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Evaluation and Verification of Seafloor Acoustic Scattering Models

Christian de Moustier

Final Report to the
Office of Naval Research
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For the Period 10-01-89 - 09-30-93

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Abstract

Work on evaluation and verification of seafloor acoustic scattering models was conducted. The main thrust of our efforts was directed towards implementing specified seafloor surface statistics in the computer simulation environment. This allowed us to compare results derived from acoustic data collected at sea with results from synthetic data generated with the Sonar Simulation Toolset software package, using the design parameters of the sonar system actually used to obtain the measurements at sea.

Long Term Scientific Objectives

To develop a comprehensive seafloor classification methodology based on a realistic acoustic scattering geometry, reliable acoustic signatures, and accurate classification techniques.

The general strategy is to include the design parameters of a working sonar system into the computer simulations, and to analyze concurrently the synthetic data and the data collected at sea with the sonar system. This feedback process is deemed essential to arrive at realizable solutions to the problem of seafloor classification by acoustic remote sensing methods.

Project Objectives

The objectives of this project are (1) to perform computer simulations of an ideal sonar system receiving echoes from a representation of the seafloor consisting of individual scatterers or scattering centers distributed at a boundary. (2) to obtain reliable seafloor acoustic signatures by using optimum parameter estimation techniques; and (3) to evaluate the performance of several classes of existing pattern recognition algorithms for correct recognition of the scattering geometry (hence the seafloor type) based on its acoustic signature.

Current Status and Progress

Seafloor classification: Point-scattering approach.

Results of a previously completed study of the point-scattering model (Alexandrou, et al, 1992) indicated that acoustic signatures of bottom reverberation could be obtained from the reverberation kurtosis as a function of the length of the transmitted sound. Using these signatures, a methodology for seafloor classification with a neural network architecture was tested in a computer simulation environment provided by the REVGEN/SST software package. A multilayer perceptron algorithm with backpropagation of error yielded a maximum correct classification rate of 93%. These results have been submitted for publication in the IEEE Journal of Oceanic Engineering (Alexandrou and Pantzartzis).

Neural networks VS Bayesian classifiers.

The performance of neural networks was assessed against that of optimal Bayesian classifiers that are thought to define an upper limit of classification performance. To obtain analytical derivations of the optimum classifier required that a relatively simple set of input patterns be used. In particular, the backpropagation algorithm was evaluated in the classification task of "one of M orthogonal signals". When noise-free signals were used to train the neural network, it yielded a correct classification rate in excess of 98% that was practically identical to that of the optimal Bayesian processor. However, the network performance dropped to suboptimal levels (87%) when noise was introduced into the training process. Overall, this exercise reinforced our confidence in the neural network approach to classification and we decided to continue using optimum structures as a performance standard when possible. We are currently considering using a combination of neural network and Bayesian classifiers to achieve more robust performance. A paper summarizing our findings has been submitted to the IEEE Transactions on Neural Networks (Michalopoulou, Nolte and Alexandrou).

Self-organizing maps.

We have continued our study of a different type of a neural-like algorithm, known as a self-organizing map (Kohonen). This algorithm does not require supervised training. Rather, it adaptively clusters its nodes into a number of "neighborhoods" each representing a specific class of input patterns. These structures would be useful in a survey area with unknown seafloor types. In this setting, the self-organizing map would define the boundaries of acoustically distinct provinces. Following this initial partition, sparse ground truth data can be used to geologically define each region and regular neural nets can be subsequently trained to recognize each seafloor type.

A Helmholtz-Kirchoff simulation environment.

Attempts to create realistic seafloor features using assemblages of point scatterers has been slowed by extremely high computational requirements. An alternate simulation environment was re-created using the Helmholtz-Kirchoff (HK) theory developed by Thorsos (1987) that provides the scattered field solution for a hard boundary. This solution yields the full (amplitude and phase) scattered field for a two-dimensional bottom profile characterized by two parameters: The r.m.s. roughness and the spatial correlation length. The composite roughness model developed by Jackson et. al. (1986) was used as well to simulate the angular dependence of backscattering strength for various bottom roughnesses without contributions from the sediment volume. The acoustic signatures derived from these simulations are angular dependence functions of the backscattered pressure or intensity. Such functions can be obtained from data collected with swath bathymetry systems (e.g. Sea Beam, etc.). Therefore, assuming these functions prove to be effective training patterns for neural classifiers, there should be a natural transition to real data processing and evaluation of this approach in the field.

Classification based on angular dependence functions of backscattered pressure.

The magnitude of the backscattered acoustic pressure for angles of incidence ranging from 0 to 20°, in 1° steps, was used to create feature vectors of length 21. Three vector sets were created corresponding to three different seafloor types within the dictates of the HK model. The multilayer perceptron algorithm was trained with 10 training patterns for each of the three classes. Following successful training, 100 test patterns from each class were presented to the network. Each pattern consisted of the average of 10 consecutive simulation runs. The result was error-free classification, but much more work is needed to ascertain the full potential of this approach. The classification task will become more challenging as the number and the proximity of seafloor types under consideration increase. Initial results also indicate fairly similar performance between the neural network and the Bayesian processor with the latter holding a slight advantage. However, the optimality of this processor is based on prior assumptions concerning the probability distributions of the acoustic feature

vectors, whereas the neural networks are non-parametric structures that do not require prior assumptions.

Tests with Sea Beam acoustic data

Acoustic data collected with the Sea Beam system were utilized to test the classification methodology described above. The data was processed to create angular dependence functions of pressure magnitude. For this initial pass only the 8 starboard beams were used, leading to 8-dimensional feature vectors. As in the simulated runs, a multilayer perceptron neural classifier was implemented and trained with feature vectors representing 10 ping averages. The results were consistent with the simulations. On two different data sets collected over uniform sediments, the network achieved correct classification rates of 97 and 95 percent respectively. This is encouraging, because these two seafloor regions are geologically similar and give rise to very similar angular dependence functions. More work with additional data sets is needed to establish the usefulness of this approach in the real world.

Publications Supported by ONR

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