Comparison of Passive Sonar Narrowband Detection and Wideband Detection Performance

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Abstract: *Conventional passive sonar uses wideband beam energy for target detection. In the case of low signal-to-noise ratio and strong target interference, the performance of wideband energy detection is rapidly degraded. In view of the relatively stable line spectrum of the radiated noise of underwater targets, the performance of narrowband detection and wideband detection is considered. In stable line spectrum underwater target detection, narrowband detection has performance advantages over wideband detection. However, its actual performance has disadvantages such as sensitivity to noise frequency bands. In this paper, based on the sonar equation, the theoretical methods of wideband detection and narrowband detection are analyzed and the main factors affecting detection performance are given. Simulation and sea trial data processing results verify the effectiveness of the method.*

Keywords: Narrowband detection, Wideband detection, Sonar equation, Performance analysis.

1. Introduction

In passive sonar signal processing, target detection methods can be divided into two categories: wideband detection and narrowband detection. In theory, narrowband detection has good performance for detection and early warning of underwater targets with stable line spectrum. Scholars from all over the world have carried out a lot of research, using the characteristics of line spectrum such as narrowband energy [1], frequency variance [2], space-time stability [3], amplitude and phase fluctuations [4], etc. They also considered the joint processing of narrowband spectrum characteristics and adaptive beamforming to improve performance [5-6]. Although various narrowband detection methods have been studied, the actual performance is closely related to the target noise spectrum characteristics, signal processing parameters, etc., and there are few comparative studies on its performance comparing to wideband detection.

2. Sonar Equation

Analyze the performance difference between wideband detection and narrowband detection from the perspective of sonar equation [7]:

$$FOM = SL - NL + DI - DT \quad (1)$$

Among them, the FOM value is the maximum single-way propagation loss allowed by the passive sonar, SL is the noise source radiated noise spectrum level, NL is the background noise spectrum level, DI is the receiving directivity index, and DT is the detection threshold (the signal and noise at the output of the beamformer Power ratio), DT is related to the detection index and the signal processing method, as for wideband detection:

$$DT_{WB} = 5\lg d - 5\lg BT \quad (2)$$

$5\lg d$ is detection index, $5\lg BT$ is time processing gain, B is integration bandwidth, T is integration time.

As for narrowband detection:

$$DT_{NB} = 5\lg d + 10\lg Ba - 5\lg IF \quad (3)$$

Among them, Ba is the analysis bandwidth, and IF is the integration factor. The loss caused by the adaptation of the inherent bandwidth of the line spectrum and the analysis bandwidth is not considered here.

Through the sonar equation, it can be found that factors such as DI and NL have the same effect on the two methods, while the wideband detection performance is closely related to the integration bandwidth, and the narrowband detection performance is closely related to the line spectrum level and analysis bandwidth. The working bandwidth of passive sonar is usually divided by octave. There are obvious differences in sonar working bandwidth and target noise characteristics on different frequency bands, and the performance comparison results of the two cannot be directly given.

3. Theoretical Analysis of Performance

Analyzing the performance of the two detection methods according to equation 2 and 3, focusing on the analysis of the working bandwidth and line spectrum signal-to-noise ratio factors that cause the difference, and the other factors adopt the same parameters. DI takes 16.8dB (48 elements), NL takes 65dB, $5\lg d$ takes 10dB, and T takes 4s. In narrowband detection, the analysis bandwidth is 1Hz (sample is 1s), the integration factor IF is 4, and the line spectrum level is 10-20dB higher than the wideband spectrum level. Figure 1 shows the FOM values of the two detection methods at different integration bandwidths.

It can be seen from Figure 1 that the narrowband detection performance has nothing to do with the bandwidth, and the FOM value is directly related to the line spectrum level. When the integration bandwidth is less than 100Hz, the narrowband detection performance is better than the wideband detection; when the line spectrum SNR is 20dB, the narrowband detection performance is better than wideband detection; when the line spectrum SNR is less than 15dB, wideband detection is better than narrowband detection above 1000Hz.

Figure 1: FOM value of passive sonar

4. Elements Level Signal Simulation Analysis

The elements level signal simulation method is used to compare and analyze the performance of the two detection methods. The detection signal processing flow is shown in Figure 2.

Figure 2: Signal processing flow of detection

First, transform the time domain array elements signal in to frequency domain using Fourier transformation. Then do CBF (conventional beamforming) on the frequency domain signal to get its array gain. Then the time is integrated, and the final target azimuth spectrum can be obtained.

In the simulation, it is assumed that the uniform linear array is composed of 48 elements, the distance between the elements is half a wavelength, and the sampling frequency is 16384Hz. Set the incident direction of the target signal to 120°, where the target signal is composed of a wideband continuous spectrum and a line spectrum. The line spectrum SNR is 10, 15dB, and 20dB, respectively, and the background noise is isotropic noise. The simulation objects are very low frequency sonar (50-100Hz) and low frequency sonar (1000-2000Hz), and the integration time is 4s. In line spectrum detection, constant false alarm processing is adopted, and the spectrum is normalized by the TPM (Two-Pass Mean) background equalization method [8], and the trend item in the spectrogram is eliminated, so that the output spectrum maintains a constant virtual threshold for a fixed line spectrum threshold. Probability of alarm. The Monte Carlo method [9] is used to perform 1000 simulations, and the results are shown in Figure 3.

Figure 3: Monte Carlo simulation of line spectrum detection

The line spectrum detection threshold is set to 7.9dB, which corresponds to a false alarm rate of 1%. As the input signal-to-noise ratio increases, the probability of corresponding false alarms quickly decreases to a fairly low level.

The minimum detection SNR of sonar under various conditions is statistically compared (the output SNR detection threshold is 10dB), and the results are shown in Table 1. It can be seen that the wideband minimum detection SNR is basically unchanged, and the narrowband minimum detection SNR is closely related to the line spectrum SNR. The higher the line spectrum SNR, the lower the minimum detection SNR; for very low frequency sonar, due to the small integration bandwidth, the wideband processing gain is limited, and the improvement of narrowband detection performance is more obvious.

Table 1: Compare of minimum detection SNR

SNR	WB/dB	NB/dB	WB/dB	NB/dB
	low frequency		very low frequency	
10dB	-25.0	-25.0	-19.0	-19.8
15dB	-25.0	-26.0	-19.5	-24.0
20dB	-25.0	-30.0	-20.0	-27.0

In order to measure the working characteristics of wideband detection and narrowband detection better, the ROC curves of the two methods are simulated. Take VLF sonar as an example. When the input SNR is -25dB and the line spectrum SNR is 20dB, the ROC curve is shown in Figure 4. It can be seen that under the same false alarm probability, the detection probability of narrowband detection is higher than that of the wideband detection. The detection probability of both increases as the false alarm probability increases, and the performance of narrowband detection tends to be more stable. Under the condition of lower false alarm probability, the probability of narrowband detection is much higher than that of wideband detection, which is obviously more suitable for practical use.

Figure 4: ROC curve of the two methods

Figure 5 shows the comparison of the azimuth history of wideband detection and narrowband detection under the condition of VLF sonar -25dB, where the line spectrum SNR is 20dB. The upper sub-picture shows the results of wideband detection, and the lower sub-picture shows the results of narrow band detection. It can be seen that the wideband detection has failed, and the target has been submerged in the noise background and cannot be distinguished. The narrowband detection shows that the target azimuth is 120° in multiple time snapshots, which is consistent with the true value and can be effectively detected. Prove its performance superiority relative to the wideband detection.

Figure 5: Bears of time for two detection methods at low SNR

5. Conclusion and Outlook

Based on the passive sonar equation, this paper analyzes the theoretical performance of wideband detection and narrowband detection methods, and gives the main factors that affect their detection performance. Through the method of element level signal simulation, the correctness of the theoretical analysis is verified. The analysis results show that in the low frequency and very low frequency range, narrow-band detection can better extract target information, and under the same conditions, the performance of narrow band detection is better. It can provide a useful reference for the design of different functional types of sonar. Narrowband detection shows its potential in the field of passive sonar signal processing. It is worth more experts and scholars to carry out in-depth research.

Subsequent consideration is to combine narrowband detection with image processing and other algorithms, and further consider the performance improvement of the algorithm in the state of unstable line spectrum.

In the following research work, wideband detection and narrowband detection will also be combined, and the advantages of the two will be combined to further enhance the target detection ability.

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Author Profile

Tianhao Yang (1995-), received his Bachelor degree in Harbin Engineering University in 2017, respectively. Now, he stays in Hangzhou Applied Acoustic Research Institute to study passive sonar signal processing and line spectrum detection methods.