Active Sonar Detection Using Adaptive Time-Frequency Feature

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Introduction

In the complex variable shallow water acoustic channel, the regular signal emitted by the active sonar would propagate through multiple paths and be scattered by the target. Compared with the transmitted signal, the echo signal has a time delay and Doppler spread. This leads to a great decrease of the correlation between the copy vector of the matched filter and the target echo, which degrades target detection and estimation performance. This paper uses the time-frequency feature extracted from the target echo to adaptively weight copy vector of the matched filter. The target detection performance of the active sonar is improved by solving the mismatch between original transmitted signal and target echo.

Adaptive Time-frequency Feature Detector

From the analysis in section II.B, we can see that the key point to realize the adaptive time-frequency feature detector (ATFFD) is to adaptively estimate the coefficient $w$ from the data. Specific implementation steps are as follows.

1. Process matched filtering of the beamforming output data: $y_i = s^Hx_i$, where $y = [y(1)\ y(2) \cdots y(N)]^T$ represents the output data of the beam field data after matched filtering, $s = [s(1)\ s(2) \cdots s(N)]^T$ indicates the copy vector of the emission signal and $x = [x(1)\ x(2) \cdots x(N)]^T$ represents the beamforming output data.

2. Find the position of the maximum value of the matched filter output. If the maximum position is less than half the width of the signal pulse or larger than $N$ subtracting half the width of the transmitted signal, the processed data does not contain the echo signal. Under this condition, the conventional matched filter output is used as the result of the adaptive time-frequency feature detector. Otherwise, compare the energy of the output data with the threshold. If the maximum energy is lower than the threshold, then the processing data does not contain the echo signal, and vice versa, the processed data contains the echo signal.

3. Implement time-frequency analysis of the beam space data which contain echo signal, and extract the time-frequency coefficient of the target echo, which can be expressed as: $w = [w(1) \ w(2) \cdots w(N)]$.

4. A new copy vector is obtained by weighting the target echo with the extracted time-frequency coefficients.

5. The beam space data is then matched filtered by the new copy vector: $y_n = s^Hx$. Specific processes are shown in Fig. 1.

Simulation and Real Data Experiments

The performance of the adaptive detector is verified by simulation. The target echo is extracted from the actual sea trial data. Add the noise data with SNR=35dB into the echo data. The results of conventional matched filter detector and the adaptive time-frequency feature detector are shown in Fig. 2.

The performance is then compared under Probability of False Alarm (Pfa) equals 0.01 and 0.001, respectively. The noise data is generated by Monte Carlo simulation and the number of Monte Carlo simulations is 10000. As shown in Fig. 3, the performance of the adaptive time-frequency feature detector is much better than that of the conventional matched filter detector with a higher probability of detection (Pd).

Fig.4(a) and Fig. 5 (b). The output SNR is significantly improved by the adaptive time-frequency feature compared with the conventional matched filtering process.

Summary

To solve the mismatch problem of the target echo in shallow water channel, an adaptive time-frequency feature detector is proposed in this paper. The time-frequency feature matching is realized by adaptively weighting the copy vector with the coefficients extracted from the time-frequency analysis of the target echo after beamforming. Experiments of both simulated and real data verified the effectiveness of the proposed method. The performance of the matched filter is improved in shallow water.