Session 3aUW

Underwater Acoustics and Signal Processing in Acoustics: Robust Array Processing

Claire Debever, Chair
Scripps Inst. of Oceanography, Marine Physical Lab., 8820 Shellback Way, La Jolla, CA 92093-0238

Chair's Introduction—8:30

Invited Papers

8:35

3aUW1. Spatial coherence? Henry Cox (Lockheed Martin, 4350 N. Fairfax Dr., Ste. 470, Arlington, VA 22203, harry.cox@lmco.com)

The term spatial coherence is frequently used to summarize the impact of the propagation environment on array performance and to suggest a limitation on useful array aperture. A source of considerable confusion is that there is no single widely accepted precise meaning of the term. In general, coherence implies a fixed phase relationship and involves time as well as space. The time duration over which the measurement is made or for which the phase relationship appears fixed is central to the measurements of coherence. A number of different measurements types and associated data analyses are described and the results are interpreted in terms of the pertinent aspects of acoustic propagation, such as multipath, surface and internal waves, etc. The effects of source and receiver motion are also considered. The implications for array performance and the robustness of beamforming approaches in the face of environmental variability and uncertainty are also discussed. Examples are given from recent shallow water experiments. [Work supported in part by NAVSEA Contract No. N00024-07-C-5210.]

8:55

3aUW2. Image-based refocusing of ultrasound arrays in the presence of strongly scattering objects. John Ballard and Emad Ebbini (Dept. Elec. and Comput. Eng., Univ. of Minnesota, 200 Union St. SE, Minneapolis, MN 55455, ball0250@umn.edu)

Ultrasound phased arrays are currently being investigated for a dual-mode (imaging/therapy) operation in targeting deep-seated abdominal tumors for selective destruction noninvasively. In some cases, e.g., liver tumors, the target is partially obstructed by the ribcage, which limits the array gain at the target. In addition, the intensity at the ribs may be high enough to cause treatment-limiting pain and/or collateral damage to the tissues surrounding the ribs in the path of the therapeutic beam. Using the imaging capabilities of these dual-mode arrays, we have formulated and experimentally verified a robust minimum variance beamforming algorithm for adaptive refocusing in the presence of the ribs. The algorithm utilizes image data of the treatment region formed using conventional beamforming in estimating the array steering vector at the target and the weighting matrix that maximizes the array gain at the target. In this paper, we will describe the mathematical formulation and present experimental data to demonstrate its robustness. We will also discuss the implications of the method, the use of ultrasound phased arrays for imaging, and therapy of trans-thoracic targets such as the liver and the heart.

9:15

3aUW3. Bayesian localization and tracking with environmental and array-element uncertainties. Stan Dosso (School of Earth and Ocean Sci., Univ. of Victoria, Victoria, BC V8W 3P6, Canada, sdosso@uvic.ca), Dag Tollefsen (Norwegian Defence Res. Establishment, 3191 Horten, Norway), and Michael Wilmut (Univ. of Victoria, Victoria, BC V8W 3P6, Canada)

This paper considers matched-field source localization and tracking when environmental parameters and/or array-element positions are not well known. A Bayesian formulation is applied in which source, array, and environmental parameters are considered unknown random variables constrained by noisy acoustic data and by prior information on parameter values (e.g., physical limits for environmental properties and element positions) and on interparameter relationships (e.g., limits on source speed and interelement spacing). The goal then is to extract source information from the posterior probability density (PPD). One approach is based on maximizing the PPD over all parameters to obtain optimal source locations. A key to solving this problem efficiently is that the VITERBI algorithm is applied to compute the highest-probability source track for each environment/array realization: this provides the optimal track, while requiring the optimization is applied only over the nuisance parameters. A second approach involves integrating the PPD over unknown environmental and array parameters to represent source-location information as a series of joint marginal probability surfaces over range and depth. Given the strong nonlinearity of this problem, marginal PPDs are computed numerically using efficient Markov-chain Monte Carlo importance sampling methods. The approaches are illustrated with examples based on simulated and measured acoustic data.

9:35

3aUW4. Robust adaptive beamforming: Evolution of approaches, analysis, and comparison. Sergiy A. Vorobyov (Dept. of ECE, Univ. of Alberta, 9107-116 St., Edmonton, AB T6G 2V4, Canada)

A so-called worst-case-based robust adaptive beamforming approach has been proposed a few years ago. This approach has been followed up by a number of works, which significantly improved the implementation issues. Recently, two new approaches have been developed: the probability constrained based and sequential quadratic programing based approaches. The probability constraint based design requires the distortionless response constraint to be kept with a certain selected probability, while the worst-case-based design requires this constraint to be kept for the worst-case operational conditions. The sequential quadratic programing based approach uses the iterative estimation of the signal steering vector and, therefore, is significantly different from two two aforementioned designs. In this paper, we overview, analyze, and compare all the aforementioned approaches to robust adaptive beamforming design.

9:55

3aUW5. Robust processing techniques for underwater acoustics. Lisa Zurk (ECE Dept., Portland State Univ., P.O. Box 751, Portland, OR 97207, zurkl@pdx.edu)

The performance of sonar signal processing methods in shallow water waveguides is highly sensitive to the effects of the acoustic wave propagation, and the nature of this propagation is often critically dependent on the exact nature of the underwater channel. Signal processing formulations that exploit the structure of the channel have been shown to increase detection and localization performance when the channel properties are known. However, for many tactical situations, channel parameters are poorly unknown or "uncertain," thus motivating the need for robust processing techniques that do not require exquisite knowledge of the environment but may still exhibit the increased performance of full field methods. The goal of devising robust processing approaches remains of high interest and is an ongoing topic for signal processing research. This presentation first provides some metrics of environmental uncertainty and the effect on the sonar signal processing then provides a review of several proposed approaches for achieving robustness. The algorithms are grouped into the following three categories: robust matched field processing algorithms, guide source calibration techniques, and invariance processing (both passive and active). The presentation concludes with a discussion of ongoing research and future areas for investigation.

10:15—10:30 Break

Contributed Papers

10:30

3aUW6. Broadband high frequency matched-field processing. Claire Debever and William A. Kuperman (Scripps Inst. of Oceanogr., UCSD, 9500 Gilman Dr., Mail Code 0238, La Jolla, CA 92093-0238, cdebever@ucsd.edu)

Adaptive matched-field processing (MFP) is extremely sensitive to environmental uncertainties. While conventional and adaptive techniques may work for low-frequency signals in well-studied environments, the localization performance usually degrades rapidly as frequency increases, such that MFP in the 3.5 kHz regime, in shallow water environments, is typically problematic. A broadband coherent method [IEEE J. Ocean. Eng. **21**, 384–392], combined with white noise constraint and principal component techniques, is implemented to construct robust replicas from experimental data. Matched-field tomography is then used to better understand the origin of the frequency dependent MFP mismatch (uncertain bottom structure, sound speed fluctuations, or both), and the results are compared with simulations. Ultimately, we want to gain some insights into how to implement a robust matched-field processor for high-frequency scenarios without using experimental data to create replica vectors. In particular, we are seeking to understand the thresholds for adaptive processors as function of signal to noise ratio and frequency dependent environmental mismatch. [Work supported by ONR.]

10:45

3aUW7. Geoacoustic tracking. Caglar Yardim, Peter Gerstoft, and William Hodgkiss (Marine Physical Lab., Scripps Inst. of Oceanogr.-0238 9500 Gilman Dr., La Jolla, CA 92093-0238)

This paper shows how to incorporate tracking techniques such as the extended Kalman, unscented Kalman, and particle filters into geoacoustic inversion problems. This enables not only the inversion of environmental parameters but also the spatial and temporal tracking of them, making geoacoustic tracking a natural extension to geoacoustic inversion techniques. Water column and seabed properties are tracked in simulation and using the MAPEX2000 experimental data for both vertical and horizontal line arrays. Filter performances are compared in terms of filter efficiencies using the posterior Cramér–Rao lower bound. Tracking capabilities of the geoacoustic filters under slowly and quickly changing environments are studied in terms of divergence statistics. The suitability of each filter in geoacoustic tracking is discussed in terms of the track quality, complexity of the probability density function of environmental parameters, nonlinearity of the geoacoustic propagation, and computational cost. The results show that geoacoustic tracking can provide continuously environmental estimates and their uncertainties using only a fraction of the computational power of classical geoacoustic inversion schemes. [Work supported by ONR-N00014-05-1-0264.]

11:00

3aUW8. Inversion of ocean environmental variations via time reversal acoustics. Wen Xu and Jianlong Li (Zheda Rd. 38, Dept. of Information Sci. and Electron. Eng., Zhejiang Univ., Hangzhou 310027, China)

Time reversal (TR) processing is derived from the invariance of the wave equation for lossless medium to change in the sign of the time variable. By retransmitting the TR version of the time-dispersed received signal propagated from a probe source (PS) to a source-receiver array, one can reacquire the transmitted pulse at the PS location (time compression and spatial focusing) when the waveguide environment is time invariant. However, if some environmental variations occur between the two transmissions, the retrofocusing signal will be defocused. This paper presents a new method of environmental parameter inversion by comparing the difference of the focused signals measured at the PS location with/without environmental perturbations. Because the sound speed profile (SSP) plays a critical role in an uncertainty ocean environment, inversion of the SSP represented in terms of the empirical orthogonal functions is developed and discussed in detail. Simulations demonstrate some advantages of environmental inversion via TR: (1) great signal-to-noise ratios can be obtained at the PS location; (2) variations of the environment at different times can be directly inverted by repeatedly retransmitting either the same received signal generated by one PS transmission or the updated received signals generated by updated PS transmissions.

11:15

3aUW9. Arrival time estimation from sound signals in the ocean: A particle filtering approach. Rashi Jain and Zoi-Heleni Michalopoulou (Dept. of Mathematical Sci., New Jersey Inst. of Technol., Newark, NJ 07102, rj45@njit.edu)

The focus of this work is on accurate arrival time estimation from measured time-series at an array of vertically separated hydrophones in the ocean. We develop a particle filtering approach that treats arrival times as "targets", dynamically modeling their "location" at arrays of spatially separated receivers. Using Monte Carlo simulations, we perform an evaluation of our method and compare it to conventional maximum likelihood estimation, whereas we also compare our errors to Cramer–Rao bounds. The comparison demonstrates an advantage in using the proposed approach, which can be employed for minimization of uncertainty in arrival time estimation. Improved arrival time estimates can then be used for accurate geoacoustic inversion and source localization. [Work supported by ONR.]

The Journal of the Acoustical Society of America

Vol. 124, No. 4, Pt. 2 of 2, October 2008 http://asa.aip.org

156th Meeting
Acoustical Society of America

Doral Golf Resort and Spa
Miami, Florida
10–14 November 2008

Table of Contents on p. A5

Published by the Acoustical Society of America through the American Institute of Physics