Broadband Mine Detection and Classification in Shallow Water

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LONG-TERM GOALS

Our long term goal is to advance development of underwater mine reconnaissance sonar for shallow water environments. Specifically, we wish to increase the range at which classification of mine-like returns can be done successfully (low probability of false alarms) and thus increase the reconnaissance area coverage rate. We also wish to improve the detection of buried mines in sandy bottom environments.

OBJECTIVES

We seek to explore the potential of low frequency and broad band signals not currently used by Mine Countermeasure (MCM) sonar systems to improve the performance of such systems. In moderately shallow water (deeper than the surf zone), sonar signal interference is usually dominated by reverberation rather than by ambient noise, so that new reverberation suppression techniques are needed to improve performance. We combine broadband signals and advanced imaging techniques to achieve robust detection and classification, and operate at relatively low (for MCM) acoustic frequencies to mitigate attenuation and scattering effects of the shallow water environment for increased range of operation. Our objectives are to develop the required algorithms and to test them in a realistic shallow water environment with realistic mines and mine-like targets. We wish to emphasize the sloping sandy bottom environment which will result in substantial multipath interaction with the surface and bottom interfaces, and make detection of buried mines more challenging.

APPROACH

This project has been done as a collaboration between the Applied Physics Lab (University of Washington) and Arete Engineering and Technology Corporation (San Diego). The approach relies on a combination of broadband algorithm development and at sea experiments which use a 2-20 kHz testbed sonar and a set of about 20 targets including mines, mine-like clutter, test spheres and corner reflectors, and a large granite rock. Our approach applies broadband signals and processing methods to classify detections, using the spectrum to estimate overall object length and curvature and to classify mines from other objects. Detection of buried mines is attempted using low frequency signals which penetrate the bottom better than high frequencies when energy is incident below the critical angle of

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total internal reflection. Finally, we examine multi-ping and multi-look coherent and incoherent processing techniques for reverberation suppression to extend the detection and classification range.

WORK COMPLETED

The third experiment in our Puget Sound shallow water site (Spring Beach III) was conducted in November 1997. A schematic of the experiment is presented in Fig 1. The goals of this phase of work were: 1) to evaluate the accuracy of a model that estimated the change in free-field response of a target when it was placed on a sandy bottom as a function of incident angle, 2) to examine multipath target returns using coherent and incoherent processing when the array was bottom mounted, and 3) to evaluate the potential of low frequencies (below 5 kHz) for buried mine detection. In addition, we examined the use of the testbed array to provide environmental information in the vicinity of the array (turned on its side), especially about bottom properties (Fig. 2).

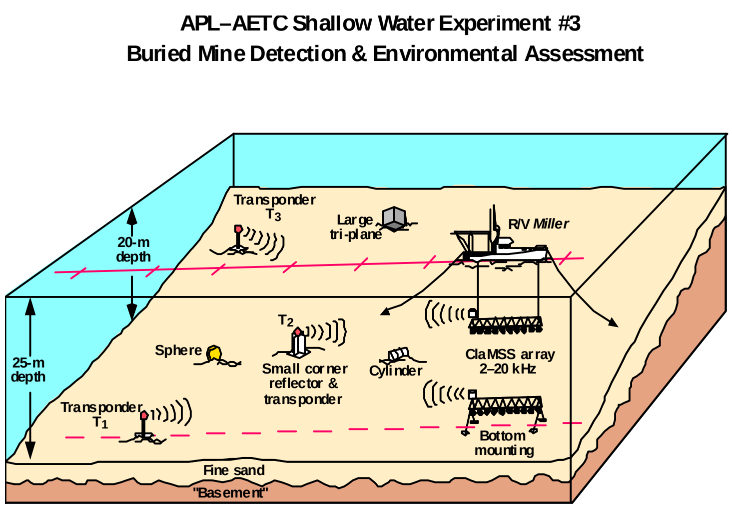

Fig. 1. A diagram of the Spring Beach III experiment. Transponders and corner reflectors were used to help track the array when it was suspended. When array was bottom mounted, all randomness in returns was assumed to be due to propagation and scattering effects.

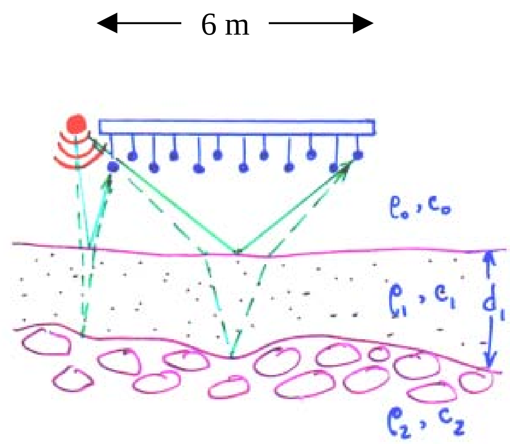

Fig. 2. Obtaining acoustic information about the bottom using short range pings that permit exploring a wide range of above critical incidence angles. Such bistatic data leads to independent estimates of sound speed

The SBIII experiment utilized 3 narrow-band (100 Hz) transponders centered at distinct frequencies (8, 12, and 16 kHz) to allow automated array registration. Even with only 100 Hz of bandwidth, we have demonstrated that the distance from the array to each transponder can be estimated robustly to a precision of about one meter with no a priori positioning information required. By design, the 8 kHz transponder coincides spatially with a corner reflector so that the distance to the corner reflector is known at all times to within a meter. Given an initial estimate good to within a meter, the corner reflector can then be localized to higher precision (a few cm) using the full 5-19 kHz bandwidth in a completely automated fashion. In addition, because array depth is now important, the automated process now includes array depth estimated to a precision of a few cm by measuring source-surface-hydrophone arrival times.

RESULTS

In these and previous tests, careful measurements of target responses from the 24” test sphere and 2 meter cylinder as a function of aspect angle and frequency has validated the use of physical models of target radiation patterns and spectra for classification. The models are based on Kirchhoff scattering by rigid bodies, and do not include internal structural effects (we measured very little elastic response and it has been suggested that this is due to the concrete or sand filler used in the mine shapes).

Perhaps the most important result is the validation of a ray based model that accounts for multiple local interactions of the sonar signal with the target (direct path) and the bottom (coherent multipaths) for incident grazing angles below the critical angle (about 22°); see Fig. 3. For this wide range of angles, the multipaths interfere with the direct path and produce significant interference nulls in the (free-field) target response spectrum. These nulls can easily defeat a classification algorithm trained on free-field data. If f_n is the frequency of the n’th null,

$$l_n = \frac{4R}{2n+1}(q_{inc} + q_{slope}), \text{ with } l_n = \frac{c}{f_n}. \qquad (1)$$

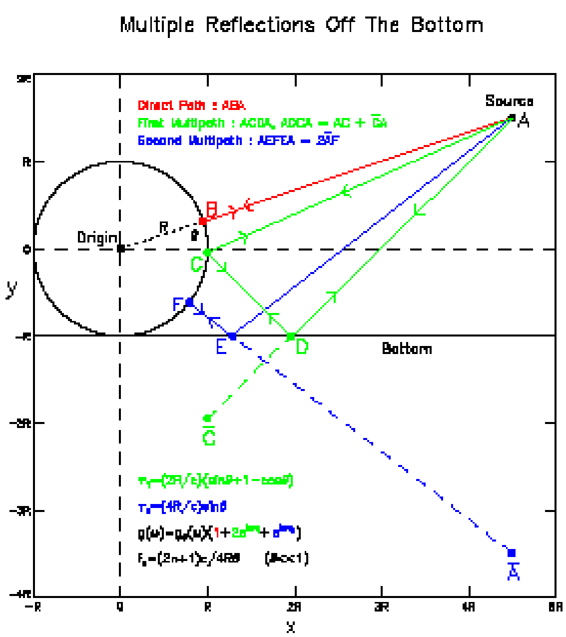

Fig. 3. Multipaths occuring for bottom reflections near the target. For low incident grazing angles the two multipath families reduce to one series of “harmonics”.

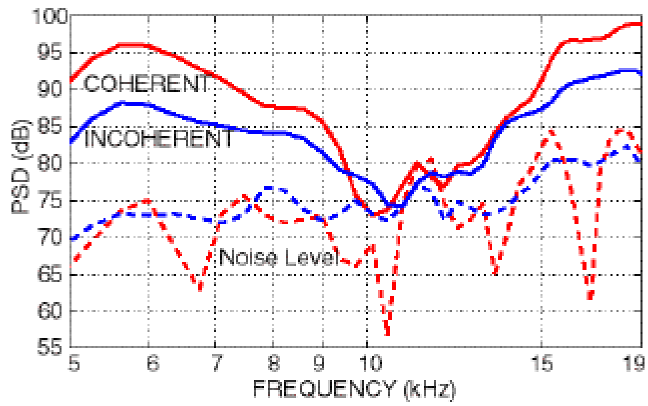

Fig. 4. Coherent and incoherent spectra for the DEU cylindrical target. The coherent sum clearly has better signal to noise ratio. The spectral low near 10 kHz is due to strong interference between the direct path and a bottom reflected multipath.

Figure 4 shows spectra summed both coherently and incoherently over 11 pings for a representative array depth. The target is a cylindrical “Diver Evaluation Unit” (DEU) with 20” diameter and 55” length. There is a 20 dB decrease down to the level of noise (dashed lines) in the middle of the band. Similar nulls arise displaced in frequency for different array depths. We emphasize that the presence of unmistakable nulls at frequencies in strict accordance with Eq. (1) was an outcome of the SB3 experiment that was predicted specifically before the experiment was performed.

Finally, comparisons between coherent and incoherent summation of multiple pings from the bottom mounted array indicate that the direct path arrival time jitter due to variations in water sound speed are small but measurable, even for the short range of 50 to 80 meters. While the signals are still sufficiently repeatable to provide nearly optimal gain from coherent processing, the first surface multipath (actually split into two nearly reciprocal paths) is highly incoherent for moderate wind conditions (about 7 knots).

IMPACT/APPLICATION

We expect that the success of MCM classification algorithms will depend on a robust understanding of the effects of the environment on the target reponse. On sandy bottoms, multipaths reflecting off the bottom in the neighborhood of the target will substantially affect the acoustic return. In order to be successful the search strategy, that is, the choice of vehicle track and sonar operation parameters, must be considered in tandem with the signal processing approach used to analyze the data. Synthetic aperture sonars and systems attempting to use the surface bounce path will be very susceptible to decorrelations by the medium, and the sea surface roughness. Existing fundamental models of wave interactions with random media have yet to be usefully transitioned to the applied community to be used in the MCM context.

TRANSITIONS

We have raised several questions in our mine hunting work that requires further input from basic research efforts. In particular, the lack of reliable propagation and scattering models for 3-D shallow water acoustics, especially in the frequency band between 1 and 20 kHz, is a serious impediment to MCM sonar performance modeling. Furthermore, the impact of the environment on the acoustic returns for bottomed or buried targets is complex and poorly understood. Finally, procedures for measuring important properties of the environment using a practical sensor suite (such as the mine sensors already on the reconnaissance vessel) must be developed to enable the search strategy to adapt to the local environment and optimize the search rate.

RELATED PROJECTS

- NRL-DC has been conducting detailed tank experiments in which very broadband scattering data has been collected from mines and mine-like objects. They have observed important target response features in the frequency band we have used (2-20kHz). They have also observed significant effects due to the nature of the filler used inside the cases. Some of the elastic response is attenuated when concrete or sand are used as filler.
- ONR “High frequency bottom scattering” DRI: This basic research project seeks to understand the roles of surface roughness and sediment inhomogeneities in producing reverberation and in detection of buried objects. We have offered specific MCM application issues to the DRI scientists for consideration, and hope to participate in one of their experiments in which the environment will be very well characterized.

PUBLICATIONS

“Low Frequency Sonar for Mine Hunting”, D. Miklovic and D. Moore (AETC), *Sea Technology* (1998) Vol. 39, pp. 39-44.