# Ship Radiated Noise Modulation Feature Extraction Based on CEEMD and Wavelet Threshold Noise Reduction

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**Abstract.** Ship propeller beats have obvious amplitude modulation to the cavitation noise of its radiation. The DEMON (Detection of Envelope Modulation on Noise) spectrum analysis technology is to demodulate the high frequency components to get the low frequency modulation components. This paper studied the new method to combine the complementary ensemble empirical mode decomposition (CEEMD) with wavelet threshold to reduce the noise. After verifying the method using both simulated signal and experimental signal, it is concluded that this algorithm has good noise suppression performance and the modulation information extracted out is clearer and more comprehensive.

## Introduction

In regard to the modulation signal detection under the condition of the strong background noise, domestic scholars have studied the extraction of the DEMON spectrum [1] by the use of modern signal processing methods such as the higher order statistics [2,3] , the time-frequency analysis [4,5], singular value analysis and so on. The methods mentioned above improved the performance of demodulation to a certain extent, but some shortcomings, such as less obvious harmonic characteristics and poor ability of noise suppression, still exist. When the target is unstable or interfered by adjacent strong target, the methods above cannot give satisfactory results. This paper presents a new method combined the CEEMD with wavelet threshold denoising to improve the performance of ship radiated noise demodulation.

## Method of Complementary Ensemble Empirical Mode Decomposition

The empirical mode decomposition (EMD) has the adaptive band division function and the characteristics of orthogonality, completeness and adaptability, etc. All the features above make it suitable for processing non-stationary nonlinear signal [6]. When the signal is intermittent, using the EMD method may lead to the phenomenon of modal aliasing and energy leakage, making the physical meaning of the intrinsic mode function (IMF) unclear. In this regard, the document [7] proposed a method named complementary ensemble empirical mode decomposition (CEEMD) based on the EEMD (Ensemble Empirical Mode Decomposition) [8]. Taking the advantage of characteristics that white noise power spectral density is evenly distributed, it adds positive and negative pairs of white noise to the original signal repeatedly, making signal continuous at different scales. And then eliminate the effects of the auxiliary noise with less average number, making the decomposition eventually have antinoise property. This method not only solves the modal aliasing and energy leakage problems of the EMD method, but also has higher operation efficiency.

CEEMD mainly includes the following steps:

a. Add the target signal with a pair of Gaussian white noise which have the same amplitude and a phase angle difference of 180° to construct two new signal $x_1$ and $x_2$.

b. Execute EMD operation to the new signal $x_1$ and $x_2$ , and each signal obtains a set of IMF, in which the $j$ -th IMF component of the $i$ -th signal is expressed as $C_{ij}$ .

c. Obtain decomposition results by averaging the plurality of sets of component:

$$c_j = \frac{1}{2n}\sum_{i=1}^{2n} c_{ij} \ . \qquad (4)$$

In order to verify CEEMD decomposition performance, execute the EEMD decomposition to the simulated signals in Fig. 1. The overall average number is 150 times and the amplitude of the noise added is 0.4 times of the signal's standard deviation. The simulated signal is shown in Fig. 1, in which $x_1(t)$ is sine wave of 30Hz, $x_2(t)$ contains the 50Hz and 650Hz intermittent signals and $x(t)$ is the combination of $x_1(t)$ and $x_2(t)$. Fig. 2 and Fig. 3 show the decomposition results using the method of EMD and CEEMD. In Fig. 3, the intermittent component with small amplitude and sine wave are decomposed accurately while there is more serious aliasing mode and fake IMF component in Fig. 2. In conclusion, CEEMD overcomes the problem of mode mixing of EMD and achieves better decomposition results.

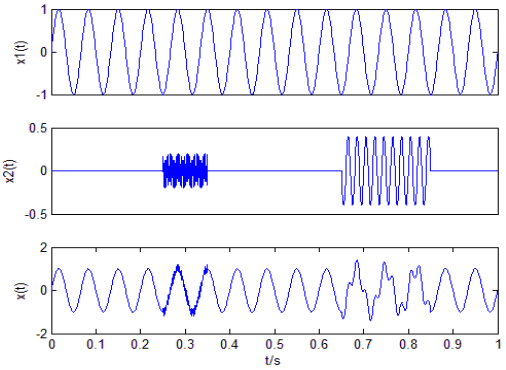

Fig.1 The Combined Signal

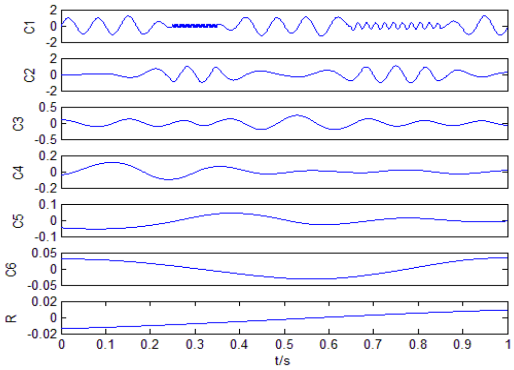

Fig.2 The Method of EMD

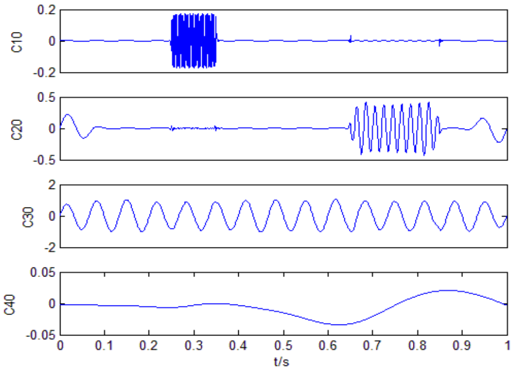

Fig.3 The Method of CEEMD

## Wavelet Threshold Denoising

The steps of the wavelet threshold denoising are as follows:

a. Transform the original signal into wavelet domain;

b. Process the threshold filtering in the wavelet domain, the threshold is determined by the adaptive Stein unbiased risk estimation (Heursure);

c. Reconstruct the denoised signal with the wavelet coefficients;

The thresholding process includes soft threshold method and hard threshold method. This paper adopted the soft threshold method to reduce the noise, whose function expression is:

$$x'_{j,k} = \begin{cases} \operatorname{sgn}(x_{j,k})(|x_{j,k} - Thr_j|) & |x_{j,k}| > Thr_j \\ 0 & |x_{j,k}| \le Thr_j \end{cases} . \qquad (4)$$

In which, $x_{j,k}$ is the $k$-th coefficient of the $j$-th layer of wavelet component, and $x'_{j,k}$ is the output of the process.

## Noise Reduction Simulation Based on CEEMD and Wavelet threshold

The specific steps are as follows:

a. Decompose the original signal s(t) into a finite number of IMF components and residue;
b. Select several IMF components according to the frequency band to be analyzed and restructure them;
c. Reduce the noise of the reconstructed signal by the wavelet soft threshold;
d. Performed Hilbert demodulation the signal after noise reduction;

The simulation signal of the ship radiated noise is:

$$s(t)=\left\{1+\sum m_i \sin(i\omega_s t+\theta_s(t))\right\}v_c(t)+v_a(t)\,. \tag{5}$$

In which, $v_c(t)$ is the cavitation noise signal, $v_a(t)$ is the marine environment noise signal, $\omega_s$ is the fundamental frequency of the ship modulation signal, $m_i$ is the modulation amplitude of the $i$-th harmonic component, $\theta_s(t)$ is the modulation phase of the $i$-th harmonic component.

The simulation parameters is set as follows: the propeller shaft frequency and its harmonic frequencies were respectively 10, 20, 30, 40, 50, 60, 70, 80, 90, 100Hz, the broadband signal is band-limited white noise in the range of 1500-2500Hz, the signal length is 5s, the sampling rate is 8kHz.

Fig. 4~ 7 illustrate the demodulation results when the SNR is -10dB and -16dB. Fig. 4 and Fig. 6 are the DEMON spectrum demodulated with the method in this paper, while Fig. 5 and Fig. 7 are the DEMON spectrum demodulated directly from the simulation signal. Contrast the four figures mentioned above with each other, and it's found that this new method made the base frequency energy more prominent. When the SNR is as low as -16dB, the fundamental frequency and its harmonics of the DEMON spectrum we demodulate are more outstanding and more information of targets shows up. Therefore, the CEEMD and wavelet threshold combined noise reduction technology has stronger noise suppression performance.

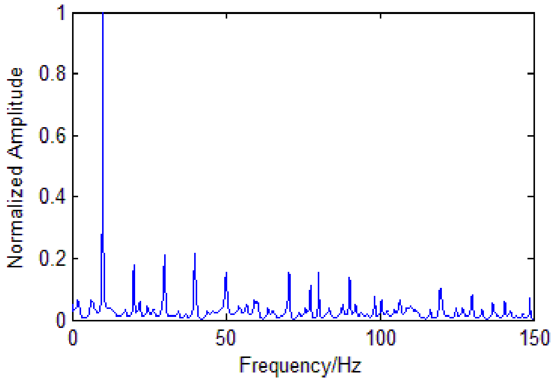

Fig.4 The New Method (SNR=-10dB)

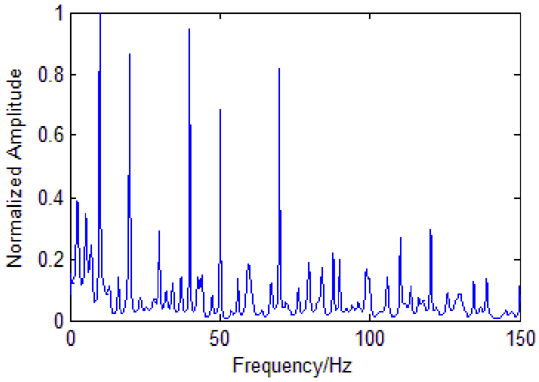

Fig.5 The Traditional Method (SNR=-10dB)

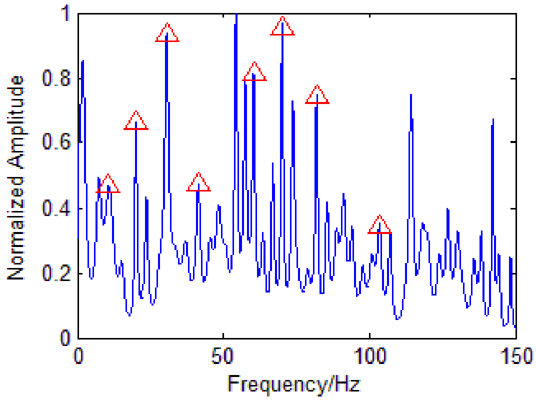

Fig.6 The New Method (SNR=-16dB)

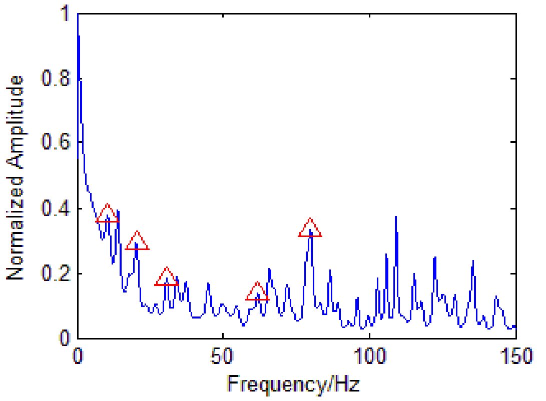

Fig.7 The Traditional Method (SNR=-16dB)

## DEMON Spectra Extraction and Analysis of the ship signal measured at sea

To further verify the effect of the demodulation algorithm, demodulate the ship noise signal recorded at sea with the two methods mentioned above. The signal length is 120s, sample rate is 4 kHz, and there is a strong and a weak target at the same time on the same bearing. Fig. 8 and Fig. 9 show the demodulation result respectively with the traditional method and the new method.

Contrasting the result in Fig. 8 with that in Fig. 9, it can be seen that both methods can extract out the information of the strong target with fundamental frequency 49Hz, but the traditional method can not detect the weak target whose fundamental frequency is 5.5Hz. The new method in this paper successfully extracted out the harmonic line spectrum of the weak target under the interference of strong target and distinguished the two targets on the adjacent bearing effectively.

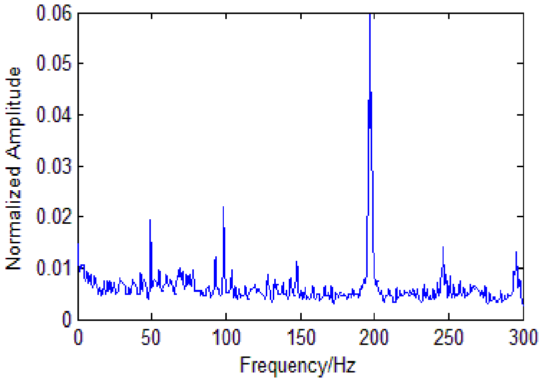

Fig.8 Result by The Traditional Method

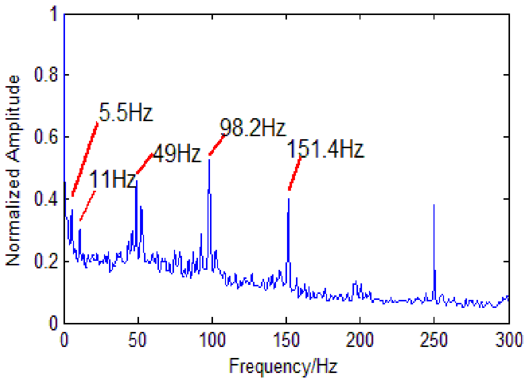

Fig.9 Result by The New Method

## Summary

This paper verified the noise reduction method combined CEEMD and wavelet threshold using both the ship radiated noise simulation signal and real recorded signal. In the condition of strong background noise interference, this method has better noise suppression performance. It achieved the effective capture of the cavitation modulation characteristics and improved the detection performance for ship radiated noise modulation characteristics.

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