Shallow Water MCM using Off-Board, Autonomous Sensor Networks and Multistatic, Time-Reversal Acoustics

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LONG-TERM GOAL

Develop environmentally adaptive bi- and multi-static time-reversal sonar concepts for autonomous off-board sensor networks for concurrent detection and classification of proud and buried targets in shallow water..

OBJECTIVES

The objective of the joint research by MIT and MPL under SWAMSI is to combine the results of two ONR sponsored SACLANTCEN (now NURC) Joint Research Programs (JRP), the GOATS multistatic MCM initiative led by MIT, and the Focused Acoustic Field, led by MPL, into a new, environmentally adaptive, multistatic sonar concept for concurrent detection and classification of proud and buried targets in shallow water, using off-board autonomous sensing platforms in conjunction with organic, on-board sonar resources. The research will develop a comprehensive System Modeling and Simulation framework which will be used for perfomance prediction and experiment planning. Concept demonstration is performed through field experiments conducted jointly with NURC. Here we report on MPL's efforts and point out the FY05 did not have an experiment but involved analysis and planning for FY06 expeeriment

APPROACH

In underwater acoustics, the robust focusing and pulse compression provided by time reversal techniques may be exploited for active sonar [1]. Backscattering from the rough water-bottom interface can be used as a surrogate probe source [2]. This method is based on the fact that a selected time-gatedportion of the reverberation signals (or backscattered signals) can be used to provide a transfer function between a Time-Reversal Array (TRA) and a corresponding range interval on the bottom (see Fig. 1). We applied this method to focus sound in the vicinity of the water-bottom interface in order to improve the detection of targets laying on the seafloor or buried in the sediments. By applying this time-reversal process iteratively for a given time-gated window of backscattered signals, we construct a set of signals for the TRA which focus on the strongest scatterer located in the selected range interval [3,4]. Successive iterations of the time-reversal process can eliminate the part of the reverberation signal which focus on the weak reflector while reinforcing the part of the signals focusing on the strongest reflector. Hence, when the reflectivity contrast between the buried target and the bottom reverberation is sufficient, focusing energy on the target is accomplished with very little

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signal processing effort. Repeating the iterative time-reversal process over a sliding time-gated window portion of the initial reverberation signals recorded in the oceanic waveguide enables the system to scan the bottom surface.

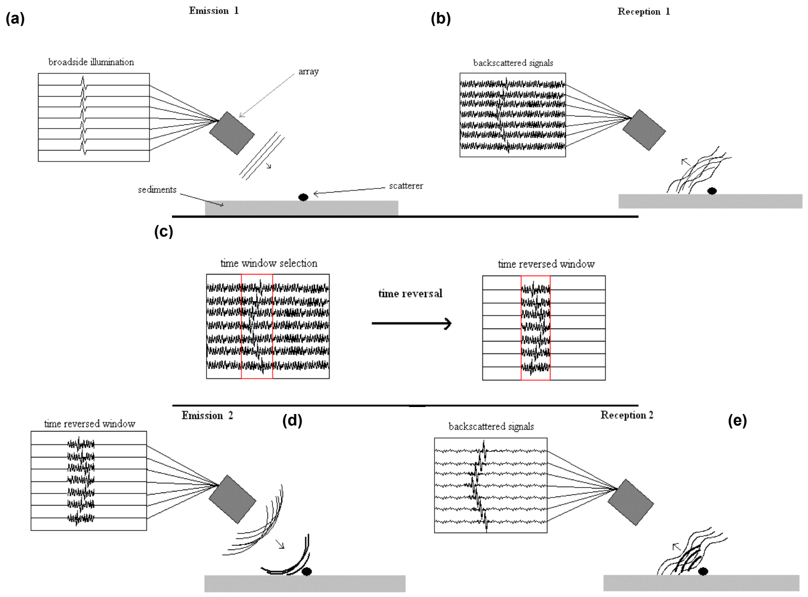

Figure 1: Diagram of an Iterative Time-Reversal process in a classical monostatic configuration. 1 iteration is used to enhance focusing on a reflector located above sediments.
(a) Broadside illumination with a pulse signal .
(b) Backscattered signals are recorded.
(c) A time window containing the potential target signal is selected in order to be time-reversed.
(d) The resulting wave illuminates the bottom.
(e) The backscattered signals reveal that the waves focused on the target since the target echo is enhanced. Further iterations can help detect weaker targets.

During practical mapping of the ocean bottom, the TRA likely will be moving between each iteration of the active time-reversal process since it would either be towed by a ship or directly mounted on the hull of a ship. This TRA motion is detrimental since the TRA would not retrofocus on the exact same range section on the bottom. One possibility to overcome this issue is a passive implementation of the iterative time-reversal process based on the inter-element impulse response matrix which corresponds to all backscattered measurements between all pairs of element (one acting as a source, one as receiver) of the TRA [3,4].

WORK COMPLETED

FAF' 04 Experiment

The FAF '04 experiment (analysis in FY05) carried out jointly with NURC, demonstrated for the first time the field performance of time-reversed reverberation focusing in a shallow water with application to target detection. The site chosen for the experiment at 42° 35.3892' N, 10° 03.8031' E near Pianosa Island, South of Elba proved ideal for deploying the billboard array and collecting backscattered reverberation data. The 28 elements of the TRA, with a center frequency of 3.5 kHz and a bandwidth of 1kHz, were assembled into a billboard configuration (roughly 8 by 1.5 m, see Fig. 2) that is a surrogate for existing sonar systems in a monostatic configuration. Based on this configuration, the billboard array provides some azimuthal resolution with horizontal angular beamwidth of approximately 16 degrees which improve target detection and localization along the seafloor by sending more acoustic power a particular patch of the seafloor and thus enhancing the backscattered reverberation measurements over ambient noise. The azimuthal rotation of the suspended billboard array around its main axis was monitored with a compass and did not exceed one or two degrees in azimuth for quiet sea conditions over time period on the order of twenty minutes. Thus the billboard array illuminates a constant area on the seafloor (at least for short ranges) during this time period. The main outcome of this study are the reflectivity map of the water-bottom interface, similar to a sonar map, but with an enhanced contrast for the strongest reflectors (or scatterers), which appear as bright spots on the reflectivity map (see Fig .3 and Fig. 4). Data collected during FAF04 are used to demonstrate experimentally the feasibility of this technique.

RESULTS

The passive iterative time-reversal technique was applied to detect a target composed of 12 small glass spheres of 50 cm diameter deployed on the seafloor. The target strength of each sphere is weak in the frequency range of the billboard array illumination ([3-4kHz]) and thus detection with conventional ASW sonar is problematic in shallow water. The billboard array azimuth was 340 degrees North. Based on GPS measurements the distance between the billboard array position near the bow of the R/V Alliance and the target location was estimated to lay at a bearing angle of 351 degrees North and at a distance of 204.5m with respect to the center of the billboard array. In order to benefit from the azimuth resolution of the billboard array, the backscattered signals are first summed coherently for the 4 elements of each horizontal sub-array (i.e. broadside beamforming in the horizontal plane). The averaged backscattered energy is then computed by summing the envelope of the broadside beamformer output signal obtained for each of the 7 staves. The reflectivity maps represent the variations of the averaged backscattered energy by the TRA, i.e. the local reflectivity of the bottom after applying the time-reversal process. Figure 3 represents the reflectivity maps computed first after passive time-reversal alone and after one iteration using a 20ms long sliding reverberation window. The vertical axis represents the distribution of the various average focusing range (from 160m to 260m). The horizontal axis is the equivalent distance d from the TRA to the waveguide bottom (obtained by converting the round trip travel times). For each reflectivity map, the strong scatterers appear as bright spots in the main diagonal delimited by the time-gated window interval on Fig. 3. The initial illumination of the water bottom interface was provided by a broadside transmission form the TRA. A strong-reflector appears as a bright spot in the main diagonal at a range 203m, which is in very good agreement with the estimated range from GPS measurements (i.e. 204.5 m). Thus this reverberation focusing technique appears robust with respect to environmental fluctuations. Detection of the target is enhanced by using the iterative time-reversal process over the conventional broadside return as illustrated in Fig. 2.c which compares the averaged backscattered energy after the initial broadside transmission to the diagonal of the two reflectivy maps in Fig. 2.a-b. Indeed the target is not visible in the broadside return but the reflectivity contrast, in the vicinity of the estimated target location (L=203m), is on the order of 5dB after time-reversal and above 9dB after one iteration of the time-reversal process.

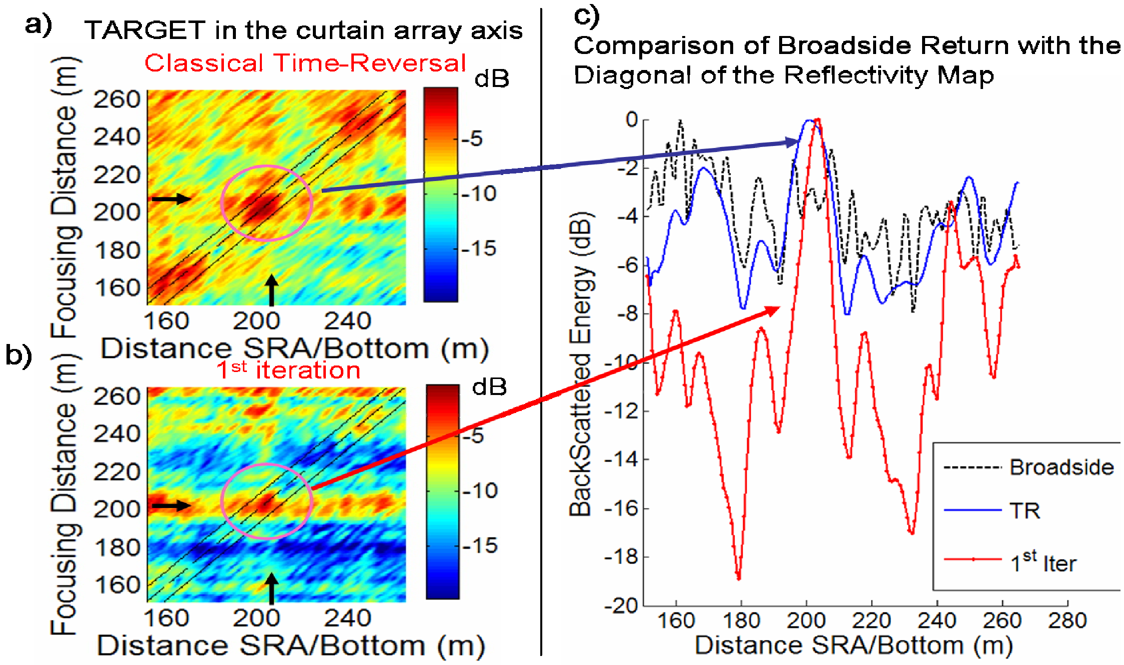

Figure 2: a) and b) Reflectivity maps for a target, located 203m away from the SRA. These maps were computed over sliding time-gated hanning window portion of Δ=20ms of the reverberation signals (delimited by the dashed lines along the main diagonal) for: a) the time-reversal process or b) 1 iteration, of the time-reversal process. The horizontal axis is the recording time (i.e. the round trip propagation) converted to the SRA/bottom distance. $d=t\,c_0/2$ (c_0=1515m/s) between the SRA to the bottom. The vertical axis is the average intentended focusing distance along the bottom being scanned by the TRA correponding to the selected time-gated window. Note the contrast improvement achieved for the strongest reflectors by using one iterations. The target location is the brightest spot at 203m. c) Comparison of the intial boradside return to the diagonal of the reflective map after iterative time-reversal.

Using the azimuthal resolution of the billboard array provides additional confirmation of the target detection and localization. By steering the effective look direction of the array to 250 degrees north, the array now illuminates a different search sector. No distinct bright spots appear now along the main diagonal of the reflectivity map in Fig. 3 c-d in comparison to Fig. 3 a-b. Thus no strong reflector should be present in this search sector. This illustrates the target search capabilities over various sector angles of this simple adaptive sonar system using the azimuthal resolution of the billboard array and the (passive) iterative time-reversal process

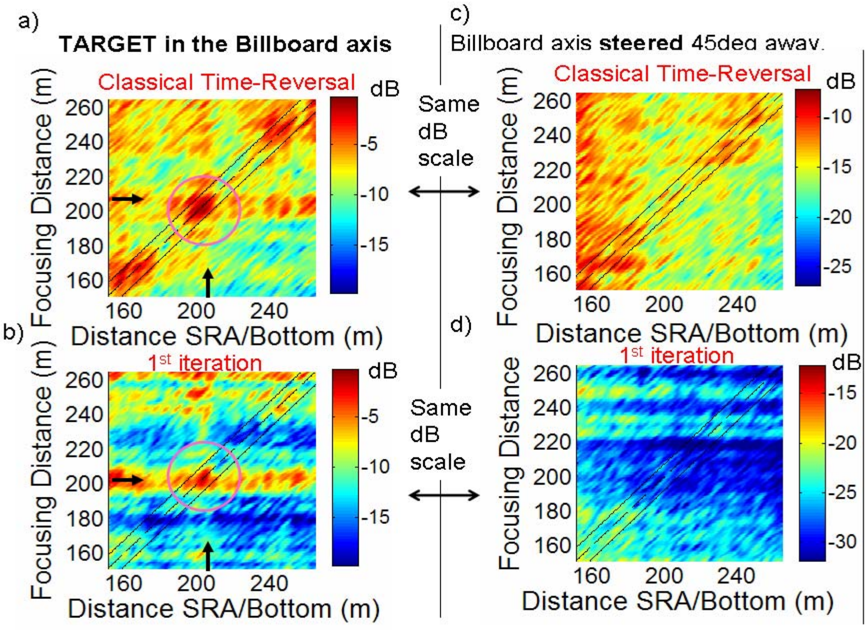

Figure 3: Comparison of the reflectivity map obtained for different look angles of the billboard array. a) and b) Same as in Fig 3, the target is in the Billboard axis. c) and d) Same but, the billboard axis is now steered 45 degrees away from the target.

IMPACT/APPLICATION

We presented a reverberation focusing technique which allows a time-reversal-array to retrofocus energy along the seafloor interface using only measured backscattered signals and minimal a-priori environmental information. For sufficient reflectivity contrast between the target and the bottom reverberation, target detection was enhanced after one iteration of the time-reversal process. 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 in a *waveguide* are crucial for mapping large and uncharted areas with little signal processing effort involved and suggest longer range MCM potential than direct line of sight applications.

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