively solve the contradictions in time and frequency domain localization. Here, use morphological mean wavelet transform to decompose the fault signals for 5 layers, then the coefficient magnitude plot obtained is shown in Figure 3. As can be seen from the figure, the morphological mean wavelet transform is a multi-resolution analysis, according with the rule which can observe the high-frequency on small-scale and the low-frequency on big-scale when analyzing signals by the traditional wavelet. Thus it can illustrate the effectiveness of morphological mean wavelet transform for signal analysis.

Figure 4 is a schematic of signal and high-frequency details after morphological mean wavelet transform for 5 layers. Figure 4(a) is the part of signal which can extract the characteristics of original signal. Figure 4(b), 4(c) and 4(d) are the part of three layers details before decomposition. It can observe or extract relevant fault impact signal's characteristics by other means to guide the fault determination. It can be seen that signal portion are consistent with the characteristics of original signal, but the details portion especially the part of details after decompose 1 layer has more accurate portrayal. And after signal reconstructing by synthetic operator, it has no different with Figure 1(c),

therefore, from the capture signal singularity sense, morphological mean wavelet analysis is better than Fourier analysis.

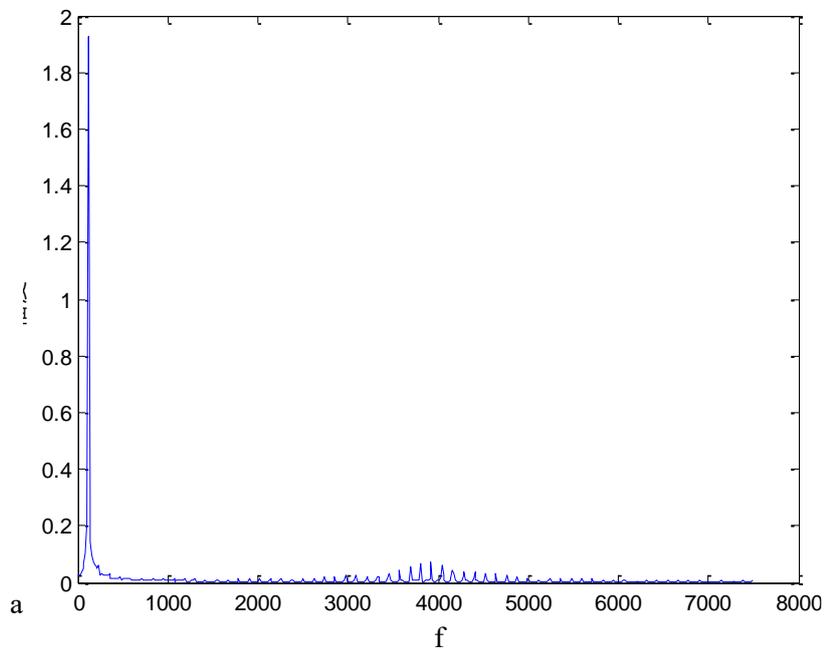


Figure 2. Spectrum of Fourier transform for fault signal.

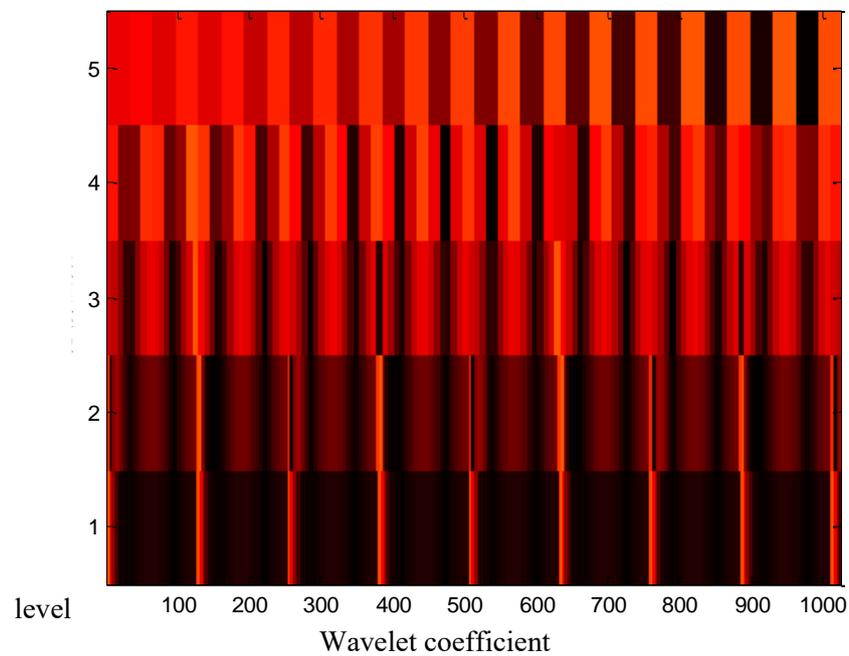


Figure 3. The morphological mean wavelet coefficient for fault signal.

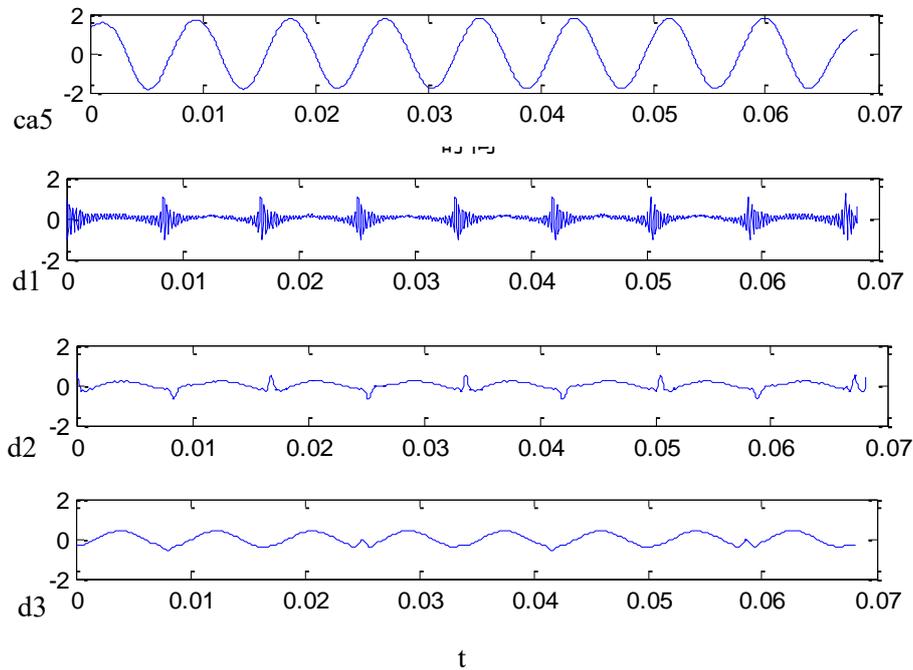
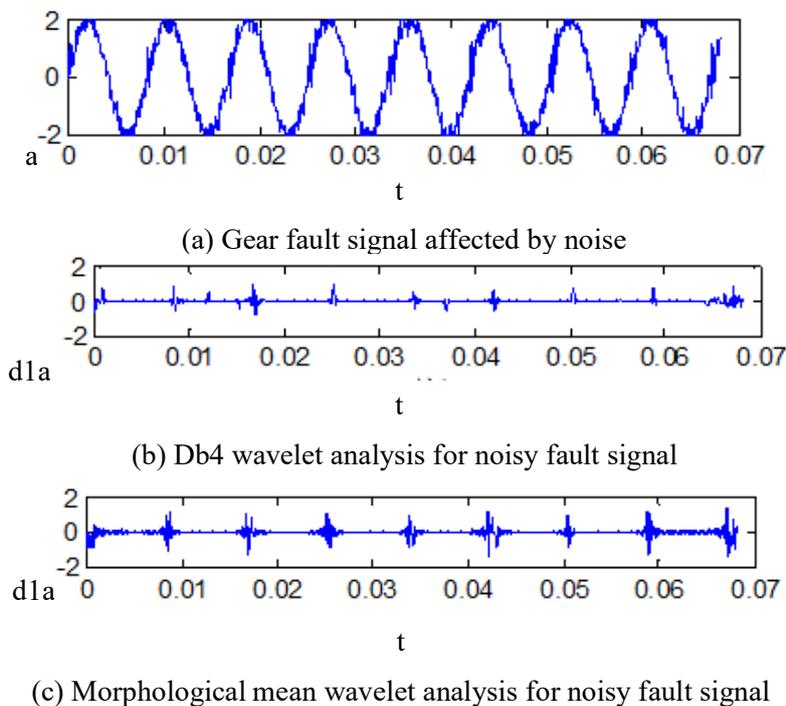


Figure 4. Signal and details after morphological mean wavelet transform.

The results obtained when noise as shown in Figure 5. Compare de-noising results, the morphological mean wavelet transform has a stronger signal singularity positioning capability, therefore, morphological mean wavelet transform has good prospects in gear fault detection. In addition, morphological mean wavelet has simple structure, easy to achieve, the building is conducive gear fault line real-time system.



(c) Morphological mean wavelet analysis for noisy fault signal

Figure 5. The result in this paper.

4. Conclusion

This paper presented the morphological mean wavelet transform which can be used for gear fault detection, and designed the general detection procedure. The simulation results showed that the denoising effect on details after signal separate is obvious and the features are more prominent in this paper. The non-stationary information of signal has saved well and the detection and analysis of fault signal is more reliable. In addition, the construction of morphological wavelet is based on simple math and easy to be implemented, and the computational complexity is significantly reduced. Further work such as a method of this paper combine with the feature extraction means to guide the actual gear fault detection and diagnosis may be considered in the future.

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