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 geoacoustic inversion.

OBJECTIVES

- Achieve accurate and computationally efficient source localization by designing estimation schemes that combine acoustic field modeling and optimization approaches.

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

APPROACH

It was first established that estimating source spectrum and noise variance concurrently with obtaining source location estimates leads to "sharper" ambiguity surfaces for localization [1]. This information was then employed to build a source localization-geoacoustic inversion processor for a multiple source, shallow water environment. The processor calculates the joint posterior probability distribution of multiple source locations, source spectra, and noise level (and potentially environmental parameters as well). Integrating over strong source locations and source spectra (and environmental parameters if those are included), the technique provides the marginal probability distribution of the location of a weak source, that can then be maximized for weak source localization. Estimation of joint probability distributions that are necessary in this approach is facilitated with Gibbs Sampling.

In parallel, the Tabu optimization method [2] was applied to data collected in the East China Sea during the 2001 ASIAEX experiment for geoacoustic inversion and source localization; this work was carried out in collaboration with Jim Miller and Gopu Potty from the University of Rhode Island. The purpose of this project was to further validate Tabu as a global optimization technique suitable to geoacoustic inversion and to ensure that the method can be generalized and operate successfully independently of the inversion environment.

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WORK COMPLETED

A matched-field processing method for multiple source localization was developed and tested on synthetic data. The method relies on first forming the joint posterior probability distribution of ranges and depths, source amplitudes and phase, and noise variance (and, potentially, uncertain environmental parameters) for an uncertain number of sources. Maximization of the joint probability distribution over the number of sources provides an estimate of the number of sources present. We then form the joint multivariate probability distribution for all source locations and source spectra. The marginal distribution of source ranges and depths can be obtained by integrating this joint multivariate distribution over source phases and amplitudes and noise variance. The new approach treats number of sources, source characteristics and noise (and, in consequence, signal to noise ratio) as unknown parameters with their own statistical descriptions. The method is described extensively in [3].

Tabu was applied to East China Sea data collected during the ASIAEX experiment. It was determined that parameter hierarchy is a crucial factor for an efficient search. Hierarchy was especially important in the "random" jumps employed by Tabu, where the method stochastically increases neighborhood size and makes "diagonal" moves to avoid getting trapped in regions of local maxima [2]. Since the number of possible diagonal moves increases significantly with search space dimension, it was here determined that the method can be generalized by always involving only the most significant parameters (identified via eigenvalue decomposition) in the diagonal move phase.

RESULTS

Localization of a weak sound source in the presence of interference was pursued with the new maximum a posteriori– Gibbs Sampling (MAP-GS) approach. The method was tested on synthetic, noisy data realizations for a range of signal-to-noise-ratio levels, and its performance was evaluated via a comparison to a simple, coherent Bartlett canceller.

The performance of the new method was found to be frequency dependent. For frequencies of a few hundred Hz, the performance of the new approach was very similar to that of the simple method. As the frequency reached values of 200 Hz and below, the performance of the new processor was superior to that of the simple canceller; the performance gain offered by the new approach was significant. Figure 1 presents probability of correct localization jointly for two sources (one strong and one weak) vs. signal-to-noise ratio as obtained from the new and conventional processors.

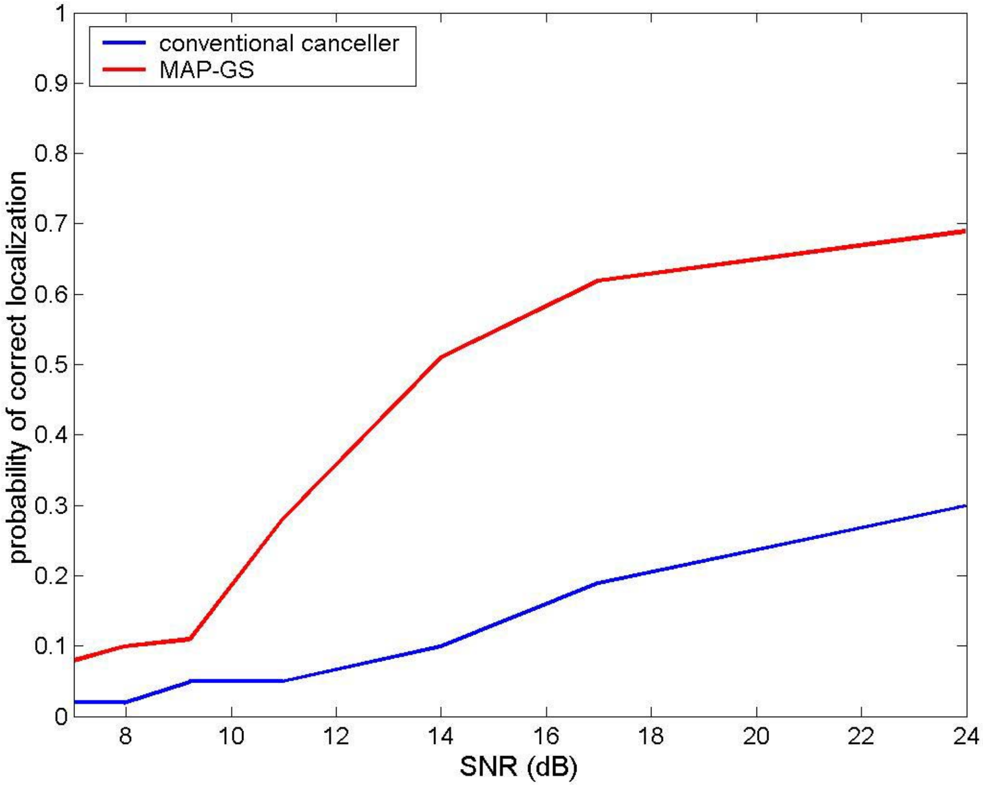

Figure 1: Probability of correct localization for the new MAP-GS processor and a conventional Bartlett canceller for a frequency of 200 Hz.

Results from the development of a Tabu localization and geoacoustic inversion scheme and its application to East China Sea data were excellent, with parameter estimates being very close to ground truth information. Source location, water column depth, and array tilt were unambiguously determined. Geoacoustic parameter estimation was relatively ambiguous because of the decreased sensitivity of the acoustic field with respect to those parameters. In spite of the uncertainty, Tabu results indicate a thin sediment at the site and a compressional wave speed in the sediment of approximately 1600 m/s as reported in Refs. [4, 5, 6]. Figure 2 shows Bartlett ambiguity surfaces calculated for a generic environment describing the experimental site and for an environment optimized with Tabu search. Significant uncertainty is present in the first ambiguity surface as indicated by the multiple side-lobes. The uncertainty is dramatically reduced when the optimized environment is employed, in which case the source is localized very clearly.

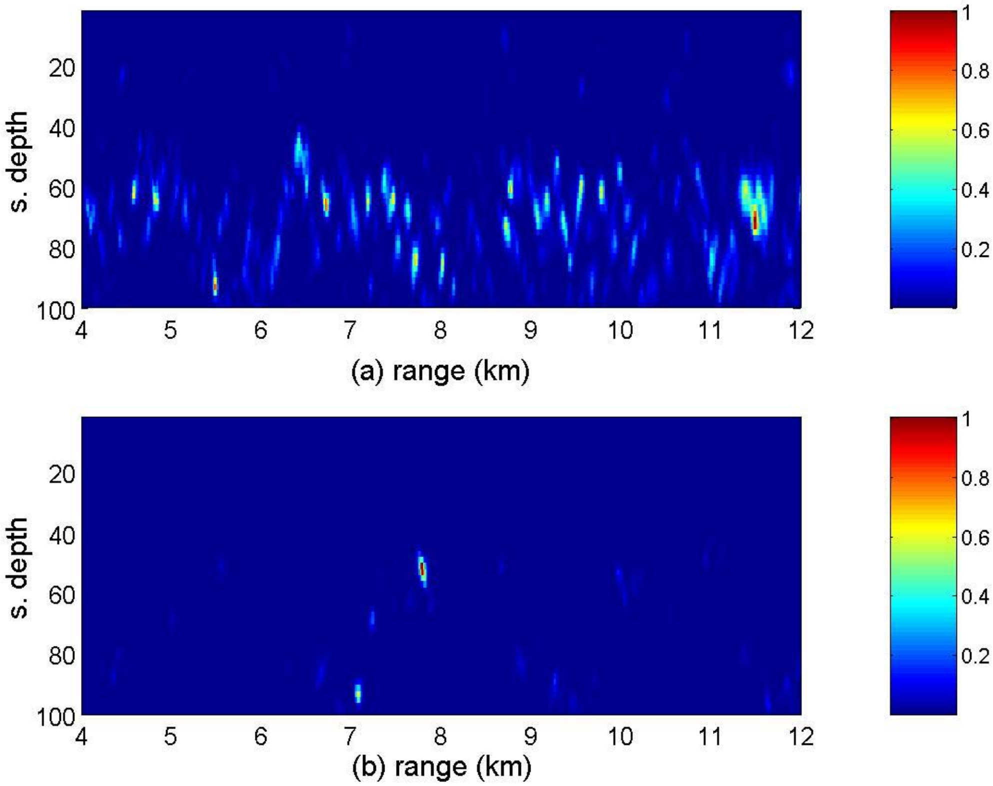

Figure 2: Ambiguity surfaces calculated for the location of a wideband source using (a) an initial (non-optimized) description of the environment and (b) environmental and receiver location parameters as determined by Tabu. The true range and depth are 7.7 km and 50 m respectively.

IMPACT

The multiple source localization work can impact significantly interference cancellation in shallow, acoustically congested waters. Such cancellation is imperative, because most sources of interest are quiet and easily masked. The new approach is general and can be applied to cases with uncertain numbers of interferers, not requiring predetermination of the number of sources present and the noise level.

The successful results from the application of Tabu to East China Sea data point to the potential of the method in efficient geoacoustic inversion, a task that is important for remote environmental monitoring. The method is fast in exploring search spaces and offers a wealth of information on local maxima and parameter correlations.

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