Ship's Harmonic Lines Suppression Using the Coherent Onion Peeler

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Introduction

Weak target detection under strong interferer conditions has been a key research topic in underwater acoustic technology. In case of a strong interferer in the detection area of the sonar, the target signal received may be rather weak, or even can not be “heard” by the sonar. Therefore, strong interferers’ suppression is necessary in order that weak targets can be found and be processed subsequently. Wilson proposed the coherent onion peeler (COP) algorithm and succeeded in suppressing tow ship noise using it. In this paper, basic principle and derivation of the COP algorithm for an equally spaced line array was given, and then a computer simulation was completed. COP was used to suppress the ship's harmonic lines in the background noise field with Gaussian statistics.

Simulation on Ship Radiated Noise

ship radiated noise in time domain can be simulated as the model:

\[ s(t) = |t| + a(t) \cdot g_1(t) + g_2(t) \]

Simulation on COP

For an equally spaced line array of 17 elements with spacing 7.5 m, Fig.5 gives simulation results of CBF and that of after COP used when the signal from the target and the noise from interferer arrives from 10° and -40° respectively. The solid line in Fig.5 shows beamformed output before COP noise suppression. The dotted line describes the output after COP, and one can see the output at the direction of the interferer falls substantially and the target presents. That is, COP reduced the interference for ship's harmonic line spectrums in low frequency successfully, and improved the ability of target detection.

Theory of COP

The COP interference suppression technology is realized by subtracting the coherent data of a single plane wave model from received data of each element. The mathematical modeling of the linear noise suppression algorithm COP for each beamformer led to the same mathematical solution.

The COP algorithm contains four steps. Next, derive the single plane wave COP algorithm for an equally spaced line array.

Direction Finding

The first step is to find the direction of the interferer using a beamforming method in frequency domain. Taking CBF as an example for simplicity, the output of the beamformer is described with the frequency and the azimuth angle:

\[ Y(f, \theta) = \frac{1}{N} \sum_{n=0}^{N-1} w_n X_n(f) \exp\{j2\pi f n \cos \theta / c\} \]

Rebuilt

When the azimuth angle of the interferer has been detected, we will rebuild N sets of new signal using the power spectrum amplitude and the position vector. So the signal spectrum for the hydrophone numbered n is:

\[ X_{reb}(f) = Y(f, \theta_{\text{max}}) \exp\{-j2\pi f n \cos \theta_{\text{max}} / c\} \]

Suppression

The remains subtracting rebuilt signal from received signal is described in frequency domain:

\[ X_{\text{new}}(f) = X_n(f) - X_{\text{reb}}(f) \]

Detection

Beamforming the N sets of signals after COP interference suppression, then the target azimuth can be derive. In case of multiple strong interferers present, one can continue to track and suppress the next strongest interferer until all interferers present are suppressed, and, hopefully, the weak signals of interest will be detected.

Conclusion

Harmonic lines are major low frequency components of ship radiated noise, which will weaken their detection performance when the sonars work in low frequency. In this paper, assuming ship’s harmonic lines to be interference, simulations on COP noise suppression were did under the condition of strong interferer and weak target. The result shows COP can suppress ship’s low frequency harmonic lines efficiently and enhance the sonar’s detection performance. Furthermore, COP has simple procedures and linear operation, which brings faster calculate speed, higher stability and practicability.