Ocean Acoustics and Signal Processing for Robust Detection and Estimation

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LONG TERM GOALS

The long term goal of this project is to develop efficient inversion algorithms for successful estimation and detection by incorporating (fully or partially) the physics of the propagation medium. Algorithms will be designed for robust ASW localization and detection and also for marine mammal localization and tracking.

OBJECTIVES

1. Achieve accurate and computationally efficient source localization by designing estimation schemes that combine full field modeling and search optimization.

2. Develop methods for passive localization and inversion of environmental parameters that select features of propagation that are essential to model for accurate inversion.

APPROACH

A matched-field approach was developed for source localization and simultaneous deconvolution of the acoustic source signature. The method is based on the calculation of the joint posterior probability density function (p.d.f.) of the source location and source spectrum parameters. Gibbs sampling, a Markov Chain Monte Carlo method, assisted in the efficient computation of the posterior probability density function of the parameters to be estimated [1]. The joint estimation approach employing Gibbs sampling is compared to localization using point estimates of the source characteristics in order to estimate the source coordinates [2,3]. (In our approach, the point estimates are replaced by probability density functions reflecting the uncertainty in the source spectrum parameters.)

Inversion for source location, bathymetry, and sound speed profile was also approached with a linear approximation to the inverse problem employing distinct arrival times of individual paths. The work was performed in collaboration with Mr. Xiaoqun Ma. The implemented inversion approach was combined with an arrival selection scheme applied to received time series for the identification of the different paths contributing to the estimation process. The linear system resulting from linearization of the inverse problem was solved using both least squares and regularization [4,5].

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In order to use the linearization inversion approaches, identification of distinct paths within the received time series is necessary. The arrival identification is performed through the maximization of the posterior p.d.f. of time delays given the received time series. A Gibbs sampling scheme is employed for efficient p.d.f. computation.

RESULTS

The Gibbs sampling approach to simultaneous localization and deconvolution improved the results of simple localization using the linear processor. The computational overhead imposed by the additional deconvolution task was minimal (the process required a small number of iterations to converge), whereas the gain in localization performance was significant. For example, for a 3 dB Signal to Noise Ratio and 10 data frames, the probability of correct localization with the linear processor was 0.55. The probability of correct localization was 0.70 for the joint deconvolution and localization approach. Figure 1 shows linear and Gibbs sampling ambiguity surfaces for the same data.

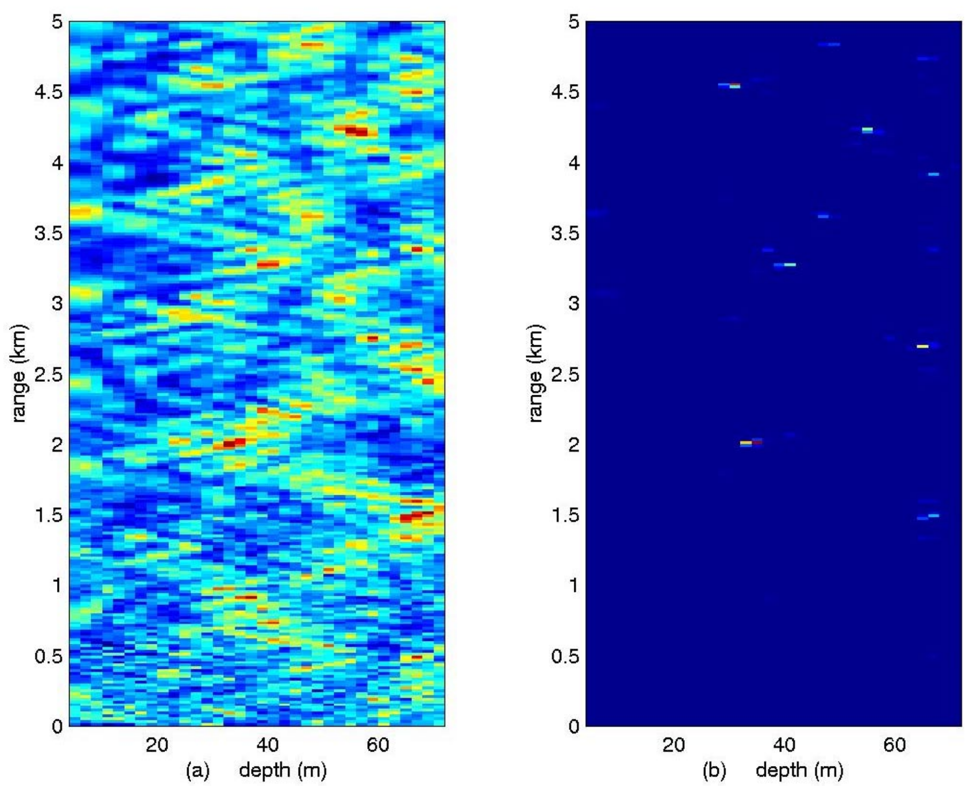

Figure 1: Source range-depth ambiguity surfaces generated for the same data with (a) the linear processor and (b) the Gibbs sampling deconvolution and localization approach. The correct source range and depth were 2 km and 34 m respectively. The source localized correctly with the Gibbs sampling method. The linear processor gave results of 1.5 km and 68 m for range and depth.

The arrival identification method using Gibbs sampling gave excellent results in time delay estimation between different paths at the receiver; only a few iterations were required for convergence of the method. Figure 2 shows arrival identification using (a) Gibbs sampling and (b) a frequently used matched filtering operation. Seven distinct paths at samples 30, 80, 90, 110, 145, 160, and 165 were present. In Figure 2(a) the p.d.f. of the time delays is shown, demonstrating peaks at the correct arrival times of the pulses. Figure 2(b) shows the normalized output of a simple matched-filter between transmitted pulse and received time series. The plots show that the p.d.f. peaks are “crisper” and less ambiguous than those of the matched-filter output.

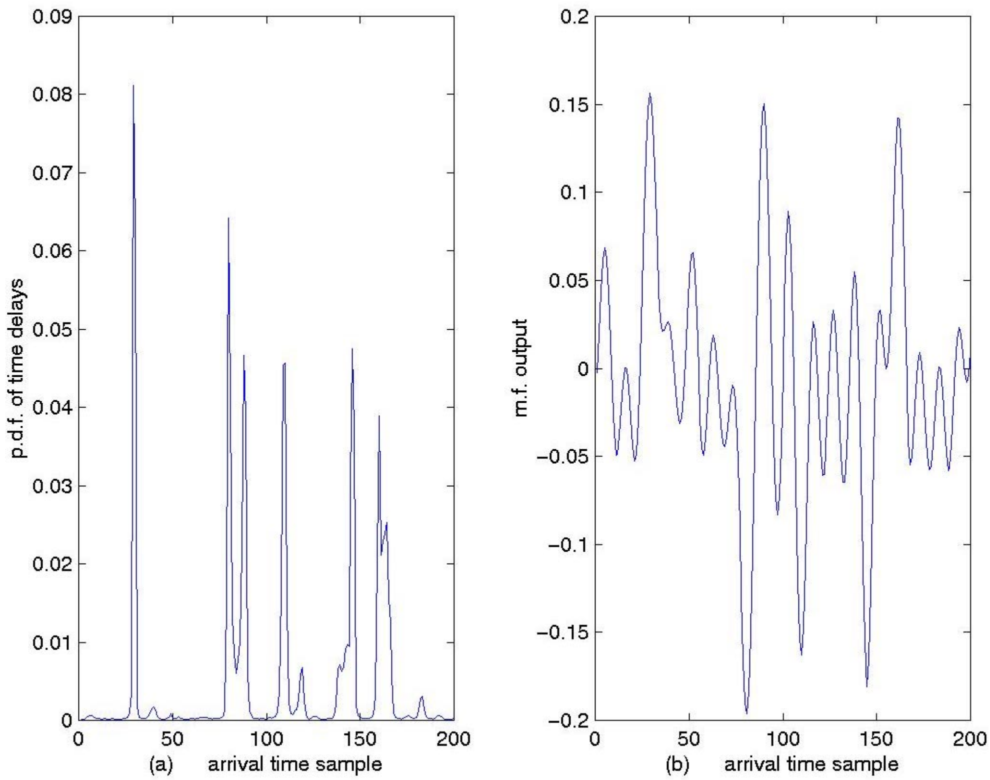

Figure 2: Arrival time identification using (a) maximization of the posterior p.d.f. using Gibbs sampling and (b) matched-filtering.

The linearization and arrival identification approach gave excellent inversion results for source (and receiving element) location, sound speed (using empirical orthogonal functions), and water depth. When prior information was available on some of the parameters, regularization in the solution of the linear system gave a significant gain in the accuracy of the estimates. Figure 3 shows the true sound speed profile and estimated sound speed profiles obtained through linearized inversion with both least squares and regularization; the regularization result is closer to the true profile than that of the least squares solution.

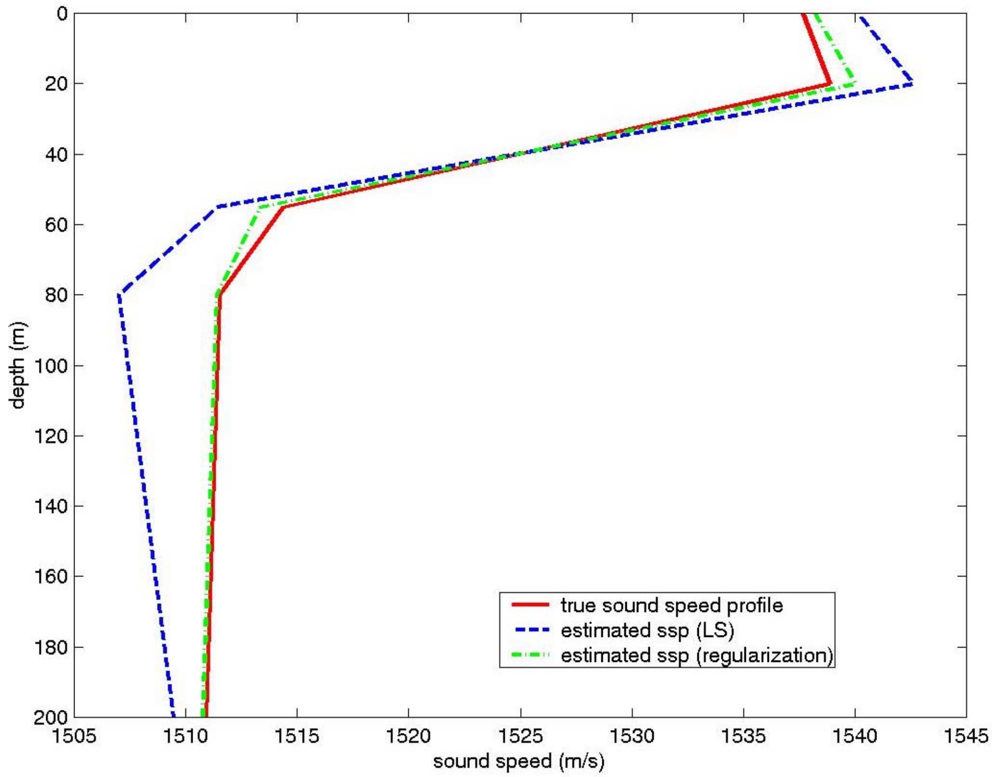

Figure 3: Sound speed profile estimation from the linearization approach with least squares and regularization. The estimated sound speed profiles are results of a single estimation run with 0.5 ms uncertainty in the arrival times.

IMPACT

The methods developed in this project facilitate localization in the ocean. The simultaneous Gibbs localization and deconvolution improves on the performance of conventional estimators without imposing computational overhead; it has the additional benefit of offering source spectrum information.

The linearization inversion approach gives in a very computationally efficient way estimates of the geometry parameters involved in an underwater sound propagation problem and could be used as an inversion pre-processor. Full-field inversion for environmental parameters can follow employing the linearization geometry parameter estimates. The search space for the full-field inversion will be reduced, since several parameters are assumed known.

RELATED PROJECTS

Work was performed in collaboration with Dr. Eduardo Mercado III (Rutgers University) on identifying relationships between frequencies used by vocalizing marine mammals and the environments in which they transmit sound. The work involved studies of sound propagation in shallow water environments frequented by humpback whales. Several interesting observations were made; as an example, the optimal receiver depth for several environments from a propagation point of view was found to coincide with the depths most frequented by whales according to the marine mammal literature.

A project was also conducted in collaboration with Mr. Owen Baker investigating the potential of the optimization algorithm TABU in inversion with underwater sound. The algorithm was studied in the context of analytically known functions with numerous local extrema; a comparison process between TABU and genetic algorithms has been initiated. The algorithms will be further compared and they will be evaluated in underwater sound inversion.

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