Stacking and Averaging Techniques for Bottom Echo Characterization

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Abstract: The characteristic bottom echo calculated from measurements made with high acoustic frequency (> 10 kHz) transducers is highly influenced by the method of stacking and averaging applied to the data ensemble. Comparisons of a geoacoustic temporal model with 33 kHz and 93 kHz echoes backscattered from fine-grain substrates reveal that a representative echo shape is obtained by averaging echoes along-track over a distance roughly equivalent to the 6 dB footprint diameter of the sonar beam pattern. For data with consistent temporal energy distributions, alignments referencing threshold minima best preserve the salient echo-shape characteristics, whereas data with less well-defined energy distributions were more successfully aligned by referencing offsets calculated from the phase slope (group delay) of the corresponding envelope spectra. [Work supported by ONR #N00014-94-1-0121]

INTRODUCTION

Bottom-looking sonars operating at frequencies greater than 30 kHz transmit acoustic signals which penetrate at most a few meters into seafloor sediments, making them well suited for characterizing the water/sediment interface. Acoustic wavelengths at these frequencies are small compared to the RMS relief of the interface, resulting in bottom echoes dominated by incoherent energy and varying significantly in amplitude and shape as the sonar translates longitudinally above the interface. Because of this variability, echoes must be treated stochastically and determining the average shape of the bottom echo involves careful selection of stacking and averaging algorithms.

APPROACH

While underway over San Diego Harbor's silt deposits, consecutive bottom echoes were measured with calibrated 33 kHz and 93 kHz piston transducers. These measurements were made in 15 to 20 meters of water depth with the transducers alternately oriented at normal and oblique incidence. Analysis of maximum amplitude spectra reveal that averaging over an echo ensemble covering the 6 dB transducer footprint provides adequate statistical representation and, in this example, 100 pings meets the criteria.

To be meaningful, such averaging must be performed on echoes that have been aligned in time, thus removing effects due to transducer heave as well as small depth variations over consecutive pings. We evaluated the merit of alignment techniques by comparison with a temporal model of seafloor acoustic backscatter which incorporates the characteristics of the sonar system and statistical representations of the sediment/volume interface: (1) (2).

RESULTS

Effects of the most promising alignment techniques are illustrated in the model vs average echo envelope comparisons of figure 1. The model input parameters are characteristic of a coarse silt substrate, and the data result from 100 stacked and averaged echoes. Comparisons for the 33 kHz transducer oriented 2 degrees from nadir are presented in the top row, while the bottom row demonstrates comparisons for the 93 kHz transducer oriented 8.5 degrees off normal incidence. The signal to error ratios (S/E) listed above the plots represent the total energy of the measured signal divided by the total energy of the discrepancy between model and data. Higher signal to error ratios imply a better match of model and data.

Figure 1.a results from averaging raw (non-aligned) echoes under conditions of moderate temporal dispersion, such as vessel heave and small changes in water depth. The model represents the "correct" solution, and the calculated average falls well short of qualifying as a "good match." Alignments based on signal to noise enhancement techniques (e.g. peak tracking and matched filters) often produce vertical disproportions, illustrated by the peak tracking result of figure 1.b. Typically, lower frequency echoes originating from "smooth" substrates exhibit consistent temporal energy distributions when measured near normal incidence. Under these conditions, alignment based on a minimum threshold preserves the integrity of the average echo's rising edge, as demonstrated by the 26 dB signal to error match of figure 1.c.
The effectiveness of minimum threshold alignment suffers in noisy measurement environments, or when the dis-
placement of the maximum temporal energy lobe is inconsistent - as is the case with high acoustic frequencies, com-
paratively “rough” substrates, and off normal incidence. Under these conditions, employing an alignment technique
based on the temporal distribution of energy in the echoes can be more beneficial. The group delay (grd) of the
individual echoes (x[n]) is defined as: \( \text{grd}(x[n]) = -\frac{\pi}{\omega_0} \arg[X(e^{j\omega})] \), and is expressed in radians relative to the
resolution frequency (\( \omega_0 \)) of the echo’s discrete time Fourier transform (X(e^{j\omega})). For the 93 kHz, off normal mea-
surements, alignment offsets determined by group delay produce average echo shapes most consistent with theory, as
demonstrated by the 22 dB signal to error match of figure figure 1.h.

FIGURE 1. Comparisons of temporal model (dashed lines) and stacked/averaged echoes (solid lines)

SUMMARY

These examples demonstrate that for data exhibiting consistent temporal energy distributions, a representative echo
shape is obtained by averaging echoes along-track over a distance roughly equivalent to the 6 dB footprint diameter
of the sonar beam pattern and aligned using a minimum threshold technique. For data with less well-defined energy
distributions, alignment via group delay calculations yields a more robust estimate of the average echo.

REFERENCES

1. Sternlicht, D. D. and de Moustier, C. P. “Temporal modeling of high frequency (30 - 100 kHz) acoustic seaﬂoor backscatter: