Correlation-Tracking with the Hydra Array

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Hydrophone arrays are widely used for tracking sources in and on the ocean such as whales, autonomous vehicles, and ships. The most common approach uses planewave beamforming in which the individual channels are combined with the appropriate delay for a presumed bearing angle. Sweeping through different bearing angles then provides a measure of the sound level in each listening direction and therefore the bearing of sound source(s). As acoustic models have become much more rapid and reliable it has become increasingly obvious that more sophisticated features of the received energy can be exploited to provide the source location in 3-space rather than just in bearing space. Here we describe the application of a correlation-based approach for a sparse, 6-phone, horizontal line array.

INTRODUCTION

The limitations of conventional planewave beamforming are obvious if one considers the extreme case of an array consisting of just a single phone. Planewaves from all points in space look the same to that single phone so there is no resolution in depth, range, or bearing. Nevertheless, it is possible to localize a source in this configuration. The phone receives a different echo pattern for each source position. Modern ocean acoustic models can easily and reliably predict that echo pattern; a comparison of measured and modeled echo patterns then reveals the source position.

The process we are describing is a model-based one that exploits more subtle features than just the arrival angle. Within this large class of model-based schemes one may include, 1) matched-field processing, 2) back-propagation/time-reversal methods, and 3) correlation processing. Interestingly all of these methods can be traced back a couple decades and despite their apparently distinct nature are identical under simple conditions. Space does not permit a complete discussion of these issues, so we confine ourselves here to an experimental demonstration of the process.

EXPERIMENTAL DEMONSTRATION

The Hydra array consists of 6 phones over a total length of about 650 m. The received data is processed autonomously relaying track information to the surface via an acoustic link. However, in these tests the data is simply stored and processed later. The array was deployed off the coast of California near San Diego as shown in Fig. 1.

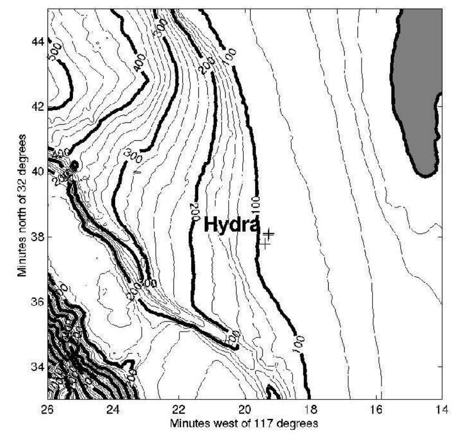

FIGURE 1. Bathymetry for the Hydra Sea Test (depths in m).

During the experiment, both tonals and linear frequency modulated (LFM) chirps were transmitted in the 30-230 Hz band. The resulting waveform thus simulates the spectrum of a surface ship. In addition, correlating the waveform on a single channel with that transmitted yields the impulse response of the channel as shown in Fig. 2. During this period the acoustic projector was towed from east to west over the array and then back again from west to east. The varying echo pattern is the signature of the source location that is exploited for ranging purposes.

As a pre-cursor to localization, one would like to have confidence that the acoustic model gives an accurate simulation. This is confirmed in Fig. 3 showing simulated impulse responses as computed by a simple beam-tracing code (BELLHOP).

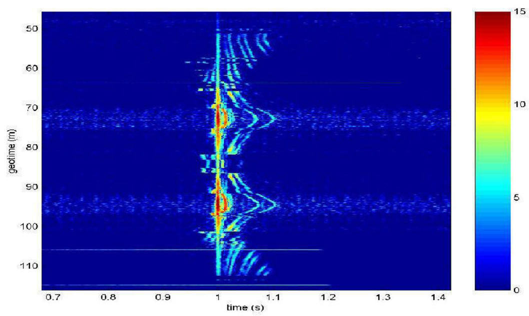

FIGURE 2. Measured impulse response as the source passed twice over the array.

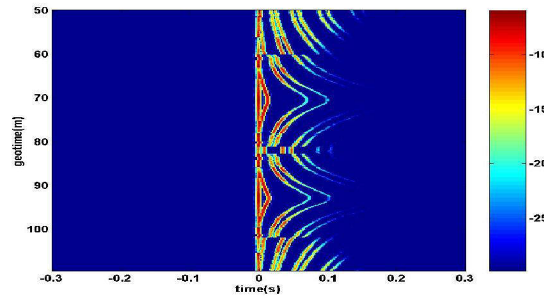

FIGURE 3. Modeled impulse response as the source passed twice over the array.

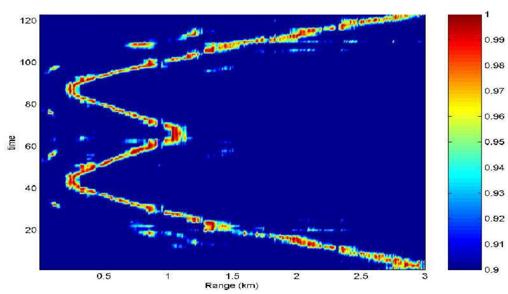

FIGURE 4. Range-time track derived by correlation processing.

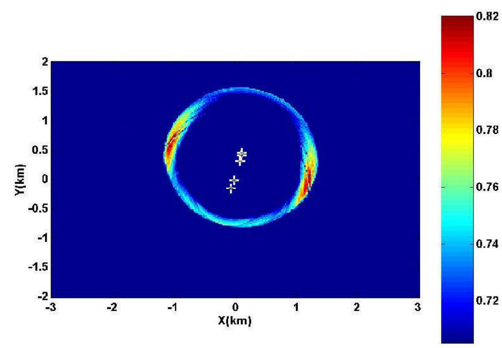

FIGURE 5. Range/cross-range localization derived by correlation processing.

To do the source tracking we use the acoustic model to predict the echo pattern for a set of possible source ranges. Then the measured echo pattern is compared to the ensemble of modeled echo patterns. Each candidate range generates a unique impulse response so that when the best match between model and data is found, the source range has been identified.

We measure the similarity of measured and modeled data by correlating the logs of the envelopes. The argument for this is developed more thoroughly in [1,2]. Figure 4 shows the correlation (similarity between model and data) as a function of the candidate range and using just a single phone in the array. The process is repeated over the 2-hour period of the experiment to reveal the source track. Note that time-held is over 90%. Comparisons to GPS data verify that the range is accurate to a few percent.

Using additional phones (and then comparing modeled and measured *cross*-correlations) we achieve both azimuthal resolution and increased gain. Figure 5 shows localization in the latititude-longitude plane using the full array. This is a snapshot taken at a time when the source is at about 1.5 km range. Other results (not shown) also show reliable tracking in depth. Future work will demonstrate autonomous, real-time processing in the Hydra array.

ACKNOWLEDGMENTS

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