Acoustic clutter removal, Hong Kong Ship Channel

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ABSTRACT

With the widespread availability of recreational and military underwater vehicles, maintaining underwater security in ship channels and harbors is more challenging than ever before. Ship traffic, high background noise and widespread acoustic clutter make detection of potential threats technically difficult and costly. The objective of this paper is to demonstrate how maximum length sequences, m-sequences, can remove both stationary and moving clutter in a ship channel or harbor environment, considerably improving opportunities for threat detection. As an example of the potential for clutter removal, the performance of a notional traffic monitoring system with underwater coverage is simulated for a segment of the Hong Kong Ship Channel.

Keywords: m-sequences, clutter, harbor defense, ship channel defense, coherent subtraction

Introduction

Maximum length sequences have been used to probe the dynamics of our oceans since Steinberg and Birdsall's 1964 pioneering experiment in the Florida Straits.[1] In the following 50 years, oceanographic studies using m-sequences with near-stationary acoustic sources and receivers were conducted at longer range, eventually leading to tomography, the Heard Island experiment, the Greenland Sea experiment, ATOC and many others. The list of current and past investigators is far too lengthy to properly credit all but a few.[2-14]

Recently, m-sequence studies and experiments have focused on harbor and near-shore defense, rather than oceanography.[15-17] In these areas the challenge has been to find small acoustic targets in the presence of clutter from underway commercial shipping, bottom features and moored vessels. The objective of this paper is to demonstrate, through simulation, how m-sequences can remove both stationary and moving clutter in a ship channel or harbor environment, considerably improving opportunities for threat detection in near-shore environments.

A Notional System for Ship Channel Monitoring

The Hong Kong Ship Channel is one of many possible locations for our notional system. As shown in Figure 1, a promontory provides a physical acoustic barrier between the acoustic projector and the horizontal line array receiver. *Separating the source and receiver eliminates the direct acoustic path* which, because of its high energy, can limit the performance of bistatic systems. (Unlike historic "ping-the-listen" sonars, m-sequence transmissions are low power and long duration. "Listening" continues throughout the signal transmission.) The geometry also places moving clutter sources near-perpendicular to the source and receiver paths, *minimizing the Doppler channels and array beams that need to be processed*.

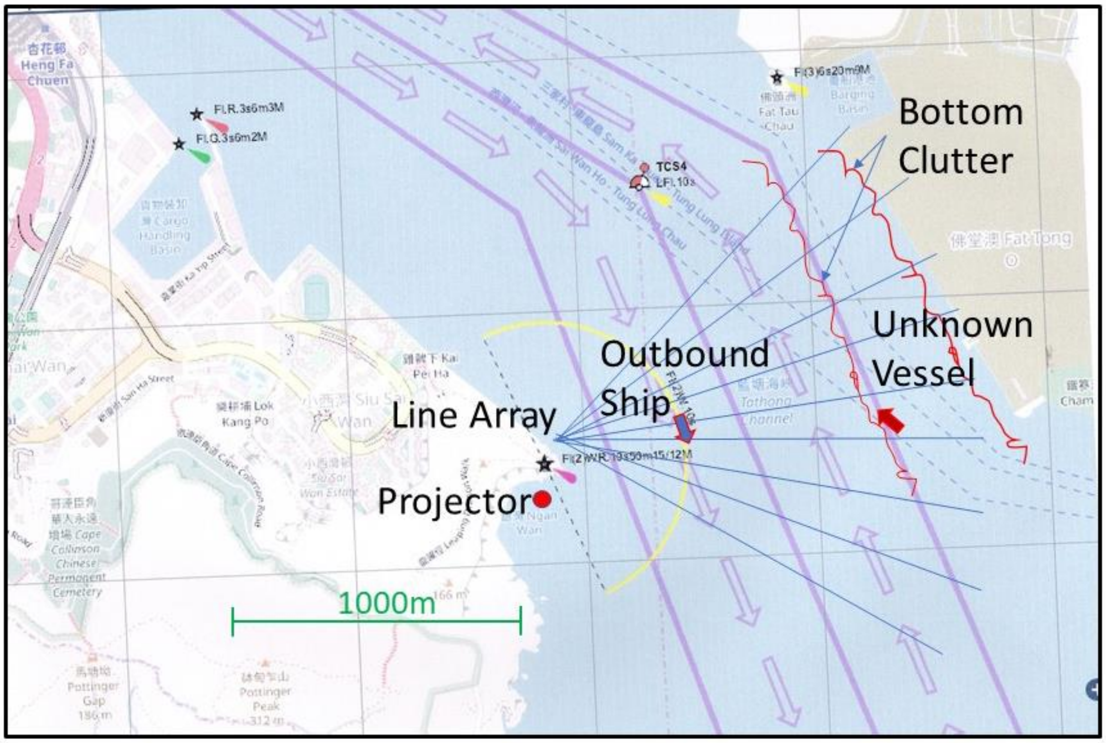

Figure 1: A notional system for ship channel monitoring

In Figure 1 the red lines near the far shore and on the shipping channel boundary indicate regions where acoustic clutter from the channel bottom is expected. Ten clutter points with random amplitudes are generated at both the far shore and the dredged shipping channel boundary within the 5-degree receiving array beam. In addition to bottom clutter from the channel boundary and far shore, reverberation is modeled by 33 clutter points distributed between the intersection of the source and receiver beam patterns and the far shore. (The projector beam pattern, typically 60 degrees, is not shown.) Reverberation energy is determined by bottom and surface backscattering coefficients associated with a rocky bottom and by the scattering area.[18-19] Considering the channel boundary, far shore clutter and reverberation, 53 clutter sources are included in the receive beam.

Two moving vessels are modeled. The outbound ship is traveling at 20 knots with a +15dB target strength. Doppler-shifted, direct and surface-reflected acoustic paths are included, to and from the ship, resulting in four closely spaced acoustic arrivals at the receiver. Similar modeling represents the unknown inbound submerged vessel traveling just beyond the ship channel. The speed of the unknown vessel is 6 knots, target strength -15dB and depth 6m. The objective is to detect the submerged vessel in the presence of reverberation, bottom clutter and the much larger +15dB moving ship.

“Simulation” is a word that has been used to describe a variety of systems with widely varying complexity. As shown in Figure 2, the simulation in this work separates the signal processing and environmental algorithms in such a way that the environmental portion of code can be replaced by the “real” ocean, thereby simplifying the transition from simulation to experiment.

The m-sequence is designed, usually with some trial-and-error, in the first block. Sequence duration is chosen to exceed the out-and-back bistatic distance. For the chosen environment, the carrier frequency is 5kHz, with 8 samples per cycle, 6 carrier cycles per sequence digit, 2047 digits per sequence and 5 sequences per transmission. The resulting duration of a single sequence is over 2 seconds, long enough for acoustic propagation across the ship channel and back. The carrier frequency was chosen based on the availability of reasonably priced, directional, linear acoustic projectors.

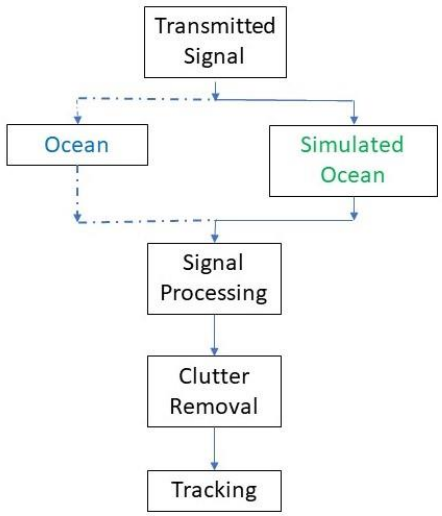

Figure 2: Simulation

In the environmental simulation, sound speed is isovelocity. Doppler spreading of surface-reflected paths is included for shipping and for the unknown vessel. Ambient noise spectrum level is 70dB, representative of harbors.[19] The line array beam pattern is modeled as a pie-shaped segment with coherent gain for clutter and incoherent gain for noise.

The received, demodulated signal, representing clutter and target, is the superposition of 61 time delayed and Doppler-shifted m-sequences. Filtering, demodulation and correlation are similar to what has been published in the past[15] with the exception that the received signal is demultiplexed into 48 sequences, each with 2047 complex samples. Each sequence is then processed individually with time and frequency corrections before correlation with a zero Doppler reference. In addition, *the received signal is bandpass filtered to smooth the m-sequence phase transition and to avoid computational noise from the interpolation algorithm*. With these changes the zero Doppler autocorrelation noise floor, shown in Figure 3(a), is more than 250dB below the autocorrelation peak. The peak width at 3dB points is 56 samples, one sample for

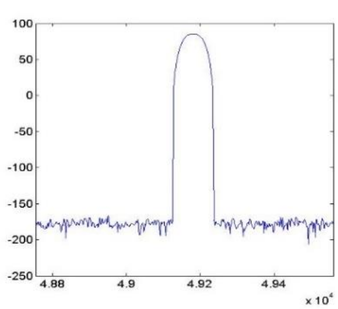

Figure 3(a) Autocorrelation

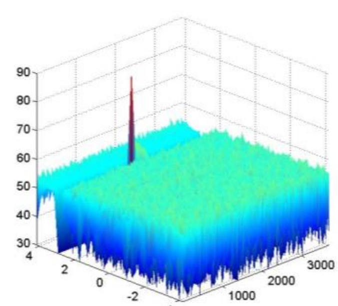

Figure 3(b) Ambiguity Function

each of the 56 time-multiplexed m-sequences. The autocorrelation noise floor for Doppler-shifted signals (not shown) is limited by filtering and is approximately 80dB below the peak. The ambiguity function floor for Doppler shifted signals, Figure 3(b), is approximately 26dB below the function peak and has near-uniform variability.

Simulations with noise, clutter and shipping are shown in Figure 4. Axes are source-object-receiver Doppler (+4 to -4 knots), source-object receiver distance (0 to 3600 meters) and received energy after beamforming and m-sequence processing (10log|A|^2). Noise alone is shown in Figure 4(a). Reverberation, beginning at the intersection of source and receiver area coverage, clutter from the dredged shipping channel and clutter from the far shore have been added to noise in Figure 4(b). In Figure 4(c), clutter from a +15dB moving ship and a -15dB underwater vehicle (hidden by the ambiguity function floor) have been added.

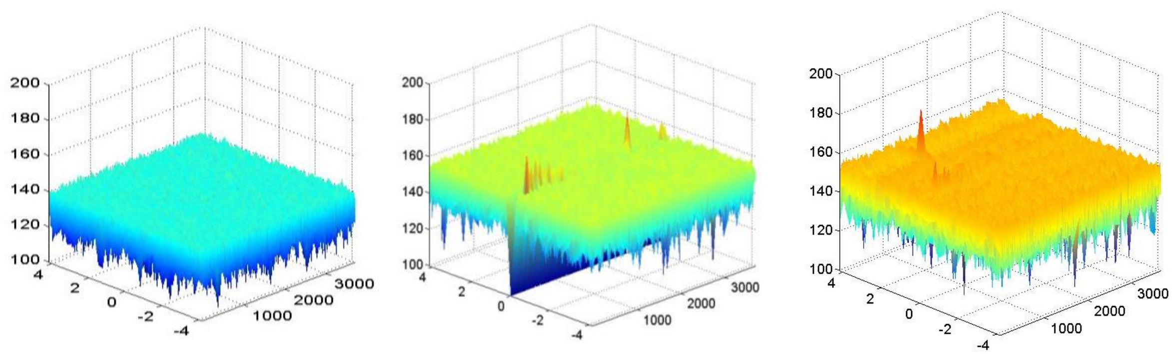

Figure 4(a) Figure 4(b) Figure 4(c)

Figure 4: Ambiguity function with (a) ambient noise, (b) noise, reverberation and boundary clutter, (c) noise, reverberation, boundary clutter +15dB shipping and -15dB underwater vehicle.

We define "coherent subtraction" as the operations that transform clutter from the ambiguity function to the time-domain where it can be subtracted from the original received signal. The coherent subtraction steps are: (1) identify areas containing clutter in the ambiguity function range-Doppler plane, (2) time and frequency correct clutter from the complex ambiguity function to its original Doppler frequency, (3) inverse transform the clutter segment from the ambiguity function domain to the time domain, (4) coherently subtract the complex time-domain clutter from the demodulated, complex received signal, and (5) reprocess the "cleaned" signal. The process is illustrated in Figure 5.

The ambiguity function before coherent subtraction is shown in Figure 5(a). Although reverberation, bottom clutter and the submerged -15dB inbound vessel are present, they are masked by the ambiguity function floor generated by the outbound ship. In Figure 5(b), the +15dB outbound vessel has been coherently subtracted from the received signal, and the ambiguity function reprocessed. Correlations from the unidentified vessel, bottom clutter and reverberation remain. After the third iteration, Figure 5(c), boundary clutter residuals have been coherently subtracted, and only the -15dB, 6 knot target remains.

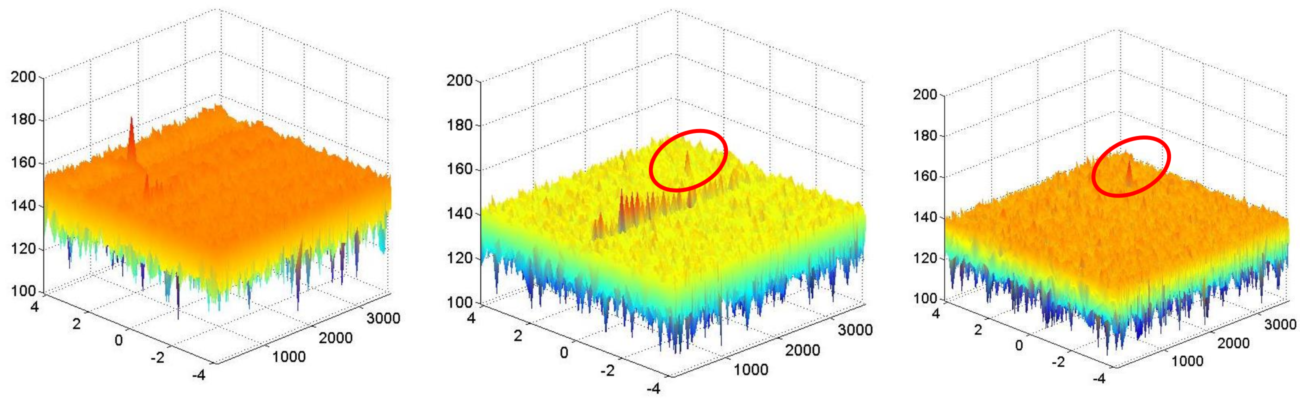

Figure 5(a) Figure 5(b) Figure 5(c)

Figure 5: Ambiguity function (a) before coherent subtraction, (b) after one iteration removes clutter from the moving ship, (c) after a second iteration removes reverberation and boundary clutter leaving the submerged target clearly visible.

Summary

With the widespread availability of recreational and military underwater vehicles, maintaining underwater security in ship channels and harbors is more challenging than ever before. This work demonstrates that, with attention to computational noise, coherent subtraction may provide a practical method for reducing clutter in a complex ship channel or harbor environment. Careful placement of the acoustic source and line array receiver can reduce signal processing complexity, minimize equipment cost and minimize the personnel required for system operation and maintenance.

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