

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

Arrival times and amplitudes of distinct frequencies (within a single mode or across different modes) provide a wealth of information on environmental properties of the propagation medium and source location. Demonstration of the role of modal arrival times and amplitudes in geoacoustic inversion and source localization has been discussed in [1, 2, 3].

Typically, extraction of modal information from the reception of signals that have traveled long distances in dispersive underwater environments is performed with time-frequency or wavelet analysis [4]. Accurate identification of modes and their amplitudes and arrival times is, however, challenging. The uncertainty in the process has an impact on the accuracy of geoacoustic inversion and source localization, which has not been, to date, quantified.

In this work, a high-resolution method is developed for modal decomposition of a received signal and modal arrival time estimation. The method employs principles of dynamical systems for multiple source tracking [5] and applies those to the extraction of “frequency trajectories” from spectrograms of received signals [6, 7, 8]. Every mode in the short time Fourier transform representation of the signal is treated as a distinct source track with small changes in location (frequency, in our case) at each time step. We generate a particle filter that exploits two relationships, one for frequency updating vs. time (state equation) and the second one for comparison of the Fourier transform representation of a

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synthetic signal for the chosen state to that of the true signal (observation equation). After a few initial steps, the particle filter identifies distinct “tracks” and reports probability distributions around them. The method also estimates the number of tracks (modes) present at each time using a stochastic mechanism that allows modes to “be born” or expire.

The approach, developed in collaboration with Ivan Zorych (postdoctoral fellow at NJIT), provides higher resolution estimates than conventional time-frequency analysis; it allows stochastic frequency perturbations and does not restrict the search for modes to a pre-specified frequency grid typically employed in such problems.

WORK COMPLETED

The described approach was designed and applied to synthetic data. The data simulated received signals propagating in a shallow water environment and traveling a distance of 20 km from the source. The frequency content of the signals was between 200 and 600 Hz. Tests are underway that explore the application of the method to real data collected during the ASIAEX experiment.

RESULTS

Figure 1 presents the spectrogram of a synthetic received signal. Dispersion curves corresponding to several modes can be clearly identified; other modes are, however, not that clear. It is also evident and well known from time-frequency analysis that, although general dispersion curve tracks can be extracted from this representation, frequencies and arrival times cannot be both accurately estimated.

Figure 2 demonstrates the local maxima selected from the spectrogram of Figure 1, by setting thresholds that determine the presence or absence of a mode. Although some general features on the modes are clear, we can see that not all modes can be tracked without interruption. In addition, there are several ambiguous local maxima that could signify either the presence of modes that are very poorly identified or noise.

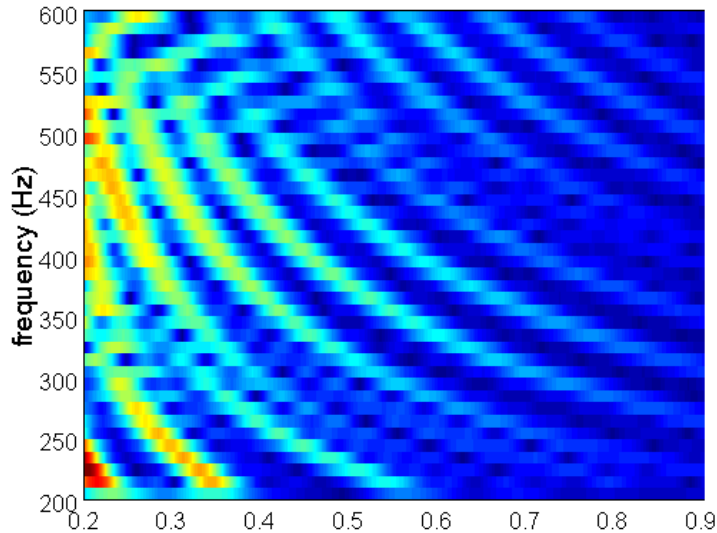


Figure 1: Spectrogram of a signal that has propagated 20 km from the source in a shallow water environment. The frequency content of the signal was between 200 and 600 Hz.

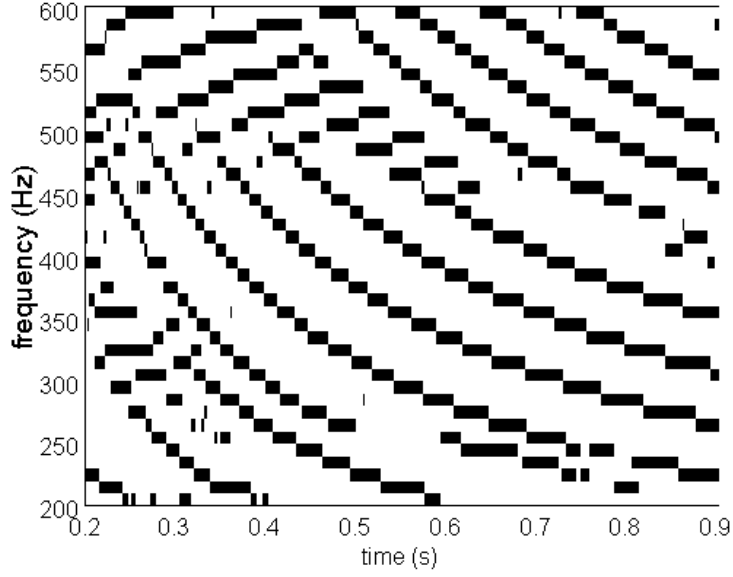


Figure 2: Mode selection with local maximization from the spectrogram of Fig.1.

Figure 3 presents the time-frequency representation obtained by applying the particle filter mode tracker to the received signal. Dispersion curves that have been numerically calculated for the given propagation medium are superimposed on the particle filter tracks of Figure 3. The comparison shows a very close match between estimated and true dispersion curves. The new process identifies modes that are missed in the local maximum process of Figure 2; modes that were highly ambiguous in Figure 2 are now clearly outlined. Frequency resolution is also improved, with frequencies allowed to take values in between the frequency grid points selected for the Fourier transforms of Figure 1.

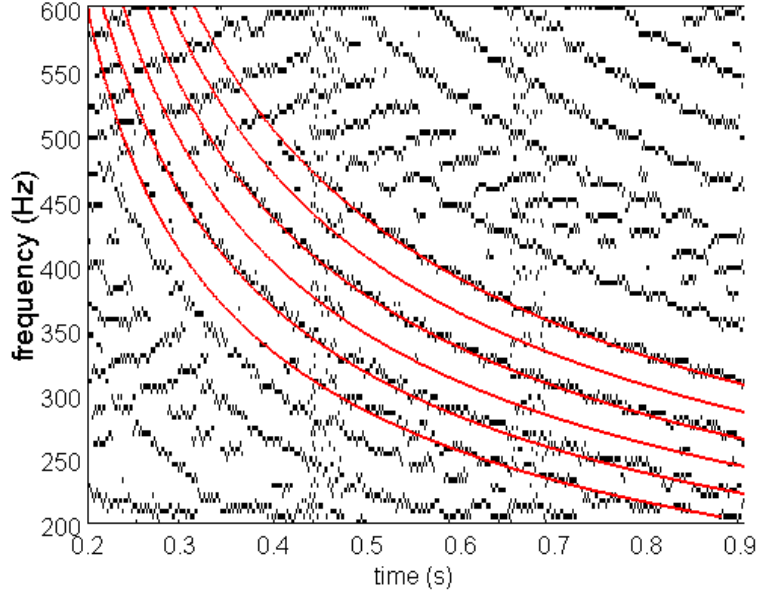


Figure 3: Mode selection with particle filtering applied to an acoustic signal; numerically obtained dispersion curves are superimposed on the estimated tracks, demonstrating a good match between true and estimated curves.

The particle filter process is Bayesian in nature and calculates posterior probability distributions of modes being present at a given time. This property allows us to probabilistically quantify mode detection and identification as well as uncertainty in the estimation process. Probability distributions of modes being present at a single snapshot are shown in Figure 4.

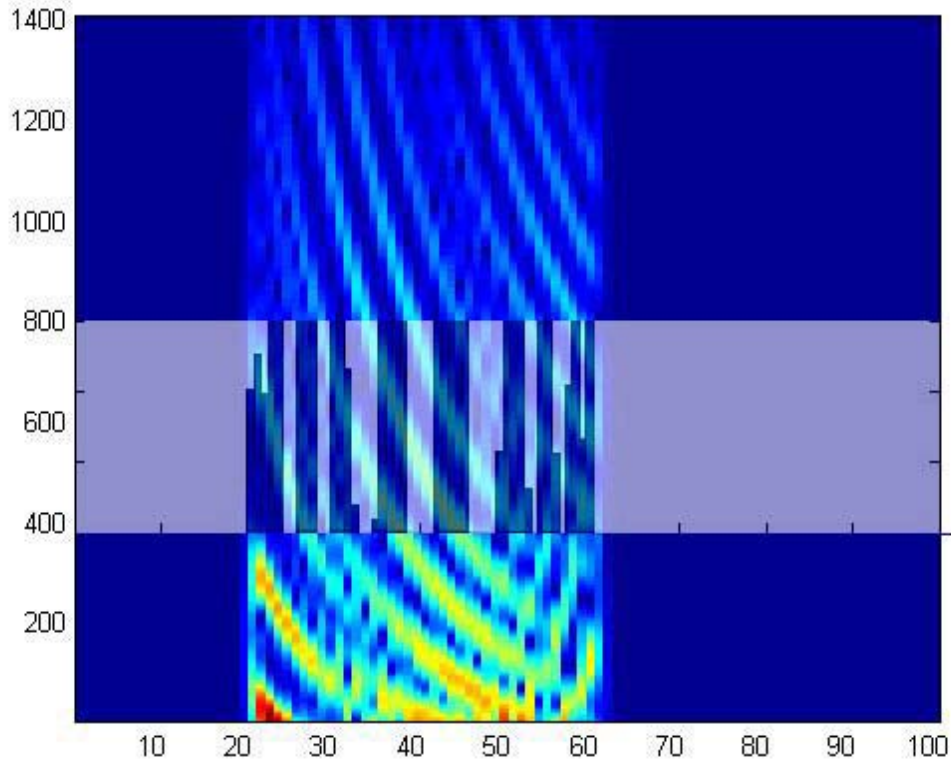


Figure 4: Estimated probability distributions of modes present at a specific time as calculated by the particle filter tracker; the probability distributions are superimposed on the spectrogram of the received signal.

IMPACT

The significance of dispersion curve estimation in geoacoustic inversion has been extensively studied with several methods designed to produce geoacoustic parameter estimates from dispersion estimates of acoustic signals. The reliability of these methods is intimately tied to the ability of accurately extracting “mode trajectories” from time-frequency representations. The new method provides estimation of such trajectories with high resolution revealing information that is often masked in simple spectrograms. The method also produces posterior probability distributions of modal trajectories, which can then be used to quantify uncertainty in the estimation of geoacoustic parameters.

RELATED PROJECTS

Employing similar principles to the particle filter mode tracker, a high resolution time-delay estimator for short range, high frequency pulses was designed (in collaboration with Rashi Jain). The algorithm is currently being tested on arrival time estimation in multipath environments with an unknown number of arriving paths at the receiving phones.

A collaboration is also underway with Dr. Lisa Zurk (Portland State University) on developing a variant of the particle filter tracker introduced in this project for active target tracking employing the invariance principle [9].

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