OS-CFAR detection of targets in the water column and on the seafloor with a multibeam echosounder

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***Abstract*—Ordered statistic constant false alarm rate (OS-CFAR) detection is applied to the beamformed output of a multibeam echosounder to obtain estimates of the signal-to-clutter ratio across all angles at each range increment or time slice. Assuming proper compensation for transmission losses due to spreading and absorption of acoustic energy in the water column, a threshold is chosen to detect echoes in the water column above and close to the bottom, with minimal masking due to bottom echoes appearing in the sidelobes of other beams at the same range. Results are demonstrated with a multibeam echosounder operating at a single frequency of 160 kHz for all beams. This technique obviates the need for more sophisticated multibeam echosounders that avoid sidelobe masking by transmitting and receiving at different acoustic frequencies in neighboring beams.**

Keywords—CFAR; midwater target detection; multibeam echosounder.

I. Introduction

Increasingly, commercial fishermen use low cost multibeam echosounders to manage their net tows by visualizing simultaneously a 120º swath of bottom topography and fish schools in the water column along the ship's track. Such visualization is essential for aiming the net at a fish school while keeping it away from obstructions that are likely to damage it. However, bottom echoes captured in the sidelobes of the outer beams of the echosounder tend to obscure weaker echoes from targets in the water column. Sophisticated multifrequency multibeam sonars developed in the last 10 y (e.g. [1]) address sidelobe masking by steering beams at different acoustic frequencies across the angular sector of interest.

The solution presented here works with a multibeam echosounder operating at a single acoustic frequency. This solution relies on a variant of the ordered statistic constant false alarm rate (OS-CFAR) detection method used in radar to obtain estimates of the signal-to-clutter ratio at each range increment [2; 3; 4-Ch. 7:7.6]. OS-CFAR is less sensitive than other CFAR methods to the presence of multiple targets and to nonhomogeneous clutter distributions in the reference window. The variant implemented here operates in the angle domain, rather than the range domain, and it estimates the signal-to-clutter ratio across all angles at a given time slice or range increment at the output of the beamformer. The term clutter is used somewhat generically here to encompass an unknown combination of clutter and noise against which a signal is to be detected.

In the following we describe the technique and show qualitative results obtained with a multibeam echosounder operating at 160 kHz. A quantitative assessment of the method with the usual performance metrics of probability of detection and probability of false alarm for a given signal-to-noise ratio is being submitted separately for publication in a Journal article.

II. Method

A. Conventional OS-CFAR

Chapter 7 of [4] provides an excellent overview of CFAR detection. All CFAR detection techniques rely on a sliding reference window centered on the cell of interest with guard cells immediately adjacent to the center cell, and a specified number of reference cells (data samples) on either side of the guard cells. Guard cells are meant to ward against targets that occupy more than one range cell and might bias the estimate of clutter power in the reference cells. The reference window may be one-dimensional (range), or two-dimensional (range, Doppler) or (range, cross-range).

OS-CFAR departs from other CFAR techniques by its use of quantiles instead of statistical moments (usually the first moment, which is approximated by the arithmetic mean) to estimate clutter power in the reference window and set a detection threshold. Whereas use of statistical moments presumes a homogeneous clutter distribution in the reference window, quantiles apply equally well to homogeneous and nonhomogeneous clutter distributions. In addition, OS-CFAR can handle multiple targets in the reference window. By contrast, the performance of other CFAR methods degrades when there is more than one target in the window.

In OS-CFAR, the data samples in the reference window are sorted in ascending order of intensity or magnitude. For N sorted samples in the reference window, the kth element ($1 \leq k \leq N$) corresponds to the kth quantile. For instance, the median is the quantile $k = N/2$. The procedure consists in selecting a particular quantile and in using its corresponding intensity value as an estimate of the clutter power in the reference window. In practice, k should be between $N/2$ and $3N/4$ [2]. Guard cells are not necessary in OS-CFAR.

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B. *OS-CFAR Applied to the Angular Power Spectrum*

In multibeam echosounding, one hundred or more beams are steered simultaneously by a receive array to form a fan covering a sector spanning up to ± 80º about broadside. If the sonar uses a fast Fourier transform (FFT) beamformer, echoes reaching the receive array are beamformed and a sequence of angular power spectra is formed (one per time sample). If the sonar uses a time-delay beamformer, beams are formed simultaneously but separately. However, the overall output of the beamformer at the end of a ping cycle has the same shape as the output of the FFT beamformer: a sequence of angular power spectra. Target detection can be applied to this sequence in range or in angle, or both. However, inherent in the multibeam geometry is the issue of cross-talk between beams through their respective sidelobes. Strong echoes received from normal incidence on the bottom appear in the sidelobes of all the other beams in the fan. In addition, there is usually more than 50% overlap between the mainlobes of adjacent beams, so targets closely spaced in angle might not be resolved.

The OS-CFAR concept is applied to the angular power spectrum by first forming an ordered statistic across all beams for each time slice. Then, the kth quantile is selected and its intensity for a given time slice is used to normalize the corresponding spectrum. This normalization converts the sequence of spectra with varying power levels to a common signal-to-noise ratio (or signal-to-clutter ratio) reference. This means that a common detection threshold can be applied to the entire sequence of spectra with an effectively constant false alarm rate.

There is no sliding reference window in this implementation and at each time slice, the clutter power estimate is based on a large number of beams (N > 100) compared to the number of samples typically used in range OS-CFAR (e.g. N=32, [2]).

III. RESULTS

Results obtained with a multibeam echosounder operating at 160 kHz are shown in Fig. 1. This sonar has a receive array with 26 elements and beamforming was done with a 128-point FFT beamformer. For each time slice, the output of the beamformer was rank-ordered in increasing intensity and the 75^{th} quantile retained. The intensity value corresponding to this quantile for any given spectrum was used to normalize that specific spectrum. The important detail here is that although the same 75^{th} quantile is selected in each case, the corresponding intensity varies from one angular power spectrum to the next.

Echoes in the water column are detected above and close to the bottom, with minimal masking due to bottom echoes appearing in the sidelobes of other beams across the swath. A detection threshold of 10 dB was used in this example.

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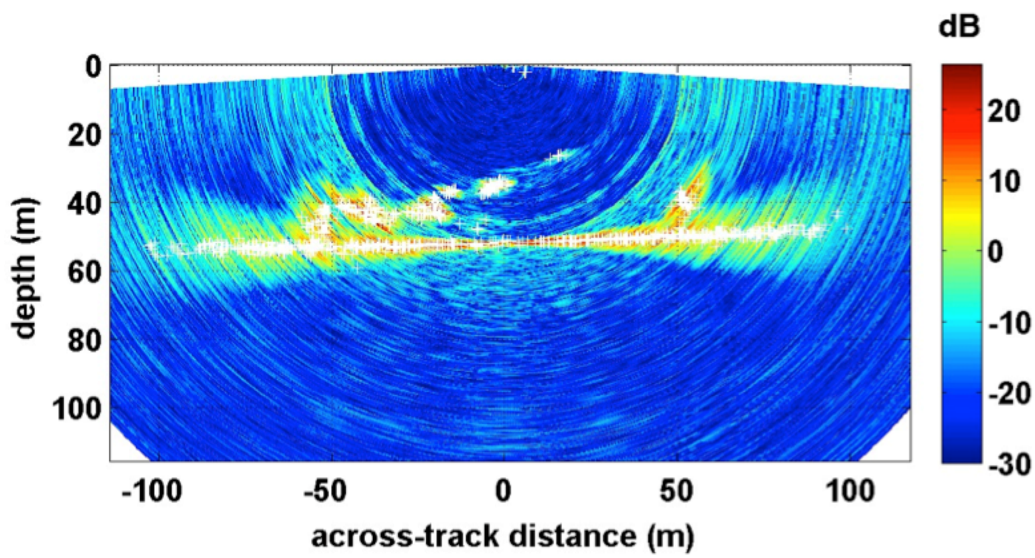

Fig. 1. Detection of the bottom and targets in the water column in a single sonar ping of a multibeam echo-sounder operating at 160 kHz. Uncalibrated acoustic backscatter strength is displayed on a relative decibel scale with high values corresponding to high ocean volume or seafloor backscatter strength. White "+" symbols identify all the detections including targets in the water column within and outside the "spherical region" (as depicted in Fig. 1b of [1]) and along the bottom at about 55 m depth in this example.