A Book of Abstracts for the

2005 Underwater Acoustic

Signal Processing Workshop

October 5–7, 2005

Alton Jones Campus

University of Rhode Island

West Greenwich, RI, USA

UASP 2005

Welcome to the 2005 IEEE workshop on Underwater Acoustic Signal Processing. This year the special session, organized by Dr. G. Clifford Carter, will be on *Underwater Acoustic Signal Processing Applications to Homeland Security.*

The organizing committee would like to thank and acknowledge the continued sponsorship of Dr. John Tague at the Office of Naval Research, James Barbera from the IEEE Oceanic Engineering Society for their sponsorship of the Wednesday evening dinner, and thanks Martin Cohen and Mark Ferguson for their efforts in arranging for Raytheon Systems Company to sponsor our Thursday evening dinner. We are also honored to present this year's UASP Award Dr. Norman Owsley.

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2005 UASP Award Presented to Dr. Norman L. Owsley

in recognition of his contributions to array signal processing and Naval research and development throughout the first 37 years of his career.

Dr. Norman L. Owsley's career began in 1968 when he graduated from Duke University and joined the U.S. Navy Underwater Sound Laboratory in New London, Connecticut. For over thirty years, he performed research and development in signal processing with application to Navy sonar systems. After retiring from Navy civil service in 1999, his interests shifted to the application of passive sonar signal processing to noninvasive testing for coronary artery disease until he was coaxed back into the Navy fold from 2001–2005 to manage the Office of Naval Research's Shallow Water Array Performance project aiming to understand the limits of passive sonar performance in shallow water environments.

During these past 37 years Dr. Owsley has established himself as one of the driving forces in advancing the state-of-the-art in underwater acoustic array signal processing. His research has spanned several areas in array signal processing including adaptive array processing, dominant mode rejection beamforming, towed-array shape estimation, and multi-line arrays as well as other areas such as long-range acoustic communications and medical acoustics. The significance of Dr. Owsley's accomplishments is demonstrated not only by his publication and citation record, but more importantly by the impact of his efforts to educate the next generation, transition research into Navy systems, and his leadership and guidance in Naval working groups and research management.

It is in recognition of these contributions to array signal processing and Naval research and development that we the underwater acoustic signal processing community are honored to present the UASP Award to Dr. Norman L. Owsley.

Schedule at a glance

Wednesday October 5, 2005		Thursday October 6, 2005		Friday October 7, 2005	
		8:00-9:15	Session B Laurel	8:00-9:45	Session G Laurel
		9:15-10:00	Session C Laurel	9:45-10:15	Break Laurel
		10:00-10:30	Break Laurel	10:15-12:00	Session H Laurel
		10:30-12:00	Session D Laurel	12:00-1:00	Lunch Whisp. Pines
		12:00-1:00	Lunch Whisp. Pines	1:00-2:15	Session I Laurel
		1:00-2:45	Session E Laurel		
		2:45-3:15	Break Laurel		
		3:15-5:00	Session F Laurel		
5:00-6:00	Welcome Reception				
6:00-8:00	OES Dinner Whisp. Pines	6:00-8:00	Raytheon Dinner Whisp. Pines		
8:00-9:30	Session A Laurel	8:00-?	SOB Session Laurel		

Sessions: Titles and presenters

Session A: Wednesday Evening, 8:00pm–9:30pm

Special Session: UASP Applications to Homeland Security

A–1 *Underwater Port Security Signal Processing Challenges*,
Richard Hansen, United States Coast Guard Research & Development Center

A–2 *The Navy Maritime Security Test and Evaluation Site*,
Dallas Meggitt, Sound & Sea Technology

A–3 *A Low-power, High-resolution Doppler Sonar for Ship and Harbor Defense*,
Harry DeFerrari, University of Miami

Session B: Thursday Morning, 8:00am–9:15am

Special Session: UASP Applications to Homeland Security

B–1 *Acoustical Signature of a Diver in an Estuary Harbor Environment*,
Alexander Sutin, Center for Maritime Systems, Stevens Institute of Technology

B–2 *Measurements of the Target Strength and Radiated Noise of Divers Wearing SCUBA Equipment*,
Roy Manstan, Naval Undersea Warfare Center

B–3 *Bearing Estimation and Tracking for a Swimmer Defense Sonar Node of Slightly Overlapping Directional Transducers*,
Geoffrey Edelson, BAE Systems E&IS

Session C: Thursday Morning, 9:15am–10:00am

Multistatic Active Sonar

C–1 *Multistatic Sensor Placement with the Complementary Use of Doppler Sensitive and Insensitive Waveforms*,
Doug Grimmett, NATO Undersea Research Center

C–2 *Synchronising Multiple Sonar Systems in Time and Space: Towards Accurate Contact Information for Multistatic Systems*,
Pascal de Theije, TNO

Session D: Thursday Morning, 10:30am–12:00noon

Multistatic Sonar Tracking

D–1 *Progress in Multistatic Sonar Tracking for Undersea Surveillance*,
Stefano Coraluppi, NATO Undersea Research Centre

D–2 *Probabilistic Multi-Hypothesis Tracking for Distributed Active Sensors*,
Christian Hempel, Naval Undersea Warfare Center

D–3 *Distributed Environmentally-Adaptive Detection, Classification, and Localization Using a Cooperative Sensor Network*,
James Pitton, Univ. of Washington Applied Physics Laboratory

Session E: Thursday Afternoon, 1:00pm–2:45pm

Adaptive Array Processing

E–1 *Robust Detection in Nonstationary Noise,*
Samuel Earp, Multisensor Science, LLC

E–2 *Simulation of Adaptive Beamformers in Non-Stationary Interference,*
Bruce Newhall, Johns Hopkins University Applied Physics Laboratory

E–3 *Accurate Rectangular Window Subspace Tracking,*
Timothy Toolan, University of Rhode Island, Department of Electrical Engineering

E–4 *Multi-Rank MVDR Beamforming,*
Henry Cox, Lockheed Martin Orincon

Session F: Thursday Afternoon, 3:15pm-5:00pm

Sonar Performance Analysis and Simulation

F–1 *Fading Channel Capacity and Passive Sonar Resolution,*
John Buck, University of Massachusetts Dartmouth

F–2 *Rate Distortion Theory Bounds on Passive Sonar Performance,*
Tianzhu Meng, University of Massachusetts Dartmouth

F–3 *Passive Sonar Performance Prediction using a Moving Source of Opportunity,*
Jeffrey Krolik, Duke University

F–4 *A Simulation Package for Autonomous Underwater Vehicle Signal Processing,*
John Ianniello, SAIC

Session G: Friday Morning, 8:00am–9:45am

Mine Classification and Low Frequency ACOMMS

G–1 *Filtering Strategies for Measuring the 2-D Spatial Structure of Elastic Scattering from Buried, Liquid-Filled Symmetric Objects*,
Ivars Kirsteins, Naval Undersea Warfare Center

G–2 *Comparison of Two Model-based Echo Processing Schemes for Man-made Object Recognition; Application to a Tank Experiment Data Set*,
Manell Zakharia, French Naval Academy

G–3 *Baseline Classification of Acoustical Signatures of Mine-Like Objects*,
Juri Sildam, Defence Research and Development Canada Atlantic

G–4 *Long-Range Underwater Acoustic Communications Using a Multi-Mode Decision Feedback Equalizer*,
Tarun Chandrayadula, George Mason University

Session H: Friday Morning, 10:15am–12:00noon

Detection and Classification

H–1 *Bounds on the Performance of Nonparametric Detectors/Normalizers Operating on Square-law Data*,
Ashwin Sarma, Naval Undersea Warfare Center

H–2 *Detection Enhancement Using Multiple Time-reversed Guide Sources in Shallow Water*,
David Calvo, Acoustics Division, Naval Research Laboratory

H–3 *Synthetic Aperture Sonar (SAS) Processing for Improved Mid-frequency Active Multi-ping Classification*,
Geoffrey Edelson, BAE Systems E&IS

H–4 *Hybrid Joint PDF Estimation and Classification for Sparse Systems*,
James Gelb, Applied Research Labs, UT Austin

Session I: Friday Afternoon, 1:00pm-2:15pm

Underwater Acoustics

I–1 *Adaptive Processing for Range Dependent Propagation Studies,*
Kevin Heaney, OASIS, Inc.

I–2 *Wigner and Ambiguity Function Approximation Methods for Acoustic Propagation,*
Patrick Loughlin, University of Pittsburgh

I–3 *Propagation Path Data Fusion and Uncertainty Characterizations,*
Cathy Ann Clark, Naval Undersea Warfare Center

Abstract Listings

Underwater Port Security Signal Processing Challenges

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The United States Coast Guard, under the Department of Homeland Security, is the lead federal agency for the safety and security of our ports and waterways. This means providing for the safe transit of transportation and commerce, as well as allowing recreational use of our waters. Increased focus has been placed on security for our waterways, a critical element in our national infrastructure.

One of the most challenging areas is providing the means to protect against threats from under the surface of the water. Whether it is a diver trying to deliver an explosive device or an parasitic object attached to a legitimate vessel entering our ports, the Underwater Port Security Program is tasked with ensuring that the Coast Guard and our port partners have the proper tools to prevent these threats for reaching their target.

This presentation will define the challenges the Coast Guard feels this mission presents to the Underwater Acoustic Signal Processing community. It will define work that has been done to date and the obstacles that remain to be conquered.

Short Bio: Mr. Hansen has been with the Coast Guard's Research & Development Center for 12 years. He has served as a Project Manager on a wide variety of projects and now heads up the coordination of projects in the area of port security. Prior to the R&D Center, he worked for the Navy at Supervisor of Shipbuilding in Groton, CT, Portsmouth Naval Shipyard in Portsmouth, NH, and Norfolk Naval Shipyard in Norfolk, VA. He has a Bachelor's degree in Mechanical Engineering from Northeastern University and Master's Degree in Fire Protection Engineering from Worcester Polytechnic Institute in Worcester, MA.

The Navy Maritime Security Test and Evaluation Site

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The Navy Maritime Security Test and Evaluation Site (NMSTES), located in Port Hueneme, California, provides a site for objective testing and evaluation of components, equipment and systems for application to port and harbor security, including swimmer detection and interdiction. The initial uses of NMSTES for U.S. Navy applications. However, the facility also provides the capabilities needed for testing and evaluation of equipment and systems for application to commercial ports and harbors.

NMSTES supports the Department of Defense in demonstrating and validating port and harbor security goals and initiatives. Deep-draft port facilities provide a highly visible target for terrorists. Threats to the shipping of weapons and cargo have both economic and national defense concerns. Security systems at most ports are not sufficiently developed nor integrated to counter the broad range of sea and underwater threats that are within easy reach of terrorists.

NMSTES is located at the Port of Hueneme, California, a deepwater military and commercial port, and is managed by the Naval Facilities Engineering Service Center (NFESC). NMSTES provides a realistic, yet controlled environment for accomplishing sensor Test & Evaluation (T&E) exercises with minimal interruption to existing port traffic. The initial operations at NMSTES have concentrated on underwater sensors and systems.

A Low-power, High-resolution Doppler Sonar for Ship and Harbor Defense

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A signal processing approach is developed for continuous bi-static m-sequence sonar that resolves target returns in a fine grained arrival-time/doppler space. Long continuous m-sequences are the sonar signal. M-sequences have linear sensitivity in time and doppler and a perfect pulse compression (correlation) property that eliminates temporal leakage. The unique correlation property of m-sequences leads to a signal sampling method that resolves sonar returns in a complete ortho-normal (CON) data set. The CON data allows zero doppler returns from the direct arrival, multi-paths and reverberation to be set to zero without effect on other data points. In this way, the direct blast and the zero-doppler bottom reverberation and all their doppler leakage is eliminated. The process is called Coordinate Zeroing (CZ). In effect, clutter is reduces to negligible levels allowing detections of very slow moving targets. Gains of 30 to 40 db are realized over a simple pulse and 10 to 13 dB over a one second FM sweep of equal bandwidth, by extending the temporal coherent integration time. One has the energy of CW with the resolution of a pulse. The Hadamard transform and a linear temporal doppler search algorithm reduce the computational burden. There are several advantages for barrier sonar and harbor defense. The additional gain can be used to reduce source levels to mitigate marine mammal concerns and to reduce power consumption for autonomous systems. The doppler processing shifts the detection problem from a reverberation limited to noise limited process. The sonar will operate best as a barrier when a target passes between source and receiver owing to the increase in target strength from near forward scatter (about 15 dB over direct backscatter). The approach is extended to S sources each transmitting one of a set of orthogonal m-sequences to R receivers thus producing M=SxR independent sonars operation over the same space. The validity of the approach is demonstrated for numerical experiments and for real ocean data collected for propagation experiments over a 10 km range in the Florida Straits. As an example, the return from a low doppler target is imbedded in a very large number of reverberation returns all with much higher signal level, 20 dB or more. As the zero doppler contributions are removed by CZ the doppler return from the target becomes detectable. In the example, the clutter background is reduced by 60 dB.

Acoustical Signature of a Diver in an Estuary Harbor Environment

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Stevens Institute of Technology is performing research aimed at the collection of acoustical parameters that are needed for the development of a diver detection system. According to the passive sonar equation the main acoustic parameters are: swimmer Sound Radiation Level, Transmission Loss and Noise Level. Knowledge of these parameters is necessary for the estimation of diver location and for the optimization of the detection system. Measurements of the diver radiation signal were conducted in the Stevens high-speed towing tank, and in the Hudson River. These preliminary experiments demonstrated that the primary source of the diver sound is associated with the mechanics and air flows of the diving gear. Less intensive, low frequency sound is produced by air bubbles exhaled by the diver. The spectra of acoustic noise in the Hudson River measured over a wide range of environmental conditions are also presented.

Measurements of the Target Strength and Radiated Noise of
Divers Wearing SCUBA Equipment

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It is a well known fact that terrorist organizations have been training individuals in basic SCUBA diving techniques. While most recent emphasis has been related to terrorist threats from the air, on land, or from the surface of the sea, both the Department of Defense and Department of Homeland Security recognize the potential for an attack by divers. The detection and engagement of a terrorist diver depends entirely on underwater acoustic technology. Most current diver detection systems, whether using passive or active sonar, rely on a limited amount of data related to the acoustic characteristics of the threat. Most systems are capable of detecting a swimming target in the water column at significant ranges. However, they are less effective at classification of the detected target as being a human diver. Multiple false targets become a limiting factor in the ability to reliably engage the perceived threat. The current classification algorithms are insufficient to reduce these false targets. Signal processing, based on knowledge of acoustic characteristics unique to the diver, will provide the key to algorithm development.

Recently, the Naval Undersea Warfare Center (NUWC) completed a series of measurements of the target strength and radiated noise of divers wearing commercial off-the-shelf (COTS) SCUBA equipment. The measurements were made in the anechoic pool at the NUWC Acoustic Test Facility (ATF). The presentation will provide an overview of the measurement methodology and will describe the acoustic characteristics that may provide clues to target classification.

Bearing Estimation and Tracking for a Swimmer Defense Sonar Node of Slightly Overlapping Directional Transducers

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Although there are active sonar systems that have been developed specifically for detecting swimmers, they are generally very expensive and have limited range. A potentially less expensive approach is to deploy a larger number of nodes that are less capable than existing swimmer detection sonars and network them together. Instead of using a complex multi-element phased array with electronic beamforming, a recently developed node relies on a set of air-backed parabolic reflectors each with an omni-directional transducer to achieve narrow beams. This approach allows flexibility in the location and orientation of the search beams. To avoid performance degrading acoustic interactions and ambiguity in the origin of target echo signals, the available operating frequency band needs to be effectively managed among the channels on an individual node.

The physical configuration of the sonar node presents signal processing challenges for estimating bearing to resolutions less than a beamwidth and for tracking through and across beams. In our approach, the beam of interest's matched filter replica is also used on its two adjacent beams' receptions. The ratio of each cross-matched filter (left and right hand neighbor) to the center self-matched filter is computed at the ranges corresponding to a threshold detection. Because the target is large relative to the resolution in range, we can examine the distribution of these ratio values relative to our knowledge of the transducers' beampatterns. The distribution is compared between the right and left hand sides to localize the target within the beam.

Swimmers can exhibit low target strength and many swimmer defense installation sights reside in acoustic clutter fields that are dense and highly dynamic. To successfully detect and track swimmers in such an environment, we have employed a windowed Hough-Transform (HT) tracker. Previously, the HT has received wide use for track initiation. However, because of the processing gain required to continually track a weak target in such a significant clutter field, the HT is used in this case to maintain as well as to initiate tracks. The maintenance is accomplished by clustering and comparing tracks over a parameterized Hough-Space.

Multistatic Sensor Placement with the Complementary Use of Doppler Sensitive and Insensitive Waveforms

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Anti-submarine warfare operations are increasing challenged due to the quiet nature of current threat submarines, and the complexity of shallow water acoustic environments. Multistatic sonar has the potential to improve ASW operations by increasing detection range, area coverage, signal excess, target holding, and target localization.

An issue of main importance for multistatic operation is sensor placement. One of the main strengths of a multistatic sonar configuration is its inherent geometric diversity, which provides favorable, complementary detection opportunities among the multiple source-receiver pairs. This is further improved through the combined use of Doppler-sensitive and Doppler-insensitive waveforms. Through the combined use of sensor distribution and waveform diversity, a capable, robust surveillance network is achieved. The threat target's tactics will become much more complicated and constrained.

This report describes the underlying concepts that provide for this detection diversity, including the effects of the geometry, target strength, and Doppler behavior for bistatic geometries. The Q-function is described, which quantifies the Doppler performance of sonar waveforms in rejecting reverberation.

A simplified sonar equation model is described. It is then used to demonstrate and quantify the potential gains of multi-sensor, multi-waveform distributed fields. The use of both Doppler sensitive and insensitive waveforms is shown to provide complementary detection benefits. The combined signal excess for a multistatic network using diverse waveform types is shown to be higher, and cover larger areas than what is achievable with single sensor pairs or waveform choices. The modeling results suggest the relevant placement principles for distributed multistatic sonar surveillance scenarios.

The described modeling approach may also be relevant to and enable future work in: sensor placement/management optimization, intelligent waveform selections schemes within adaptive multistatic networks, multistatic fusion algorithms utilizing SNR-aided tracking, and simulation for multistatic tracker evaluation.

Synchronising Multiple Sonar Systems in Time and Space: Towards Accurate Contact Information for Multistatic Systems

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For automatic data fusion and (multistatic) tracking, accurate knowledge of the position of acoustic contacts is crucial. In order to have an accurate target position, the fundamental system parameters (such as sonar positions, time synchronisation between sonars, bearing estimates, sound-speed estimate) should be available as accurate as possible. Together with the NATO Undersea Research Centre and the Royal Netherlands Navy, TNO has carried out a number of experiments during the ADULTS 2003 sea trial. These experiments were meant to monitor the systems and evaluate the accuracies in the above fundamental parameters. On top of that, accurate measurements were done on the constant system parameters, such as time latency in the source, time latency in the receiver, position GPS antenna on ship, zero point (in position) of beamforming, and zero point (in time) of matched filtering. The analyses of the experiments resulted in realistic estimates of the errors in sound-speed, source position, source layback, receiver position, bearing accuracy, time latency of source and receiver. More important, we were able to get a 'consistent' system in terms of all positions and time labels.

Even for perfect measurements of the sonar positions, sound speed, bearing, and time synchronisation, some important effects have to be taken into account in order to transform the measured quantities (time,bearing) to geographic positions (longitude,latitude). These effects are:

- include source and receiver movement during ping

- include possible time-Doppler coupling for FM pulses

- convert from position/direction relative to receiver to position/direction relative to tow ship

- convert from position/direction relative to tow ship to (longitude,latitude).

All four steps are not trivial, in general. We have derived explicitly the formulas to apply all effects. These are included in the TNO postprocessing software STARE.

The estimates of the relevant parameters, together with the accurate formulas to transform from measurements to positions, are used in the analyses of the ADULTS 2003 experiments. During the workshop we will demonstrate the accuracy of the alignment of contacts, observed with different source-receiver pairs, for a few experiments.

Progress in Multistatic Sonar Tracking for Undersea Surveillance

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Multistatic sonar networks have the potential to provide an effective undersea surveillance capability, by introducing high contact data rates, area coverage, geometric diversity, and the possibility for covert receivers. In order fully to exploit the potential of these networks, it is important to develop effective techniques for sensor fusion and target tracking.

Research in multistatic tracking at NURC is supported by an ongoing sea trial program and has led to the development of the distributed multi-hypothesis tracker (DMHT). This tracker has the following key features:

1. It accounts for system and measurement uncertainties (including source and receiver locations, sound speed, receiver array orientation, and contact time and bearing information);

2. It includes logic based track management, recursive nonlinear filtering, and efficient LP-based track-oriented multi-hypothesis data association;

3. It allows for a number of tracking modules to be utilized in a flexible multi-stage (distributed) fusion architecture.

We have quantified the superior performance of the DMHT relative to a (single-module) MHT and a (non-MHT) baseline tracker, with both simulated and sea trial data that does not exhibit detection redundancy. Additionally, we have developed a simple tracker performance model that predicts tracker performance as a function of contact data characteristics, tracker architecture, and tracker parameter settings. This model is useful in understanding tradeoffs in tracker architecture design and parameter settings.

Ongoing multistatic research at NURC is focused on the following:

1. Further evaluation of the MHT and DMHT trackers with sea trial data. Initial results indicate that in benign environments with detection redundancy the performance of the trackers is comparable. As the false alarm rate increases with detection redundancy, the DMHT is challenged relative to the MHT due to the inability of the single-sensor trackers to handle a high level of false contacts with a low ping repetition time as compared with the MHT. Conversely, the MHT is challenged relative to the DMHT as detection redundancy is lost.

2. Sensor management and adaptive processing. We are exploring sensor placement algorithms to optimize localization and detection performance, waveform selection and adaptive SNR thresholding of contact data based on current active track information, and an interacting multiple-model (IMM) approach to adaptive estimation of target maneuverability.

3. Feature-aided tracking. We are enhancing our DMHT tracker to exploit single-ping classification information based on contact statistical features, as well as to exploit correlations over time in contact features.

4. Data registration. In addition to system calibration and data registration with known scatterers and direct blast arrivals, we are exploring real-time bias correction techniques based on our distributed tracking architecture.

Probabilistic Multi-Hypothesis Tracking for Distributed
Active Sensors

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The Probabilistic Multi-Hypothesis Tracking for Active Sonar (PMHTAS) algorithm is a batch type method for tracking multiple maneuvering targets in clutter using a single active sensor. The purpose of the effort reported here is to extend the applicability of PMHTAS to distributed multi-static active sonar applications. There are several issues that are unique to multi-static tracking: data registration, sensor coverage, and target aspect effects. True multi-static target tracking requires that the data from different receivers be registered to a common frame of reference. Recent improvements in active sonar buoy receivers offer the possibility of significantly improved data registration. The PMHTAS algorithm is based on the Bayesian assumption that the prior probability of each measurement being from a target of interest is known. Within the coverage area of each sensor a target will present a range of aspect and Doppler values. Over time a target will likely move from the coverage area of one receiver to another. Therefore, generalizing PMHTAS to the multi-static case requires the ability to model the coverage area of each source receiver combination and accurately estimate of the probability of detection within each coverage area as a function of target aspect, target Doppler, and the prevailing environmental propagation and reverberation conditions. The existing PMHTAS algorithm includes schemes to adapt the distributions for clutter and target echo amplitude to the observed reverberation and target Doppler. The extensions of PMHTAS to contend with multi-static tracking issues described above along with performance results on simulated data will be presented.

Distributed Environmentally-Adaptive Detection, Classification, and Localization Using a Cooperative Sensor Network

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We are developing algorithms for environmentally adaptive sonar signal processing using a distributed network of active acoustic sensors. In particular, we are investigating distributed detection, classification, and localization (DCL) algorithms incorporating environmental inversion. Knowledge of the environment can lead to more accurate state estimation of a target's position and velocity. The goal is to develop a joint parameter estimation process, wherein both target parameters and environmental acoustic parameters (primarily bottom geoacoustic) are estimated. The methods will be suitable for application to the nonlinear inversion problems encountered in ocean acoustics, and will be nested within a cooperative sensor network system concept. We are also investigating the problem of placing sensors to maximize DCL performance in spatially and temporally varying environments based on a priori environmental information, and transmit strategies that maximize the likelihood of holding tracked targets in a distributed sensor field constrained by the need to maintain some minimal level of DCL performance in the rest of the field.

Robust Detection in Nonstationary Noise

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This work presents a theory for beamforming and detection in nonstationary noise. A Bayesian analysis results in new procedures to estimate adaptive weights and perform weak signal detection in a non-stationary noise environment. The weight estimation procedure can be viewed as a robust regression procedure that results in an M-estimator for the adaptive weight vector. The accompanying weak signal detection test can be viewed as a temporally weighted energy detector, with a data-dependent temporal weighting that is computed recursively.

Simulation results indicate that the resulting detection performance is superior to adaptive processing systems that do not explicitly account for nonstationarity. Signals that are virtually undetectable by standard means in non-stationary environments are reliably detected. An independent comparison of this system with other techniques (adaptive beamforming, derivative-based updating, others) is underway, and first results are very positive.

The processing for the new system is recursive, and does require more computational resources than accepted techniques. However, run times appear to be acceptable, and real time implementation appears to be possible.

A key question for any robust technique is the performance penalty when nominal conditions (stationary noise) apply. The new theory generalizes the standard theory, and includes the stationary condition as a special case.

[Ms. Khine Latt, RPS Program Manager, DARPA Advanced Technology Office]

Simulation of Adaptive Beamformers in Non-Stationary Interference

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The detection performance of several adaptive processors for low frequency passive sonar was simulated. The simulation represents the area of the Robust Passive Sonar (RPS) 2 experiment, in shallow water off California in September, 2002. The interference was generated by 100 moving merchant ships, randomly distributed over area with a realistic density. Each ship generated Gaussian noise. A normal mode model (ORCA) was used to simulate the coherent multipath propagation of the energy from each ship to each element of an 88 element twin-line towed receiver array. Narrowband results in a selected frequency bin were generated at a one second rate for a total of 800 seconds. At each second, the ships were moved at realistic speeds, and propagation was recalculated from the new ranges. The result was a realistic simulation of a time series of NB snapshots of non-stationary array data. A quiet moving source was also simulated in the same manner. One hundred different realizations of the target source location were performed. Source detection was quantified by the deflection ratio averaged over the target locations. The same simulated data were used to compare performance of a variety of processors with a conventional beamformer. The base-line RPS case was a white noise gain constrained ABF. This used a reduced rank approximation. The rank was varied from 5 to full rank (88). Two cases were simulated depending on the number of snapshots in the covariance average. The snapshot deficient case used the number of snapshots equal to the rank, while the snapshot rich case used 4 times as many snapshots. As expected, the snapshot deficient case exhibited significant estimation bias, producing large apparent gains in reducing the mean noise. However, the noise variance remained high, so the deflection ratio exhibited much less gain. Performance of the baseline ABF was compared to a few processors that explicitly account for non-stationarity. Derivative based updating [1] (DBU) was found to perform lower than the baseline. It can be shown that DBU has an increased estimation variance, which may account for this loss. A covariance spectral filtering [2] approach was found to achieve improved detection over the baseline ABF. A new normalized time window method [3] also demonstrates improvement above the baseline.

[1] Zatman, M., *Performance Analysis of the Derivative Based Updating Method*, Proceedings of Adaptive Sensor Array Processing Workshop, 2001

[2] Newhall, B.K., *Covariance Matrix Filtering for Adaptive Beamforming with Moving Interference in Shallow Water*, IEEE Underwater Acoustic Signal Processing Workshop, October, 2001

[3] Earp, S.L., *Theory of Robust Beamforming in Non-Stationary Noise*, Multisensor Science, LLC Report, April 2, 2005.

Accurate Rectangular Window Subspace Tracking

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A new $O(nr^2)$ subspace tracking algorithm which gives accurate estimates of the r largest singular values and corresponding left singular vectors of overlapping rectangular matrices is presented. This algorithm has evolved from the Fast Approximate Subspace Tracking (FAST) algorithm by Real, Tufts, and Cooley, but has significantly better accuracy and computational efficiency.

When there are abrupt changes in data, or the data is changing rapidly, a rectangular window can often give better performance than an exponential window because it can limit exactly how much older data is included. Additionally, some methods for estimating the signal subspace dimension require the singular values of the strong subspace. This algorithm can update the r largest singular values and corresponding left singular vectors in $O(nr^2)$, where n is the number of channels and r is the dimension of the strong subspace that we are tracking. There are no assumptions made about the strong subspace, but the accuracy of our singular vector and singular value estimates is related to the separation between the strong "signal" subspace and the weak "noise" subspace, which is just the signal to noise ratio.

In this presentation we give an analytical explanation using the rank-two secular equation, of why this algorithm is accurate, and show how it can be used to track a strong subspace. We will also show some variations of the algorithm which are practical for use in a real-time system.

Multi-Rank MVDR Beamforming

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The underlying assumption in most of the literature on adaptive beamforming is that the signal covariance matrix has rank one and can be represented by a steering vector. In practical applications in underwater acoustics using long towed arrays, this assumption is frequently violated due to motion of the target, or the array itself, and multi-path propagation in which a signal is spread over multiple beams. Exceeding the coherence length supported by the medium also leads to increased signal rank. A related problem occurs when the signal is actually rank one, such as coherent multipath, but knowledge about it is best described by a multi-rank subspace. A generalization of the classic MVDR approach is examined. The optimization criteria is the minimization of output power subject to the constraint that any signal in a specified multi-rank sub-space is passed without distortion. The structure that results looks like several parallel coupled adaptive beamformers whose number is equal to the dimension of the subspace. Summing the power across these outputs is an estimate of total power in the specified sub-space. The distortionless constraint permits a variety of coherent and incoherent processing approaches to be performed on the beamformer outputs. An approach to using multi-rank MVDR as a preprocessor and the estimating the rank and location of the signal is presented. A multi-rank generalized sidelobe canceler formulation is presented and discussed. After deriving the basic results, the realistic situation with limited snapshot availability is examined. Simulations are used to examine the effectiveness of the multi-rank approaches and compare with rank one methods currently in use. For example, when a signal is spread across multiple beams one could consider averaging or OR-ing across multiple rank one adaptive beamformers. However each of these would suffer mismatch and signal suppression that cannot be recovered by incoherently combining them. Specific situations examined include coherent and incoherent multi-path, moving target, and nearfield sources. A new detection statistic is presented for the situation in which signal-free snapshots are not available.

Fading Channel Capacity and Passive Sonar Resolution

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Passive sonar algorithms process the pressure field observed at an array of hydrophones and estimate the location of the acoustic source from the pressure observations and knowledge of the acoustic environment. Historically, the performance of passive sonar algorithms has been quantified in terms of the mean squared error between the estimated source location and its true location. An alternative perspective is to divide the search region in disjoint partitions, then attempt to assign the source to the correct partition with the minimum probability of error (P_e). Within this perspective, information theory provides important necessary conditions characterizing the tradeoff between the SNR and the number of partitions if the sources are to be assigned to the correct partition with arbitrarily small P_e. Previous work [Buck, IEEE Proc. SAM 2002] described how to compute these performance bounds for a given environment and array geometry.

   A shortcoming of the approach described in [Buck, IEEE Proc. SAM 2002] was that the source level was presumed to be known. In practice, the absolute level of the acoustic source would not be known. This restriction can be mapped onto the fading channel problem in communication theory. Recent results [Abou-Faycal *et al.*, IEEE Trans. Info. Th., May 2001] presented upper bounds on the channel capacity for a fading channel. For the SNRs typical in passive sonar, there is much less mutual information available for the unknown source level scenario than the previously presented known source level scenario. This implies substantially less resolution is possible while achieving arbitrarily small P_e. Results will be presented contrasting the unknown source level case with the known source level case for single-frequency stationary sources in typical shallow water environments.

Rate Distortion Theory Bounds on Passive Sonar Performance

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Information theory provides a novel perspective on the performance bounds for passive sonar. Classical approaches use the minimum mean squared error to bound passive sonar performance. In contrast, the information theoretic approach begins by partitioning the search space and then considers the problem of assigning an unknown source to the correct partition based on pressure observations from a hydrophone array. The goal is to assign the source to the correct partition with the minimum possible probability of error (P_e).

Prior work [Buck, Proc. IEEE SAM Workshop, 2002] described necessary conditions for achieving arbitrarily small P_e as a tradeoff between SNR and the range extent, or resolution, of the partitions. This paper presents a method to extend these results using rate distortion theory to find necessary conditions for any P_e, not just arbitrarily small ones.

For a given partition, rate distortion theory provides an algorithm to calculate the minimum required information rate in order to achieve the desired P_e. The Gaussian channel capacity sets an upper limit on information rate received at the array, which implies a lower bound on P_e for a given partition. For a given environment and array geometry, the Gaussian channel capacity is determined by the SNR. Thus this method describes the tradeoff between the range resolution, SNR and P_e. Specifically, for a desired range resolution, this method provides the minimum achievable P_e for a given SNR, or the minimum SNR to achieve a given P_e. Examples of these bounds will be given for typical shallow water environments.

Passive Sonar Performance Prediction using a Moving
Source of Opportunity

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This paper concerns the use of a moving source to predict passive sonar detection performance. Reception from a known source of opportunity (SO) provides the ability to estimate transmission loss (TL) and fully-coherent array gain (AG), two critical parameters in the sonar equation. However, source motion complicates this measurement because the resulting space-time signal wavefront can change significantly over the observation interval. In this paper, a methodology is presented for estimating TL and fully-coherent AG based on using the eigenvectors of short-time averaged array covariance matrices which have maximum projection onto hypothesized SO steering vectors. These eigenvectors are then used to beamform the SO and form estimates of TL and AG. Averaging these estimates over time and frequency is performed as determined by the spread in phase and group velocities in the multipath channel. Given TL and fully-coherent AG, the detection performance of other processors can then be predicted. In this paper, the probability of detection versus SNR is predicted for the adaptive matched subspace detector (AMSD). The AMSD with assumed multi-rank signal wavefront and unknown noise covariance matrix can be expected to upper bound the performance of practical adaptive sonar detectors. Detection performance achieved with experimental test data (not used in the process of estimating AG and TL) is compared with theory. The results show excellent agreement for cases where the rank of the detector accounts for uncertainty in the signal wavefront and sufficient integration time is available to estimate the noise covariance matrix. Theory versus real data comparisons are made using both the single source and interference dominated scenarios.

A Simulation Package for Autonomous Underwater Vehicle Signal Processing

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A set of MATLAB routines which simulate the behavior of autonomous underwater vehicles (AUVs) operating in a collaborative mode is described. The vehicles in the package consist of one or more contacts and one or more AUVs. The AUVs are equipped with line arrays. At each time step the simulation moves the contact(s) along prescribed routes, which can contain any number of prescribed turns and speed changes. The radiated noise of the contacts to each of the AUVs is modeled via straight line ray acoustics. The received signals at the AUVs are beamformed, detections are declared, and bearing tracks from a simulated beam interpolation contact follower are begun. After initial detection, each AUV executes a turn to determine which side of the AUV the contact is on. The trackers then continuously track the contact(s). The trackers are stabilized against array pitch and yaw, which can be set at any desired level.

After suitable track has been declared, the AUVs communicate their bearing information to each other and a Kalman filter based localization algorithm is initiated. The localization algorithm estimates the current position, course and speed of the contact(s). Based on the relative bearings to the AUVs and the overall geometry the AUVs decide on the best maneuvers for them to jointly prosecute.

Results for different signal to noise ratios, relative vehicle speeds, and optimization strategies will be presented.

Filtering Strategies for Measuring the 2-D Spatial Structure
of Elastic Scattering from Buried, Liquid-Filled Symmetric
Objects

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Reliable classification of buried mines and objects is a much sought-after capability by the Navy. Buried objects are hard to classify because of absorption of the acoustic signal by sediments and strong interference from seabed reverberation. One potential feature is the frequency domain resonances due to quasi-periodic shell-borne waves [1,2]. Although promising, frequency resonance-based methods are prone to corruption by reverberation because they are based on single channel time series measurements of the objects response.

A new approach under study here considers the use of the unique 2-D spatial structure of Lamb-type wave and internal reflection scattering associated with symmetric objects for classification. Work in [3] showed that manmade symmetric buried objects can support Lamb-type waves in the low frequency regime with a semi-coherent 2-D spatial structure that is consistent with their structural symmetries and therefore in principle could be used for classification. Preliminary in-water experimental results with a buried air-filled sphere suggest that the Lamb-type wave spatial structure can be extracted and enhanced from seabed reverberation using a line array and space-time filters designed to take advantage of the semi-coherent spatial structure of these elastic waves [3].

Starting from the previous work, we present in this paper an analysis of new data that was recently collected at the NUWC acoustic test tank to measure the spatial structure of the Lamb-type wave and internal reflections from a fluid-loaded, liquid-filled sphere. A beach stone of roughly the same size and shape was also measured and used as a false target. We describe the scattering theory and experimental data and show that the wavenumber-frequency spectrum of the sphere's elastic and internal reflection components are highly concentrated and therefore can be exploited for 2-D filtering to enhance these waves from reverberation. Motivated by the new experimental results, we develop filtering strategies based on 2-D filters and time-frequency representations and determine the achievable performance. Finally, we discuss the effects of object imperfections on the spatial characteristics of these waves and relate our results for the idealized targets to mine-like targets.

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Comparison of Two Model-based Echo Processing Schemes for Man-made Object Recognition; Application to a Tank Experiment Data Set

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The paper deals with wideband classification of sonar echoes in order to reduce the false alarms. The problem addressed is the discrimination between a man-made object (shell) and a natural one (solid) of the same shape. An experimental database including both shell echoes and the clones' ones has been built up (one response for each degree, leading to a data base of more than a thousand echoes). The model target is a cylinder with spherical end caps. Frequency range has been optimized for exciting the so-called coincidence pattern. First, a time-frequency analysis is used to understand echo formation mechanisms. Then wideband echo models are applied in order to represent the echoes with a reduced set of relevant parameters:

1. a global spectral approach using Autoregressive modeling of target impulse response

2. a target model based on generalized bright spots inspired from the time-frequency structure of the echoes.

Two classification methods have been tested; K nearest neighbor and neural network. For both methods, a randomly selected set of echoes is used for training and the remaining for classification. A recognition rate as high as 98% was obtained from a single ping in the absence of noise. The robustness of the processing to both noise and Doppler effect is then investigated.

Baseline Classification of Acoustical Signatures of Mine-Like Objects

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In the classification analysis of wideband sonar signals the temporal (or frequency or time-frequency) characteristics of the backscattered signal are considered. It is hoped that the elastic-structural response of manmade mines is significantly different than that of natural occurring objects such as rocks and hence will provide useful information for distinguishing mines from clutter. Such an approach can be seen as an addition to the spatial acoustical image analysis usually used with a high-frequency narrow-band sidescan sonar.

We investigate a typical situation where one has a very general knowledge of possible mine types but insufficient detailed knowledge of the respective wide-band acoustical signatures. In such a situation it may easily occur that a classifier that has been trained using a limited set of acoustical signatures, fails when a new mine type is encountered. To address such a problem, one has to answer two questions: 1) is it at least possible to identify a new object as lying outside the range of applicability of the classifier (i.e. detect novelty)? 2) is it possible to successfully classify objects from a new class not included in the training set? A satisfactory answer to these questions would make it possible to use a classifier that has been trained using model-simulated signatures, in real field experiments.

As an example of a data set of mine-like and non mine-like objects that includes the required diversity of mine types, we use analytical models for elastic shelled spheres and for infinite elastic shelled cylinders. We use a total of 9600 spectra. The spectra can be divided according to their shape, shell material, filling, relative thickness, and surrounding environment into eight types of mines and non-mines. The boundary between mines and non-mines is defined by the relative thickness of shells and it is found that a threshold of 3.5% is optimal for classification purposes. The objects with shells thinner or equal than 3.5% were defined as mines, whereas the rest of shells were defined as non-mines. The overall classification accuracy varied from 77 to 92%. It was found that not including certain mine types in the training set led to the failure of the classifier.

Long-Range Underwater Acoustic Communications Using a
Multi-Mode Decision Feedback Equalizer

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The underwater environment imposes challenging constraints limiting the effectiveness of long range Underwater Acoustic (UWA) communication systems. Two of the most severe constraints are: 1) the received Signal to Noise Ratio (SNR) is extremely low due to the long range from the source and 2) scattering due to internal waves increases the multipath spread, causing additional ISI. A successful long range UWA communications system must overcome these limitations.

Freitag and Stojanovic [L. Freitag and M. Stojanovic, "Basin Scale Acoustic Communication: A Feasibility Study using Tomography M-sequences", Oceans 2001, pp. 2256-2261.] demonstrated 37.5 bits/second communication capability with signals collected during the Acoustic Engineering Test (AET). The AET experiment had a 75 Hz source and a 20 channel receiving array separated by a distance of $\approx$ 3250 km. Due to the low received SNR and large channel spreads, a 20-channel Decision Feedback Equalizer (DFE) designed with a 180-tap filter on each channel was required. While it successfully equalized the AET signals, a multi-channel DFE with a total of 3600 taps is a computationally complex algorithm to implement.

This paper proposes a multi-mode DFE with lesser computational complexity than the multi-channel DFE. The new approach uses a set of spatial filters to reduce the received pressure field to a set of propagating modes for the DFE to operate on. An individual mode signal has less spread than the received signal on a single channel, which consists of a sum of modes. Lower spreads require fewer taps, meaning a significant reduction in complexity. This paper presents results of testing the multi-mode equalizer on tomographic signals collected during the 1998 North Pacific Acoustic Laboratory (NPAL) billboard array experiment. During the NPAL experiment a 75 Hz source near Kauai transmitted M sequence signals to a 40-channel receiving array at a range of 3900 km. The received signals have exceptionally low SNR due to the proximity of shipping lanes and have large multipath spreads. This paper demonstrates that the multi-mode DFE, using only a subset of modes, can successfully equalize the received signal. Initial results indicate that the mode equalizer can achieve a 7.5 bits/second rate in the noisy NPAL environment. This paper calculates the average bit error rate achievable using different subsets of modes and compares the results with the multi-channel DFE.

Bounds on the Performance of Nonparametric
Detectors/Normalizers Operating on Square-law Data

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Since the work of Capon in 1959 engineers have continued to apply nonparametric statistical tests to the problem of detecting signals in noise. Such tests are most useful when noise powers and distributions can change with time as in active sonar and radar. We briefly summarize and chronicle various methods that have been proposed for the problem of detecting fluctuating targets in noise of unknown distribution. Specifically, detectors operating on the post-matched-filtered square-law output are considered. These detectors are always compared to the Cell-Averaging Constant False Alarm Rate (CA-CFAR) detector [1,2] under the important case where the noise is Gaussian with unknown power and target echoes are Swerling I (or II) distributed for which CA-CFAR is optimal [3]. The extra SNR required to meet CA-CFAR performance (P_d and P_{fa}) is termed CFAR loss.

The historical belief is that a Uniformly Most Powerful (UMP) nonparametric test that minimizes CFAR loss in the aforementioned nominal scenario cannot be constructed. Such a test, based on Lehmann's Alternative [4] can be constructed. The structure and performance of this test will be described and its connections to other tests will be briefly explored.

[1] H.M. Finn and R.J. Johnson, *Adaptive detection mode with threshold control as a function of spatially sampled clutter-level estimates,* RCA Review, Vol. 29, pp. 414-464, September 1968.

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[3] P.P. Gandhi and S.A. Kassam, *Optimality of the Cell-Averaging CFAR Detector,* IEEE Trans. On IT, Vol. 40, pp. 1226-1228, 1994.

[4] E.L. Lehmann, *The Power of Rank Tests,* Annals of Mathematical Statistics, Vol. 24, March 1953, pp. 23-42.

Detection Enhancement Using Multiple Time-reversed Guide Sources in Shallow Water

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Detection in a monostatic, broadband, active sonar system is degraded by propagation-induced spreading. To mitigate the problem, a technique using multiple guide sources is investigated to improve probability of detection in noisy environments without explicit environmental knowledge. The approach is similar to that used in astronomy for detecting faint stars by observing the atmospheric aberration of brighter "guide" stars. In ocean acoustics, the guide sources can be any known broadband source. The technique was applied to echo detection during the 2004 Naval Research Laboratory Time-Reversal Experiment performed south of the Hudson Canyon off the coast of New Jersey. In this test, 0.25 sec LFMs were transmitted with 500 Hz bandwidths chosen over a 0.5–3.5 kHz range using the NRL 64 element source-receiver array. The transmissions were then echo-repeated by a ship at a range varying between 0.5–5 km. The echo-repeating ship also transmitted one-way, 1 sec, 1kHz bandwidth LFMs that were used as the guide-source signals. As the ship drifts, multiple guide source signals are received over a volume. These guide-source signals, which contain environmental information and characterize the propagation-induced spreading, form the basis of the technique for improving detection without having explicit environmental knowledge. Using an empirical-orthogonal-function representation of the set of monostatic guide-source signals, echoes are convolved with the time-reversed orthogonal functions as part of a filter bank. In this study, the probability of detection of noisy echoes using multiple guide-source (MGS) signals is compared with a baseline probability of detection using matched filtering. ROC curve improvement using the MGS filters is obtained using two different detectors. Significant gains in signal-to-noise ratio are obtained for echoes originating outside the volume where guide-source signals were transmitted and at significantly later transmission times than the guide source signals. Simulation results were presented for distances greater than those encountered in the experiment.

Synthetic Aperture Sonar (SAS) Processing for Improved Mid-frequency Active Multi-ping Classification

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We have designed and developed active SAS-based imaging features to aid in discriminating between persistent mid-frequency active sonar clutter and target tracks. These physics-based features are intended to enhance single- and multi-ping classification algorithms to reduce overall system false alert rates by leveraging the improved cross-range resolution of the synthetic array. The feature set emphasizes cross-range measures derived from the centerline cut through and the unaliased region around the prominent points in measured and replica SAS images, and from dynamic measures off these images as the ping count increases. Discrimination capability will be shown.

　　The input to our environmentally-adaptive SAS processing is spatially under-sampled, beamformed data that are collected without applying speed constraints to own-ship motion. In this presentation, we will also describe the two-stage ping-to-ping cross-correlation method for signal adaptive motion compensation and auto-focusing. For simple classification feature extraction at constant range, the images are then formed on a polar coordinate grid, which in turn allows for straightforward separation of the multipath components in the image from the effects of cross-range resolution and aliasing. Our objective is not to create pleasing images, but to extract information contained in the images and from the image formation process to provide accurate class discrimination.

Hybrid Joint PDF Estimation and Classification for Sparse Systems

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We present novel methods for estimating joint probability density functions (PDFs) of statistically dependent features with a focus on sparse data with planned application for general statistical interest and for computing likelihood functions for feature-based classification. The estimators involve a new class of hybrid models — combinations of estimators with minimal assumptions regarding the nature of the underlying data. The efficacy of our methods to model PDFs and to classify data sets will be presented for simulated and actual data from a variety of fields. We consider two general forms for the PDFs. 1) Semiparametric models: $\Pi_i p_i(f_i)[M_N(\mathbf{f})/\Pi_i M_i(f_i)]$, where f represents a set of N features; $p_i(f_i)$ are the marginal probabilities, and $M_N(\mathbf{f})$ is a model for the N-dimensional multivariate PDF including feature correlations with model marginals $M_i(f_i)$. 2) Expansion models: the multivariate PDF is expanded in terms of its better-sampled pairwise correlations, $\Pi_k p_k(f_k)[1 + \sum_{i<j} \xi_{ij}]$, with the 2-point functions defined as $\xi_{ij} = p_{ij}(f_i, f_j)/p_i(f_i)p_j(f_j) - 1$. We also present an adaptive PDF estimator, *pdfzoid*, for evaluating PDFs at selected locations with no assumptions about the underlying data apart from local estimates of scale (covariance ellipsoids). Its general utility and impact on the aforementioned models are presented. In all cases we present the successes and failures of the models and the necessary modifications to them such as smoothly mixing models. Preliminary results using active midfrequency sonar data for ASW (classifying target vs. nontarget) are presented.

Adaptive Processing for Range Dependent Propagation Studies

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Range dependent transmissions off the coast of Kauai were recorded during the Basin Acoustic Seamount Scattering EXperiment (BASSEX04) in September of 2004. Broadband transmissions (27 second M-sequence, 75 Hz center frequency) of the North Pacific Acoustic Laboratory (NPAL) source mounted bottom in 900m of water off the coast of Kauai were recorded using a 200m towed line array. The purpose of this portion of the test was to measure acoustic propagation in a strongly range dependent environment and examine acoustic propagation downslope over a basalt. Single element time-domain processing as well as frequency domain beamforming has been applied. The array is sparse at 75 Hz (half wavelength element spacing is at 250 Hz) so the conventional beam widths are large. The results of applying adaptive beamforming techniques to increase the beam resolution will be presented. The single element Signal-to-Noise Ratio (SNR) is on the order of 15 dB before matched filtering, so there are no issues of adequate SNR for adaptive beamforming. With such a strong single source, the spread in eigenvalues will be studied as an indication of the effect of motion, environmental variability and multipath propagation.

Wigner and Ambiguity Function Approximation Methods
for Acoustic Propagation

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An easily applied approximation method for underwater sound propagation will be presented. The approximation is formulated in terms of the classical ambiguity function as well as its 2-D Fourier transform, which is the Wigner distribution. The method is physically revealing and shows that the evolved Wigner distribution is approximately given by the initial Wigner distribution simply translated locally at each point in phase space. Propagation with energy dissipation (damping) is also taken into account. We further show that from the approximate Wigner distribution, the approximate magnitude and derivative of the phase of the acoustic wave may be obtained. Examples are given to illustrate the method. We discuss why the method may be particularly well suited to bottom-limited (shallow water) and broadband propagation. Exactly solvable examples are given to illustrate and quantify the method, with comparison to other standard approximations and the exact answer. Multidimensional and multi-mode approximations will also be discussed.

Propagation Path Data Fusion and Uncertainty Characterizations

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The Histogram-Probabilistic Multiple Hypothesis Tracking (H-PMHT) approach to tracking is a direct multitarget tracking method that eliminates data loss due to peak picking. It models the energy received on a beamformed sensor array as a superposition of source energies and background noise, allowing source-specific estimates to be formed. Extensions of the H-PMHT method have addressed mixed parametric/non-parametric state estimation problems. Of particular interest for volumetric arrays is the parametric tracking of peak source energy in azimuth angle and non-parametric estimation of the vertical angle energy distribution. This is of interest because the vertical angle energy distribution can be highly non-Gaussian and, in fact, multimodal while at the same time very informative regarding the target location in range and depth.

To exploit this capability to estimate the location of acoustic sources, an acoustic model has been developed to predict the vertical angle distribution of energy from a source at a given location in an underwater tracking environment. The resulting path dominance functions are used in conjunction with the H-PMHT output to develop a set of likelihood functions, articulated over source range and depth, that evaluate the match between predicted and received energy across vertical receive angle. Such likelihood function construction provides a data assessment capability readily incorporated into any target motion analysis algorithm to facilitate solution convergence. We give an overview of the H-PMHT method as applied to azimuth angle estimation and vertical angle energy distribution estimation, an overview of the acoustic modeling requirements for evaluating path dominance, and a discussion of candidate formulations for the desired likelihood functions. Simulated results will be used to demonstrate the utility of the vertical angle energy distribution as an information source for contact localization.

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Wednesday October 5, 2005		Thursday October 6, 2005		Friday October 7, 2005	
		8:00-9:15	Session B Laurel	8:00-9:45	Session G Laurel
		9:15-10:00	Session C Laurel	9:45-10:15	Break Laurel
		10:00-10:30	Break Laurel	10:15-12:00	Session H Laurel
		10:30-12:00	Session D Laurel	12:00-1:00	Lunch Whisp. Pines
		12:00-1:00	Lunch Whisp. Pines	1:00-2:15	Session I Laurel
		1:00-2:45	Session E Laurel		
		2:45-3:15	Break Laurel		
		3:15-5:00	Session F Laurel		
5:00-6:00	Welcome Reception				
6:00-8:00	OES Dinner Whisp. Pines	6:00-8:00	Raytheon Dinner Whisp. Pines		
8:00-9:30	Session A Laurel	8:00-?	SOB Session Laurel		