Research of Modulation Feature Extraction from Ship-Radiated Noise

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Abstract. Information degree of the future naval battle will be very highly, and Striving for information advantage is the foundation of winning modern naval battle. Accurate and prompt recognition is the premise and foundation of tactical command. Modern naval battle is fast and complicated, and submarine sonar is required to be able to detect and classify targets fast and precisely. So the passive target detection and identification is the important research part in the modern acoustic technique field. Firstly, the mechanism of ship-radiated noise is analyzed. The envelope detection model of the ship noise is built. The envelope spectrum is extracted. Through the purity of the envelope spectrum and the smoothness of the continuous spectrum, I separate the line spectrum, from which the target base-frequency related with the rotate speed of ship screws can be detected. Secondly, the method of extracting frequency features of the ship radiated noise envelop is presented by using double frequency method, which is the basis of the classification.

1. Introduction
With the continuous improvement of the requirements of marine development, marine defense and anti-submarine warfare, underwater target recognition has become the focus and hotspot of research in various countries. The key of target recognition is how to effectively extract the essential characteristics of the target category. However, due to the complex mechanism of the actual sonar transmitting sound waves, there are both broadband continuous spectrum and narrow-band line spectrum components; different frequency bands have different modulation systems; at the same time, they are affected by the time-varying spatial variation and non Gaussian characteristics of complex underwater acoustic channels. At present, there is no comprehensive and systematic description of the mechanism of underwater target’s sound generation and how the noise is interfered and distorted by the channel, so underwater target recognition has always been the focus and difficulty of research in various countries. In this paper, the method of power spectrum is used to deal with ship radiated noise, extract the spectral characteristics of envelope, smooth and purify the line spectrum and estimate the fundamental frequency of the extracted demon spectrum, and then make the machine automatically give the axial frequency information of the target under the condition of low SNR [1, 2].

2. Spectrum characteristics of ship radiated noise
It is of great significance to study the ship radiated noise spectrum, because the ship radiated noise spectrum contains a wealth of information about the ship. Different ships radiate different noise because of the differences in hull structure, ship type, propeller size, number of blades, power plant and other internal structures. The noise can be processed to get the characteristic quantity of ship type.
In the passive sonar system, the target can be detected and the type of target can be identified by the deep understanding of the radiated noise and the means of signal processing.

2.1. Noise Spectrum of Ship Radiated Noise

When ships, submarines and torpedoes are sailing and operating, thrusters and all kinds of machines are working. Their vibration radiates sound waves to the underwater through the hull, which is an important noise source of ship radiation.

The noise radiated by ships, submarines and torpedoes is the comprehensive effect of many noise sources, mainly including the rotation of thrusters, reciprocating machinery, various pumps, etc. their noise generating mechanisms are different. Therefore, the form of radiation noise spectrum is also complex. As we all know, there are two basic types of noise spectrum, one is single frequency noise, its spectrum is line spectrum, which is the most concerned part of this topic, as shown in figure 1a. The other is the broadband continuous spectrum, and the noise level is a continuous function of frequency, as shown in figure 1b; however, for the radiated noise of ships, the actual noise is a mixture of the above two types of noise in a large frequency range, and the spectrum is shown as the superposition of line spectrum and continuous spectrum, as shown in figure 1c.

**Figure 1.** Schematic diagram of ship radiated noise spectrum: (a) Line spectrum;(b) Continuous spectrum;(c) mixed spectrum by the (a) and (b).

2.2. Radiated Noise Source and Its General Characteristics

Ship radiated noise mainly includes mechanical noise, propeller noise and hydrodynamic noise, so it is very important to understand the noise source of ship radiated noise [3].

Mechanical noise: refers to the noise caused by the vibration of various kinds of machinery on the navigation or operation ship radiated to the underwater through the hull. It is the main component of ship radiated noise in low frequency.

Propeller noise: refers to the noise radiated by the rotating propeller, including the propeller cavitation noise and the noise generated by the propeller blade vibration. Because the cavitation noise is caused by a large number of bubbles with different sizes breaking immediately, the cavitation noise shows continuous spectrum. In addition to cavitation noise, the other main part of propeller noise is the so-called “singing”, which is caused by the beating of propeller blades and cutting of water flow, so it is also called rotating noise. “Singing” is a line spectrum noise component, whose spectrum is the “blade speed” spectrum directly related to the number of blades and propeller speed, which satisfies the following relationship:

\[
f_m = mnS
\]

In the above formula, \(f_m\) —— Frequency corresponding to spectrum; \(m\) ——Harmonic number; \(n\) ——Number of propeller blades; \(S\) ——Propeller speed.

This kind of “singing” is represented by the line spectrum superimposed on the continuous spectrum, which is the main component of submarine low-frequency (1-100Hz) noise. This spectrum characteristic is often used by sonar system to identify targets and estimate their speed. Hydrodynamic noise: it refers to the result of irregular and fluctuating current flowing through the moving ship surface and making the hydrodynamic force act on the ship. In this paper, we mainly discuss how to
effectively extract the line spectrum added on the continuous spectrum \([4, 5]\).

3. Extraction of Line Spectrum of Ship Radiated Noise

Through a large number of experiments, it is known that the propeller cavitation noise in the ship radiated noise will be modulated by the speed line spectrum component of the propeller blade to generate the modulation spectrum. The information of low frequency line spectrum can be interpreted from high frequency spectrum. This is the commonly used detection of envelope modulation on noise analysis method, which obtains the line spectrum component by extracting the envelope of continuous signal. Therefore, more stable line spectrum can be obtained through demon spectrum analysis.

3.1. Demodulation Method of Ship Radiated Noise-Hilbert Amplitude Demodulation

Hilbert transform, also known as orthogonal coherent demodulation, is an important tool in signal analysis. For a real causal signal, there is a Hilbert transform relationship between the real part and the virtual part of the Fourier transform, the amplitude frequency response and the phase frequency response. The Hilbert transform can be used to construct the corresponding analytical signal, and the simulation conditions are as follows in figure 2:

![Figure 2. The envelope spectrum of simulated signal.](image)

Fundamental frequency of target signal: \(\Omega=7 \text{ Hz}\); Sampling frequency: 2048Hz; Modulation factor: 0.8; SNR: 5dB. The simulation figure is shown in figure 2. Figure 2 is the spectrum of envelope signal. In order to display the envelope more clearly, the above figure is partially enlarged for display. From the figure, a series of harmonics with a fundamental frequency of 7Hz can be clearly seen.

3.2. Purification of Demon Spectrum

In the actual analysis process, because the target is far away, or the main lobe of the positioning target is shifted, or the side lobe is mixed with the interference target and so on, the signal-to-noise ratio of the collected target noise is often reduced, and the demodulation effect is reduced. For this reason, the independence of noise can be used, and the noise can be suppressed by the average effect of multiple demodulation spectra. Sometimes, different targets and ship speed have different modulation frequency bands. In some frequency bands, the modulation depth is large, in some frequency bands, the modulation depth is small, and the larger the modulation depth is, the higher the signal-to-noise ratio of demon spectrum will be taken out. In order to display the modulation situation of different frequency bands, the usual method is to pass the signal through a narrow-band filter, get the narrow-band signal, and then take the envelope. The specific method is as follows; divide the signal in the frequency domain to make each signal meet the narrow band condition, but not too narrow, because the frequency band is too narrow, the modulation signal energy is smaller; take the envelope spectrum of each frequency band signal, and accumulate the envelope spectrum of different frequency bands to get the envelope spectrum of the signal in the whole frequency band, which is called the envelope periodic graph method.
3.3. Continuous Spectrum Smoothing
The amplitude of the line spectrum at the original frequency is enhanced by the function of the envelope periodic graph. However, because the line spectrum is superimposed on the continuous spectrum, if the line spectrum feature is extracted directly from the spectrum containing the continuous spectrum, it may cause misjudgment and missed judgment due to the trend of the continuous spectrum. Therefore, the trend term in the spectrum must be extracted and subtracted from the whole spectrum to obtain the flattened spectrum with only the line spectrum component, and then the line spectrum is extracted. There are many methods of continuous spectrum smoothing, such as linear phase filter, double pass separation window algorithm and sorting truncation algorithm. However, the smoothing effect of these algorithms is not good when there is strong line spectrum or line spectrum broadening, mainly because the existence of strong line spectrum and wide line spectrum will affect the smoothing of continuous spectrum near the line spectrum, and then affect the extraction effect of line spectrum. In this paper, a local fitting method based on sliding window is used to get the continuous spectrum [6].

Set the data length \(M\) to be analyzed, divide \(m\) into \(N\) segments, each segment only contains \(K\) sampling point. The overlap rate of each segment is \(\frac{k-1}{k}\). That is, only one sample point value between two adjacent segments is new. It is equivalent to setting a rectangular window with a length of sample points in the data segment to be analyzed, constantly moving the window function, and calculating the mean value of the spectral value of each segment: \(Y_m = \frac{1}{k} \sum_{i=1}^{k} y(i)\). Set a threshold value of \(a\), if \(y(i)\) is greater than \(aY_m\), it will not participate in the estimation of the global noise mean value, and the final estimate of the mean value is: \(\hat{m}(k) = \frac{1}{\lambda} \sum_{j=1}^{\lambda} y(j)\). The mean value is regarded as the discrete points on the continuous spectrum with slow change, and the low frequency component can be obtained by the fourth-order fitting of these discrete points to get the fitting curve.

3.4. Algorithm of Suspected Line Spectrum Extraction
(1) According to the characteristics of peak shape, search the spectrum

The point where the spectrum peak is located is the local maximum point, which cannot appear in the middle point. According to the above principles, simplify the waveform in turn, remove the middle point of continuous rise or decline, leaving only the turning point [7].

(2) In the last step, only the turning point is left, and the line spectrum of the simplified spectrum is scanned to extract the line spectrum distribution. The specific judgment methods are as follows: For any point \(y_k\), if \(y_k - y_{k-1} > \sigma_{gate1}\) or \(y_k - y_{k+1} > \sigma_{gate1}\), then \(y_k\) is considered as line spectrum, otherwise it is not line spectrum to be eliminated. The threshold value is divided according to the high and low frequency range. Since the axial frequency and blade frequency are mostly concentrated in the low frequency, the threshold value set in the low frequency is slightly lower. Although the false alarm probability is increased, more suspected line spectrum can be obtained in the low frequency. Because in the actual line spectrum, because the spectral line may exist in the high side lobe, one spectral line may be misjudged as two spectral lines, then it is necessary to eliminate this misjudgment; secondly, there may be a high point of side lobe superposition between two spectral lines which are very close to each other, or it may be misjudged as line spectrum. Therefore, it is necessary to eliminate the above spectral lines that may cause misjudgment. The method of elimination is: for any point \(y_k\), select threshold \(\sigma_{gate2}\), if \(y_{k-2} - y_k < \sigma_{gate2}\) or \(y_{k+2} - y_k < \sigma_{gate2}\), and its frequency interval \(f<3Hz\), then \(y_k\) is not a line spectrum, and it will be eliminated. This kind of situation generally occurs near the fundamental frequency.
(3) From the analysis, we know that the spectrum estimator is a random variable, and the random error of power spectrum estimation is shown as "burr" on the continuous spectrum curve. Therefore, some burr caused by the random fluctuation of spectrum estimation may be included in the peak initially selected in the previous step. When the average number of times used for spectrum estimation is large, the amplitude of this pseudo peak is not large. Moreover, in the actual operation process, it is always assumed that the amplitude of line spectrum should be higher than that of continuous spectrum, so a certain threshold value can be set on the line spectrum with certain continuous spectrum interference. Only when the amplitude is higher than this threshold value, it is considered that there is line spectrum. For the selection of this threshold, the mean value of all suspected line spectra is generally selected.

(4) Finally, the remaining local maximum points are processed by card threshold, the mean value of each local maximum point is multiplied by a scale factor as the threshold, and the ratio of the difference between the local maximum point and the minimum value in the waveform to the value range of the whole waveform is calculated. Then, the local maximum point is processed by card threshold, which requires that the local maximum point is greater than the threshold value, and the ratio is greater than the set value Otherwise, it will be eliminated. Finally, the line spectrum is obtained.

4. Axial frequency extraction

(1) Sequence the amplitude sequence and select the frequency points corresponding to the P maximum amplitude as the suspected fundamental frequency data [8, 9].

(2) Look for octave.

(3) Remove two adjacent frequencies that may be the same octave.

(4) The ratio of harmonic energy to total energy is given.

By cycling the above steps p times, the harmonic sequence of the line spectrum sequence with P fundamental frequencies can be obtained. The above method of frequency doubling is to select P data which can be used as the fundamental frequency according to the two sorting of amplitude and frequency, the prior knowledge and energy, i.e. amplitude sorting, and then sort again according to the prior knowledge and frequency to find the frequency doubling from low to high.

In order to find the double frequency of each fundamental frequency, the subsequent detection algorithm is used to search the double frequency. The fundamental frequency diagram obtained from the simulation experiment and the real sea trial data is shown in figures 3 and 4.

![Figure 3. Fundamental frequency chart based on simulation.](image)
Figure 4. Fundamental frequency chart based on real data.

5. Conclusion
Ship target recognition is not only an important research content in the field of underwater acoustics, but also one of the difficulties in this field. In this paper, the feature extraction and analysis method of ship radiated noise target recognition is studied deeply. The demon spectrum demodulation method, line spectrum extraction and shaft frequency estimation based on power spectrum are systematically analyzed and simulated, and good results are achieved.

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