

Mine Classification/Identification by Structural Acoustics

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LONG-TERM GOALS

The overall goal of this program was to develop the ability to detect, classify, and identify buried and near-buried mines at far greater ranges, and thus much more rapidly, than is currently possible. This program, which emphasized buried and near-buried mines, was coordinated with the NRL 6.2 base program in MCM.

OBJECTIVES

The objective of this program was to exploit low frequency structural acoustic clues which might exist in the scattered acoustic fields from buried and near-buried mines for long range, rapid mine classification and identification. Once these structural acoustic mechanisms and clues were established in the free--field scattering from these mines, the goal was to establish the basic effects on the structural acoustic response of sediment loading and to extend the newly developed classification/identification algorithms based on these clues to the buried/near-buried, sediment-loaded case.

APPROACH

The overall effort exploited the Navy's newest and most advanced capabilities in structural and physical acoustics which are resident in the Physical Acoustic Branch at NRL. This includes nearfield acoustic holography, wavenumber (k - ω) domain processing, high accuracy scattering measurement laboratories, and an internationally recognized team of experts in acoustic scattering physics, structural acoustics, and inverse/classification algorithms. The program focused on studies of the structural and

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environmental acoustics of threat buried/near bottom mines primarily using its holographic pool facilities and its elaborate system of post processing algorithms and analysis tools. This program carried out acoustic scattering studies in the NRL sandy bottom (Bldg. 71) holographic pool facility on a series of insonified mines buried or partially buried in a well characterized bottom type. The data bases are being used to guide the development of new classification/identification algorithms for the submerged, proud and buried mine cases.

Over the life of the program these detailed bases were collected and studied on five important threat mines. Though this is far from a complete sampling, efforts will be made to extrapolate the results to different mine types.

WORK COMPLETED

By the end of FY 97, we had completed comprehensive measurements on four different mines. These measurements included scattering from the free-field mines and from some of the mines in the proud and partially-buried conditions. These measurements have uncovered a number of structural acoustic clues at low frequencies which could be used to “fingerprint” the target as a mine. Measurements were also made using buried synthetic arrays to characterize the sediment acousto-elastic parameters of our sandy--bottom pool. This information was used to conclusively decipher the effect of mine burial (and thus sediment loading) on the more important structural acoustic clues. In addition, similar scattering measurements were also made on a false target (a water-filled oil drum) in order to test the ability to discriminate between the clues presented by real mines and those from false targets.

These measurements indicate a significant potential for discrimination at these lower frequencies. Based on this, a simple discrimination algorithm based on acoustic “color” was implemented and successfully demonstrated. Finally, the NSWC-CSS PCSWAT environmental acoustic model was used to simulate the acoustic performance (S/N) for three different mine hunting system concepts for eighteen different bottom conditions operating on the strongest of the acoustic clues discovered in the mine scattering data. These results suggest sufficient S/N for exploitation.

During FY98, we carried out measurements on a fifth important threat mine and added additional measurements on the fourth mine, this time in the proud condition. In all, we have made comprehensive measurements on three cylindrical mines and two non-cylindrical mines. We also completed measurements on a second false target, a smooth large boulder. We collected measurements on a thick, hollow sphere under free-field and various burial conditions. Finally we demonstrated an efficient identification algorithm based on matched pursuits and hidden Markov models with data from five nearly identical cylindrical underwater targets and on the five-mine data set.

RESULTS

There have been six major technical results achieved during this program. These are as follows:

- (1) Low frequency (long range) structural acoustic clues have been positively identified in the scattered acoustic spectrum from submerged and partially buried mines. The level of at least one of the clues is enhanced by the sediment loading. Measurements made using a buried synthetic array of the sediment wave speeds confirm that partial burial should indeed enhance the scattering effect.
- (2) Similar scattering measurements made on a typical false target (oil drum) have allowed us to demonstrate a simple algorithm based on acoustic “color” which positively separates the scattered signals from the mines (five different types) from the signal from the oil drum.

(3) The signal levels generated from one of the low frequency structural acoustic mechanisms have been input into the NSW-CSS PCSWAT environmental acoustic simulation model. The signal-to-noise levels predicted for three conceptual synthetic aperture sonar systems — a large towed body, a large hull mounted sonar, and a small AUV — all indicate exploitability in a real world environment.

(4) An ancillary scientific result coming out of the measurements to characterize the sand-pool sediment concerns the discovery of a “virtual” slow wave (~ 1200 m/sec). This “virtual” wave was tied directly to surface roughness and disappeared when the surface was smooth.

(5) The set of measurements made on the hollow sphere (free-field, proud, half-buried, one inch burial, 4.5 inch burial, 11.5 inch burial, and 20 inch burial) demonstrate that above the sand/water critical angle structural acoustic signatures are clearly evident. This suggests that the structural acoustic signatures seen on the mines measurement set ought to remain exploitable under similar burial conditions. We have actually demonstrated this to be the case on one of the cylindrical mines in our five-mine set.

(6) A very efficient identification algorithm developed in the Base program was demonstrated on two different target sets. The model, developed by Dr. Larry Carin of Duke University, is based on matched pursuits and hidden Markov models. The algorithm accepts monostatic scattering data over a limited angular aperture (in this case up to 45°). With the target orientation totally unknown, the algorithm attempts to identify the unknown target based upon what it knows a-priori about the target set. We first applied the algorithm to measurements made on five almost identical submerged cylindrical targets (where their major differences were related to internal structure). The results were spectacular in that, with a 10 dB SNR and data only at ten angles within the 45° aperture, correct ID was made 99% of the time. When the algorithm was applied under the same conditions to the scattering from our five-mine set, correct ID was made 95% of the time. More significantly, we understand how to make a simple improvement to the algorithm which should move the real-mine performance above 99%.



NRL CONCEPT FOCUS

STRUCTURAL ACOUSTICS 6.2 PROJECT & WAVE EFFECTS ARI

UNDERSEA WARFARE

Conceptual Structural Acoustic Multi-algorithmic Identification System

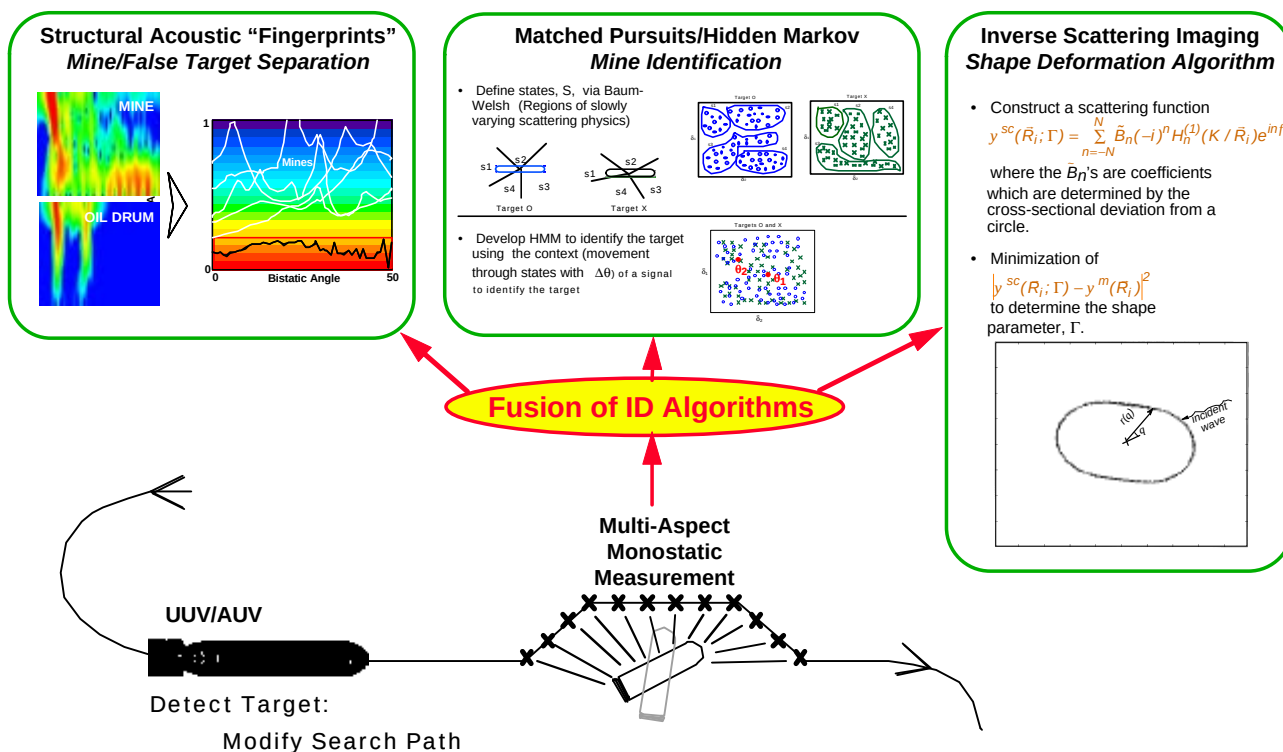


FIGURE 1

IMPACT/ APPLICATIONS

Present acoustic-based MCM systems rely heavily on traditional imaging methods for identification and classification. As such, they have been designed around a "ray-based" view of the acoustic scattering problem and have emphasized high frequency acoustics. This has led to systems which (1) are very short-range, (2) fail to capitalize on structural acoustic clues potentially available at lower frequencies, and (3) are almost useless against buried mines.

The discovery of exploitable structural acoustic clues in the low frequency spectrum of acoustic scattering from mines (especially partially buried ones) will have a major impact on mine hunting system operations. That the clues exist at frequencies lower than those used in conventional acoustic imaging systems implies that a new system based on identification through structural acoustic clues can operate at far greater ranges. In addition, the lower acoustic frequencies penetrate the water/sediment interface much more readily, significantly enhancing the ability to detect and identify buried mines.

Given the discovery, together with our progress on the matched-pursuits/hidden Markov ID algorithm and our progress in our 6.1 Base program on non-conventional imaging using low-frequency inverse scattering algorithms, NRL is currently focused on the development and demonstration of a multi-algorithmic MCM identification system concept based on a fusion of a number of new and existing identification algorithms. (See figure 1.) We are emphasizing those algorithms that could be implemented on organic assets, particularly UUV's and AUV's.

From a scientific view, in the novel work on sediment characterization using buried synthetic arrays, the existence of the commonly discussed Biot slow wave (~1200 m/sec) was not observed in the sediment with smooth interfaces. We have clearly demonstrated, however, sediment energy which could mistakenly be interpreted as the 1200 m/sec slow wave but which in fact is an artifact caused by rough scattering. This could very well clear up the scientific controversy existing in the sediment scientific community regarding the existence of such a wave.

TRANSITIONS

The data bases themselves will be first transitions from this project both to 6.3 programs seeking to develop new MCM capabilities, and where possible, to the fleet MCM operators directly. The former include such programs as JCOS, ACTD, AN/SQQ-32 Improvement, Remote Mine Hunting Systems, Underwater Mine Reconnaissance, AN/AQS-20 Sonar, and MNS programs. Next, successfully developed classification/identification algorithms will be transitioned where appropriate to these same programs. These transitions will be expedited by working closely with the MCM system designers at CSS, Panama City, and by open communication the MCM program managers at ONR and PEO Mine Warfare. In this regard meetings took place between NRL and 6.2/6.3 acoustic MCM scientists and engineers at the Coastal System Station (CSS) at Panama City, FL (10/18/97) and with the more general community at the ONR Broadband Workshop in Park City, UT (8/98). As a result, the CSS personnel are evaluating the potential of the NRL-identified low frequency clues at the present time.

RELATED PROJECTS

The overall 6.2 program in Structural Acoustics-Based Mine Classification/Identification at NRL included both the program discussed here together with the NRL Base Program. The Base Program focused on the structural acoustics of the mines themselves, the effects of internal explosive loading and casing properties thereon, and on multi-algorithmic approaches to long range classification/identification. The program discussed here emphasized the effect of sediment loading on the mine structural acoustics and the extension of classification/identification and sound coupling techniques for the proud, buried/near-buried cases.

This program was closely coordinated with the NRL 6.1 ARI entitled "Wave Effect Near the Interface of a Fluid and a Poro-Elastic Medium". The current NRL focus plans to capitalize on future scientific breakthroughs made in the ARI. Of particular interest is the work on inverse algorithms for target identification, the planned work on the development of holographically-based elastic wave back propagation techniques into the sediment layer, and the development of parabolic equation-based methods for numerically modeling the related acoustic effects.

PUBLICATIONS

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