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OCEAN ACOUSTIC SIGNAL PROCESSING: A BAYESIAN APPROACH

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The application of Bayesian methods to complex ocean acoustic processing problems, especially in shallow water, has evolved from well-known probability distributions like Gaussian leading to model-based, Kalman filtering solutions to nonparametric representations driven by the uncertain ocean environment leading to sequential Monte Carlo or equivalently particle filtering solutions. In this lecture, an overview of particle filtering methods coupled to a shallow ocean modal tracking application motivated by the nonlinear nature of underlying ocean acoustic phenomenology is presented. Beginning with a brief overview of Bayesian inference leading to sequential processors, the Bayesian paradigm is established. Simulation-based methods using sampling theory and sequential Monte Carlo realizations are discussed. Here the usual limitations of nonlinear approximations and non-gaussian processes prevalent in classical algorithms (e.g. Kalman filters) are no longer a restriction to perform Bayesian processing. It is shown how the underlying state variables are easily assimilated into this sequential Bayesian construct. With this in mind, the idea of a particle filter, which is a discrete nonparametric representation of a probability distribution, is developed and shown how it can be implemented using sequential methods. Finally, an oceanic application of this approach is discussed comparing the performance of the particle filter designs with that of the classical unscented Kalman filter.

The underlying application is modal tracking in a shallow water ocean that is an uncertain, ever changing, dispersive environment dominated by ambient and shipping noise as well as temperature variations in its upper layers (<100m) directly affecting sound propagation throughout. The processors must be able to adapt to these environmental variations while simultaneously tracking modal functions for such applications as localization, inversion and signal enhancement. The need to develop processors that are capable of tracking these changes implies a stochastic as well as an “adaptive” design.

Model-based processing techniques in ocean acoustics are well-known evolving from the pure statistical approach of maximum likelihood parameter estimation, matched-field processing and sequential model-based processing for Gaussian uncertainties. It has been clear for a long time that this constraint was not particularly realistic requiring a Bayesian approach that enables the representation of *any* uncertainty distributions. More recent model-based techniques such as the unscented Kalman filter (UKF) and particle filter (PF) have been developed to improve the distribution estimates; however, their application to the *adaptive* oceanic problem for normal-mode representations had not been fully investigated. Recall that the particle filter is a sequential Markov chain Monte Carlo (MCMC) processor capable of providing reasonable performance for a multi-modal (multiple peaked distribution) problem, while the UKF is still limited to unimodal (single peak) solutions.

The solution to this problem is accomplished by developing a sequential Bayesian processor capable of providing a joint estimation solution to the modal function tracking (estimation) and environmental adaptivity problems. The posterior distribution needed is multi-modal (multiple peaks) requiring the sequential (nonstationary) Bayesian approach. Here we develop both the UKF and PF for this shallow ocean application. Based hydrophone measurements obtained from the *23*-element vertical array deployed for the Hudson Canyon experiment using normal-mode representations, the adaptivity problem is attacked by allowing the modal coefficients to be estimated from the measurement data jointly along with tracking of the modal functions---the main objective.

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