Multi-Static Detection and Localization of Buried Targets Using Synthetic Aperture Iterative Time-Reversal Processing

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LONG TERM GOALS

To use an iterative time-reveral techniques to provide robust focusing along the ocean bottom, with little signal processing effort involved and a-priori information on the environment, to enhance the detection and localization of proud or buried target in shallow water. The second goal of providing undersea communications augment this program is being addressed outside the SWAMSI efort but would come together in the final demo.

OBJECTIVE

The objectives of the proposed MPL component of a SWAMSI continuation will develop bistatic applications of the iterative time reversal techniques to focus along the ocean bottom. Iterative time-reversal provides a simple solution for self-adaptive focusing on strong reflectors (i.e. scattering targets) located on the ocean bottom without relying on predictive or modeling capabilities of the environment and of the target of interest. These robust focusing properties are crucial for mapping large and uncharted area with little signal processing effort involved. With the experiments planned by Schmidt et al, there will be enough data to understand the ultimate limitations of the proposed self adaptive methods.

APPROACH

NURC MCM'06 Experiment: Application to bi-static detection enhancement.

Our method requires the addition of a moving (suspended, drifting) receiver that has a common synch to the TOPAS source. The previous Passive Iterative Time Reversal technique can be applied to a dynamic bi-static geometry where the source and receiver role are separate. The active source is provided by a TOPAS parametric source, mounted on a telescopic tower, insonifying a target, as per Schmidt et al. At the same time, a moving receiver (e.g. towed hydrophone from a surface platform) collects the bistatic backscatter signals from the target at several positions along its trajectory. These data are then used to construct a synthetic aperture Time-Reversal array which can be used for the passive iterative time-reversal process.

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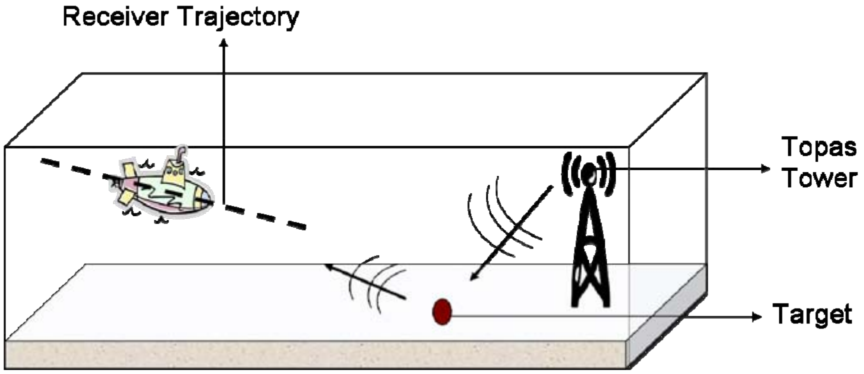


Figure 1: Schematic of bistatic implementation of time-reversal process for detection and localization of Target in shallow water. The Topas tower provides successive illumination of the target. A moving receiver (e.g. towed hydrophone from a surface platform, AUV…) collects the bistatic backscatter signals from the target at several positions along its trajectory. This moving receiver can then be used to construct a synthetic aperture Time-Reversal array which can be used for the passive iterative time-reversal process.

Only a rough estimate of the trajectory is necessary to estimate the relative position of the synthetic aperture TRA elements w.r.t to the target location. This allows to estimate which bottom patch correspond to a specific given time-gated window of the backscatter signals in order to perform a search for the target along the seafloor. Reflectivity Maps over the whole search grod could then be generated to help detect and localize the target.

Validation of the detection capabilities of the synthetic aperture time-reversal processing in this simple bistatic geometry would provide an initial demonstration for self-adaptive and robust MCM application eventually involving AUVs. The data/analysis done in the near field by Schmidt et al will also be studied in the context of relating the decomposition of the TR process to the complex elastic-properties of the combination of target-sediment.

Algorithm Development

The main issue is to separate out the environment from the structure of the target in a self adaptive method—that is, a method not requiring detail knowledge of the environment. We do this by a combination iterative time reversal and singular value decomposition analysis. Initially will consists to testing the developed algorithms by simulations. The algorithm must deal with multi-static scattering from complex elastic targets partially or completely buried in a stratified shallow water seabed. It will exploit the coupled physics of ocean waveguide propagation and target scattering using iterative time reversal for resonant target enhancement

WORK COMPLETED

We have completed the experiment planning. The experiment takes place in October 2006. We have also developed signal processing methods to detect a structured target and tested it in simulation.

RESULTS

As mentioned above, the experiment takes place this month so there are no results yet**.**
The simulation results below were obtained jointly with Henrik Schmidt.

Theory

The coupling physics of target and waveguide is illustrated in Fig. 2. The components of the simulation are propagation and scattering models. Here we use OASES and a virtual source method for the target scattering. We study a spherical shell that has resonances and for control we will compare the results with a hypothetical spherical cavity which has not structural resonances. An example of this simulation is given in Fig. 3. Looking at these typical results, it is clear from the display that we would not be be able to differentiate between the target with structural characteristics vs the simple spherical cavity. We perform some further processing in the frequency domain that is related to iterative time reversal. The basic idea is that the different sources provide different excitations to the target and we look for a common target response independent of the environment. One then sees, by singular value analysis in the frequency domain a resonance structure that is isolated from the complicating multipath structure.

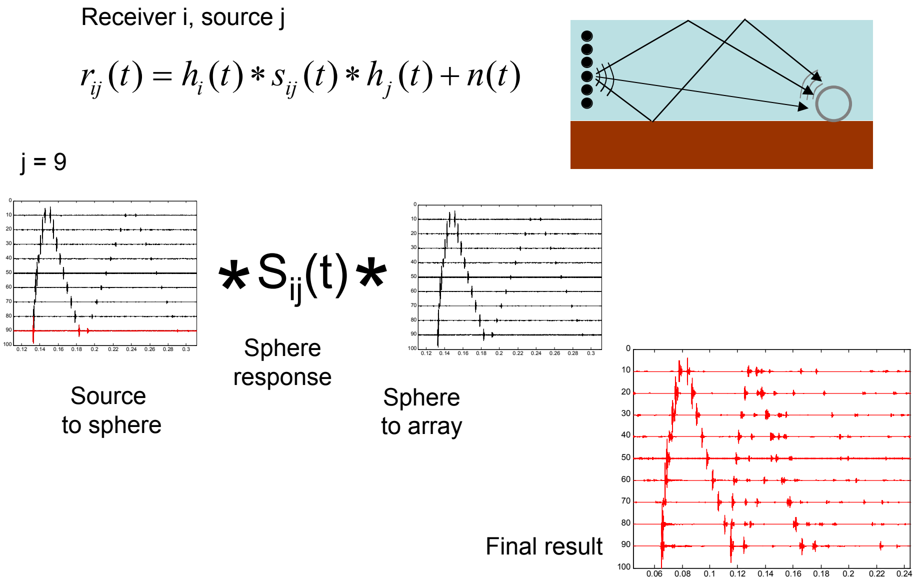


Figure 2. Here we have the steps in simulating the data for the processing algorithm. A source (array) sends a signal to a target and is scaterred back either to the same array or one located elsewhete as for the bistatic case.

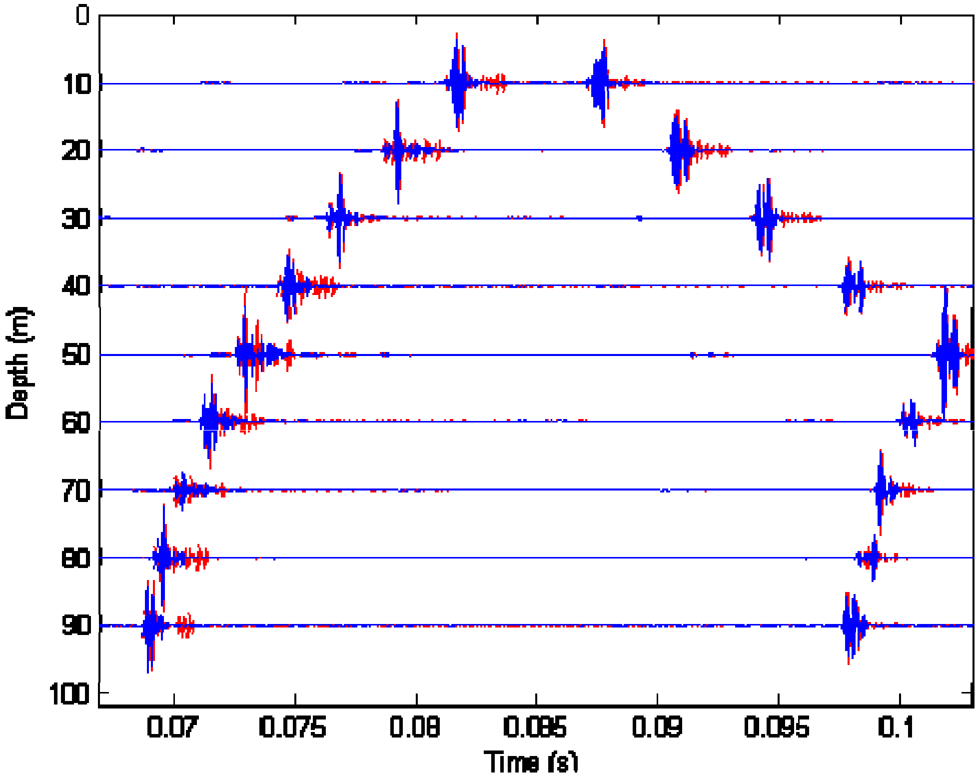


Figure 3. The backsctattered field from a spherical shell (blue) and a spherical cavity (red).

This type of processing is summarized in Fig. 4 together with some results for a buried object.
Of course, a real measurement would involve a backscattered reverberant field that would further mask any interesting structure. Figure 5, then presents results in which includes reverberation.
These preliminary results indicate how the processor works for different backscattered levels. These preliminary simulations provide insight into how the multiple source illumination is used in the SVD analysis in an attempt to eliminate the confusing multipath aspect of the returns. Further simulation is required for the case of a horizontal array that would be more representative of an experimental setup with a synthetic source and./or receive aperture.

IMPACT

This work is focused on developing potential MCM procedures that have a standoff distance that is greater than typical MCM practice. The main issue, then, as addressed in this research is to overcome the complicated propagation that masks the target structure

PUBLICATIONS

"The acoustics structure of the scattered field form a bottom-interacting elastic object in a reverberant environment,", K. Sabra, W. Higley, W. A., Kuperman and H. Schmidt. Paper in preparation.

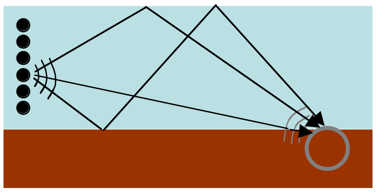
$$r_{ij}(t) = h_i(t) * s_{ij}(t) * h_j(t) + n(t)$$

$$r_{ij}(t) \rightarrow \mathbf{R}(\omega)\mathbf{R}^H(\omega) = \mathbf{U}(\omega)\mathbf{S}(\omega)\mathbf{V}^H(\omega)$$

Fourier transform

Singular Value Decomposition (SVD)

Buried Target



1st Singular Value

5th Singular Value

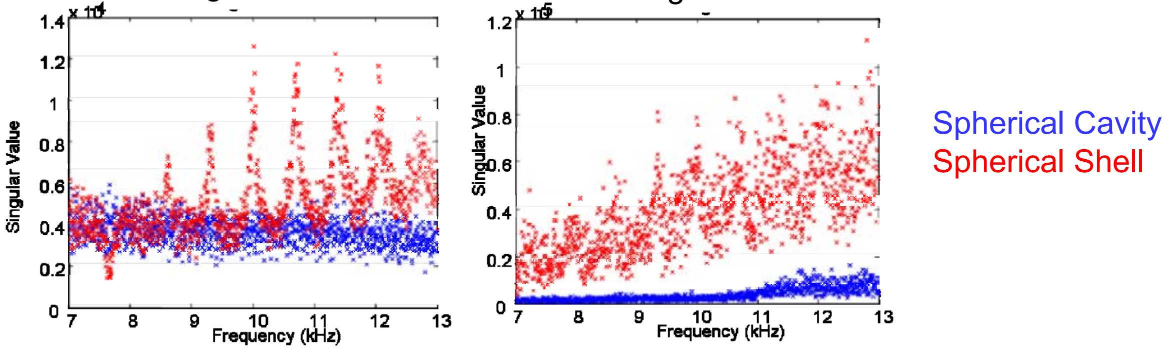


Figure 4. Singular value deomposition in the frequency domain. The multiple sources, which can also be horizontally arranged provide the different "snapshots" required for the singular value decomposition.

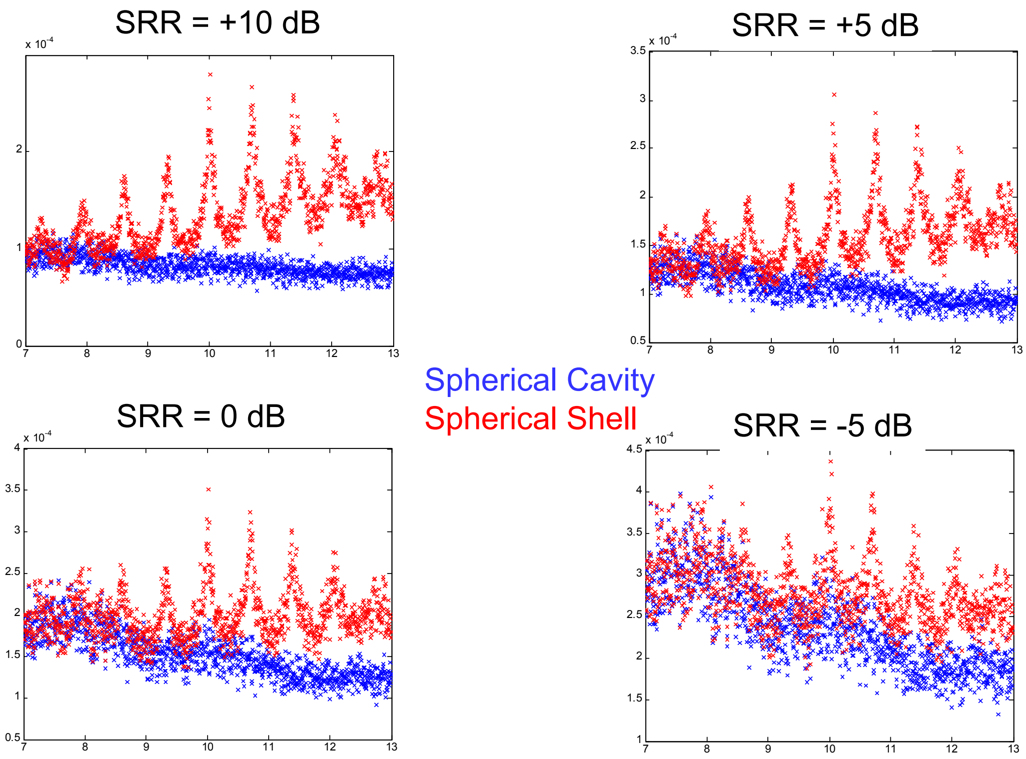


Figure 5. Processing that includes reverberation. For different reverberation leavels are shown. It is the sum of the singular values that are plotted.