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14. ABSTRACT
The reports cover progress to develop a signal processing structure that exploits available knowledge of the environment and of signal and noise variability induced by the environment. The research is directed toward passive sonar detection and classification, continuous wave (CW) and broadband signals, shallow water operation, both platform-mounted and distributed systems, and frequencies below 1 kHz. The results of this research are expected to lead to new passive sonar detectors and classifiers that take advantage of knowledge of medium variability and uncertainty. The results are mainly applicable to passive processing. However, the active processor can be considered "a detector matched to the estimated ocean." These results could have significant impact on Navy sonar system applications.

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Underwater Acoustic Signal Processing

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LONG-TERM GOALS

The long-terms goals of this project are (1) to develop a probabilistic sonar system performance prediction methodology that makes use of limited knowledge of random or uncertain environment, target and sonar system parameters, and (2) to derive detectors and classifiers which are robust in random, fluctuating media. There is no single system application, but the focus is on frequencies below 1000 Hz. An overarching goal of this project is to employ graduate students and thus train future ocean scientists.

OBJECTIVES

FY05 was the first year of this project. Important objectives are to:

- Develop a method for constructing probability density functions (pdf's) from samples of random or uncertain environmental and signal parameters.
- Select ocean acoustic models for environmental parameters and propagation
- Investigate how to exploit knowledge of received signal variability in predicting signal processor performance.
- Derive the maximum likelihood (ML) detector for random/uncertain propagation medium and system parameters.
- Derive expressions for pdfs of the detection statistics of the ML detector.
- Compute receiver operating characteristic (ROC) curves for the ML detector.
- Find and begin work with three new graduate students.

A related project with more of an ocean acoustic focus was carried out during FY99 – FY04. An FY05 objective was to close out work that had begun in prior years.

APPROACH

The first three objectives were pursed in FY05. The approach is to:

- Utilize published models for oceanographic and ocean acoustic parameters.
- Apply the maximum entropy (ME) method to construct pdf's for random or uncertain environmental and sonar parameters.

- Employ a parabolic equation (PE) ocean acoustic propagation model to estimate received signal variability from environmental and sonar system variability
- Utilize the ME method to construct pdf's for received signal parameters.
- Calculate the pdf's of the detection statistics of the conventional processors.
- Compute receiver operating characteristic (ROC) curves that incorporate the detection statistic pdf for conventional signal processors and compare performance.

Figure 1 shows a block diagram of the approach. We begin by discussing the final bullet above (corresponding to the last blocks in Fig. 1) and then work backwards.

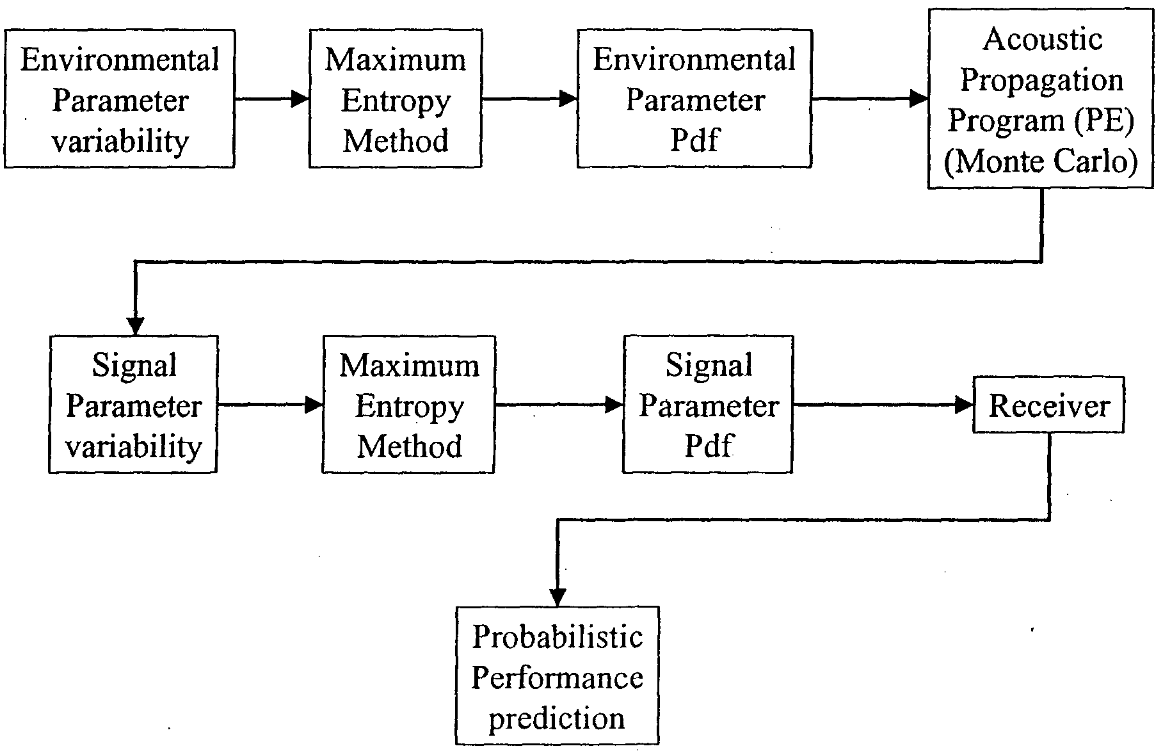

Figure 1. Approach to using knowledge of environmental variability to compute a probabilistic sonar system performance prediction.

Classic texts provide a framework for incorporating the received signal pdf's into the performance predictions for the energy detector and correlation (or matched filter) receivers (Van Trees, 2001, Vol.1; Whalen, 1995, Chap. 7). However, applying the framework can be challenging. The pdf's of the received signal under both hypotheses (H_1: received signal contains target signal plus noise; H_0: received signal contains only noise) are required. The received signal is a random variable with pdf p_0 under H_0 and pdf p_1 under H_1. Signal processing derivations often assume Gaussian noise and signal statistics in order to make the calculations tractable and obtain analytic results (e.g. Sha and Nolte, 2005). In contrast, the approach taken here is to assume Gaussian noise but utilize a signal parameter pdf that is calculated from knowledge of the sonar, the target, and the ocean medium. The detection statistic pdf is calculated from the noise and received signal pdf's, and the ROC curves are calculated numerically from the detection statistic pdf's. The final step is to present the sonar operator with a useful probabilistic prediction.

The ME method is employed to calculate pdf's for random quantities based upon available knowledge. Example quantities include sound speed and received signal amplitude. ME is an axiomatic principle that makes use of known data and information but is maximally noncommittal about what is not known or what is uncertain. Derivation of ME pdfs is formulated as a calculus of variation problem, where the ME pdf maximized Shannon's entropy (Shannon, 1948; Reza, 1961) under moment constraints. Moment constraints and range of the data represent known information. Shannon's entropy is a measure of uncertainty; maximizing the entropy produces a pdf that is maximally noncommittal about what is not known.

In general, published ocean acoustic parameter models relate the mean and (at best) the variance to the underlying environmental parameters. For example, a respected model for the spatial coherence of sound that has been forward-scattered by the ocean surface (Dahl, 2004) predicts mean spatial coherence as a function of the sea surface height correlation function, which can be calculated from the wind speed. Because available models do not fully characterize the pdf of ocean acoustic parameter, the ME method is used to calculate maximally uncertain pdf's.

The approach outlined here is being evaluated using environmental and acoustic data acquired during the Strait of Gibraltar Acoustic Monitoring Experiment (SGAME) conducted in April 1996 as a joint project between the Scripps Institution of Oceanography and the Institut für Meereskunde, University of Kiel, Germany (Tiemann, et. al. 2001).

The next three objectives will be pursued in FY06 and beyond. The approach here begins with the observation that ME pdfs derived from a fundamental principle and physical models encompass most of the density functions that are widely use in signal processing (Kapur and Kesavan, 1992). In particular ME pdfs belong to the exponential class or Koopman-Pitman-Demois class of densities (Lehman, 1986). This fortunate result leads to an efficient implementation of maximum likelihood detectors, in which the detection statistic is calculated by correlating the conditional mean estimates (CME) of the random signal and noise with received data. The CME of the noise statistic is used to implement an estimator-noise canceller. This part of the processor incorporates applicable noise characterization into processor. The processor that uses CME's of both random signal parameters and noise parameters can be called *a maximum likelihood processor for estimated ocean model.*

Co-PI Leon Sibul performed a key role in formulating the ME approach for modeling random signal and noise parameters, deriving the ML processor for detection of signals in random media, which is a generalized estimator-correlator and estimator-noise canceller structure, from a classic paper by Schwartz (1977), and in deriving mathematical expressions for pdfs of detection statistics. Graduate student John Camin began work on the project in January 2005, and had a key role in exercising the RAM PE acoustic propagation model; implementing the ME algorithm; and calculating sound speed profile pdf's from Strait of Gibraltar experiment environmental data. Graduate students Jeff Ballard and Colin Jemmott began work on the project during the summer, thus accomplishing the last objective.

WORK COMPLETED

The ME method for constructing pdf's from sample moments of a data set was implemented and applied to estimate (location and depth-dependent) pdf's of the sound speed profile (SVP) for the Strait of Gibraltar (SGAME) measurement. Matlab scripts were used to segregate SVP's into similar geographical areas, apply the ME method to estimate the depth-dependent pdf in each area, and interpolate the variability onto a regular range-depth grid suitable for numerical processing. The sound speed pdf's were used to generate statistically-valid realizations of the depth and range dependent SVP's. for the Strait of Gibraltar experiment. Each realization of the range and depth dependent SVP field was used in a Monte Carlo simulation using RAM PE. The ME method was used to generate a pdf for transmission loss (TL). Figure 2 shows some of the results.

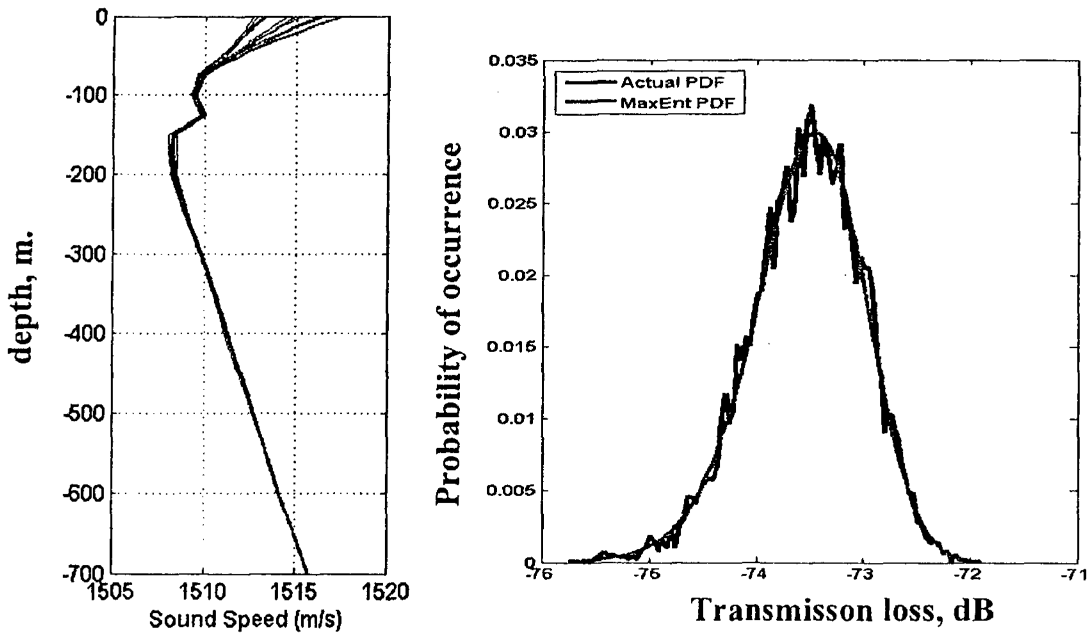

Figure 2. Use of the Maximum Entropy method to generate statistically-valid realizations of the sound speed profile (left) and transmission loss (left) using environmental data from the Strait of Gibraltar Acoustic Monitoring Experiment (Tiemann, et. al. 2001).

In order to evaluate the approach presented above, including the exponential distribution and ME method, the predicted TL pdf is being compared to the statistics of TL measured during the SGAME at 250 Hz. These results will be presented at the October 2005 Acoustical Society of America meeting in Minneapolis, MN.

To continue with the approach, the TL pdf's calculated using PE are being applied to compute detection statistic pdf's for matched filter and energy detector processors. ROC curves that take into account environmental uncertainty are then calculated from the detection statistic pdf's. Code has been written to utilize the TL pdf to compute the probability of detection (P_D) for a fixed probability of false alarm (P_{FA}) for the correlation receiver and energy detector receivers. These results will be presented at the October 2005 Acoustical Society of America meeting in Minneapolis, MN. Figure 3 shows P_D as a function of signal to noise ratio for fixed P_{FA} of 10^{-4} and using a transmission loss pdf like that shown in Figure 2.

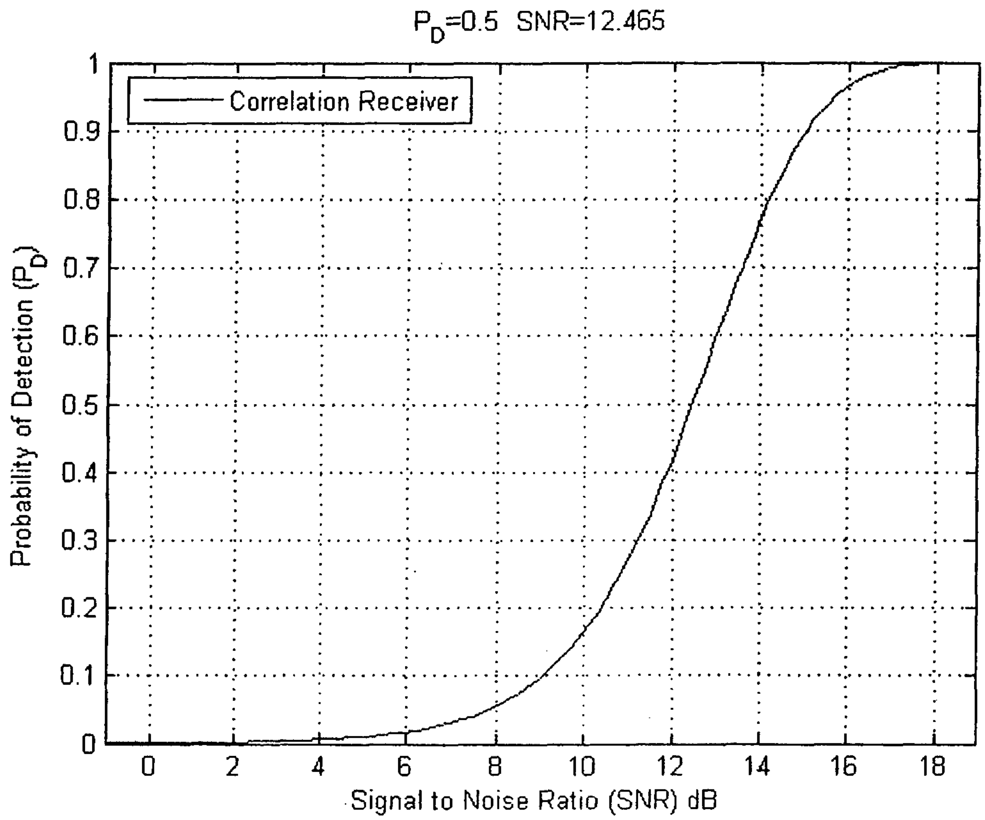

Figure 3. Predicted performance of a correlation receiver calculated using a transmission loss pdf like that shown in Figure 2. The P_{FA} is 10^{-4}.

Three efforts began under the preceding project were completed in FY05:

- Completion of research and publication of a Master of Science thesis on "Scintillation index of high frequency acoustic signals forward-scattered by the ocean surface" by graduate student Benjamin Cotté.
- Completion of a research and publication of a journal article on "On the relationship between signal bandwidth and frequency correlation for ocean surface forward scattered signals," by R. Lee Culver and David L. Bradley.
- Publication of previous research in "The use of multi-beam sonars to image bubbly ship wakes," by R. Lee Culver, Tom C. Weber, and David L. Bradley.

Citations are provided below in the section entitled "Publications."

Benjamin Cotte and Lee Culver presented papers at the November 2004 A
Society of America meeting in San Diego, CA:

- B. Cotté, D. L. Bradley, and R. L. Culver, "Scintillation index of c forward scattered HF acoustic signals: Beam pattern and pulse len
- S. D. Lutz, R. L. Culver, and D. L. Bradley, "Scintillation of short records."

Leon Sibul presented papers on the application of maximum entropy princ acoustics and inverse problems at the May 2005 Acoustical Society of Am in Vancouver, BC:

- L.H. Sibul, M.J. Roan and C.M. Coviello, " Signal processing tech inverse problems in stochastic propagation an scattering channels, in special session on Signal processing in Acoustics: Stochastic Si and Inversion.
- L.H. Sibul, R.L. Culver, D.L. Bradley, and H.J. Camin, "Maximum method for constructing environmental parameter probability dens

RESULTS

A significant insight gained in the past year is that pdfs obtained using ME lead to efficient, practical implementations of the maximum likelihood pro insight is significant because the maximum the likelihood formulation, in not lead to a practical, implementable detector (Kailath and Poor, 1998). U results from the signal processing literature, it has been shown that for ME the maximum likelihood detector can be implemented as a generalized est correlator together with a noise estimator-canceller. This is an important g previous results to a wide class of probability density functions. Previousl estimator-correlator was implemented only for Gaussian processors.

IMPACT/APPLICATIONS

The results of this research can lead to new sonar processors that take into medium randomness and uncertainty. The results will be applicable to both passive processing. The active processor can be considered "*a detector ma estimated ocean.*" These results should have significant impact on Navy s applications.

RELATED PROJECTS

The ONR Defense Research Initiative (DRI) on Capturing Uncertainty in t Tactical Environmental Picture
(http://www.onr.navy.mil/sci_tech/ocean/321_sensing/cuwg/default.asp)
This DRI, which completed in FY04, was concerned with including uncert associated with propagation channels, system parameters, and signal param performance prediction of sonar systems. The present project is concerned

issues and is drawing from progress made under the DRI. However, using ME principle to generate maximally uncertain pdfs is new and unique to the present project. Also, signal processing structures derived under this project were not considered in DRI. Sha and Nolte (Sha and Nolte, 2005) have analyzed and compared performance of a *matched ocean detector,* a *mean ocean detector* and an *unknown ocean detector.* In a similar vein, the detector developed under this project is termed the *estimated ocean detector.*

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PUBLICATIONS

Cotté, B. (**2005**). *Scintillation Index of High Frequency Acoustic Signals Forward-Scattered by the Ocean Surface,* (Master of Science thesis, The Pennsylvania State University, State College, PA).

Culver, R. L. and Bradley, D. L. (**2005**). "On the relationship between signal bandwidth and frequency correlation for ocean surface forward scattered signals," J. Acoust. Soc. Am. **118** (1), pp.129-138. (published, refereed).

Culver, R. L., Weber, T. C. and Bradley, D. L. (**2005**). "The use of multi-beam sonars to image bubbly ship wakes," Invited paper, *Proceedings of the 1st International Conference on Underwater Acoustic Measurements: Technologies and Results*, Heraklion, Greece, June 2005. (published, refereed).

REVEAL:
Receiver Exploiting Variability in Estimated Acoustic Levels

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http://www.arl.psu.edu/capabilities/rap_acoustics.html

LONG-TERM GOALS

The long-term goal of the REVEAL project is to develop a signal processing structure that exploits available knowledge of the environment and of signal and noise variability induced by the environment. The research is directed toward passive sonar detection and classification, continuous wave (CW) and broadband signals, shallow water operation, both platform-mounted and distributed systems, and frequencies below 1 kHz.

OBJECTIVES

The major FY06 objectives were to:

- Develop a method for estimating received signal and noise characteristics using physics-based models and in-situ measurements that describe ocean environmental knowledge and uncertainty.
- Develop a method for constructing probability density functions (pdf's) for signal and noise parameters from signal and noise ensembles.
- Derive the maximum likelihood (ML) detector for acoustic propagation through a random/uncertain medium.
- Compute receiver operating characteristic (ROC) curves for the ML detector and compare with standard sonar signal processors.

A related project with more of an ocean acoustic focus was carried out during FY99 – FY04. An additional FY05-FY06 objective was to finish documenting work begun in prior years.

APPROACH

General considerations. At-sea experience has shown that current passive sonar systems have difficulty distinguishing between targets and various interference and noise sources, especially in high shipping and industrial environments. To improve classification performance in a real ocean environment, the signal processor must incorporate knowledge of the deterministic component as well as the random or uncertain component of signal propagation and scattering. There is nearly always some level of environmental knowledge, e.g. water depth or historical sound speed profiles, and this knowledge provides a basis for predicting system performance. However, factors such as randomly distributed sound speed inhomogeneities, uncertainty regarding the boundary parameters, and lack of information about the source characteristics, lead to uncertainty and/or random variations in signal and noise parameters.

Physics-based models for environmental parameters and the effects of environmental variability on acoustic propagation and scattering have the subject of research for many years and results have been published in the open literature. More recently, significant progress has been made under the Office of Naval Research (ONR) Departmental Research Initiative (DRI) on Capturing Uncertainty in the Common Tactical Environmental Picture[1]. A second uncertainty DRI scheduled to begin in FY07 will contribute further knowledge. However, what is needed to apply uncertainly models and increased knowledge is a processing structure that incorporates available environmental knowledge as well as stochastic representations of signal and noise parameter uncertainty and variability. Such a structure would allow knowledge of environmental, target and sonar system parameters and parameter uncertainties to be incorporated into passive sonar detectors, estimators, classifiers and trackers. A key concept underlying the REVEAL project is that environment, target and sensor knowledge and uncertainty are inexorably intertwined with fidelity and uncertainty in signal processor outputs.

The approach to developing a signal processing structure that incorporates environmental knowledge and environment-induced signal and noise variability is presented in **Figure 1**.

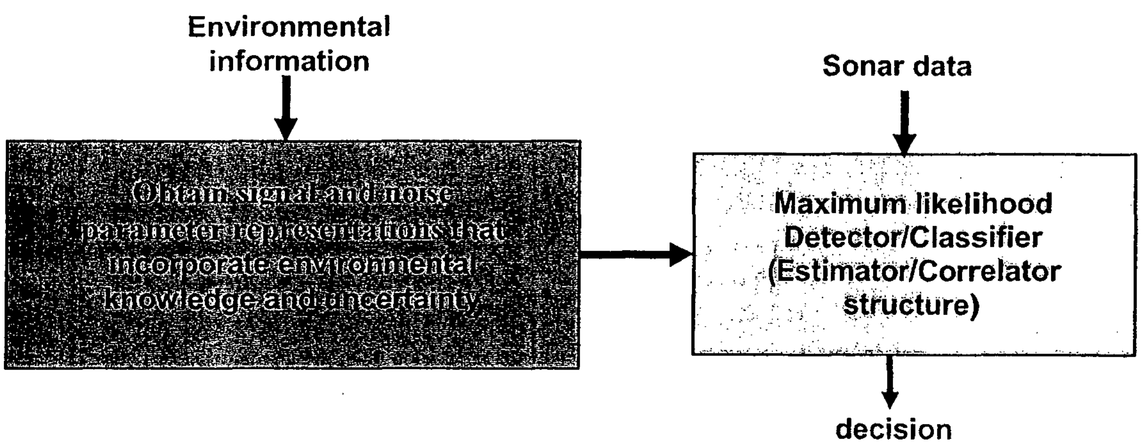

Figure 1: The REVEAL sonar signal processor which exploits environmental knowledge and a stochastic representation of environment-induced signal and noise variability.

A related point, though not the focus of this project, is that knowledge of signal parameters can be used to better predict sonar performance. More realistic performance prediction will result from incorporating knowledge of the environment and of environmental variability (e.g. sound velocity, bathymetry and surface roughness variability) into the acoustic predictions.

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[1] http://www.onr.navy.mil/sci_tech/ocean/321_sensing/cuwg/

received signal pdf's, and the ROC curves are calculated numerically from the detection statistic pdf's. The final step is to present the sonar operator with a useful probabilistic prediction.

The ME method is employed to calculate pdf's for random quantities based upon available knowledge. Example quantities include sound speed and received signal amplitude. ME is an axiomatic principle that makes use of known data and information but is maximally noncommittal about what is not known or what is uncertain. Derivation of ME pdfs is formulated as a calculus of variation problem, where the ME pdf maximized Shannon's entropy (Shannon, 1948; Reza, 1961) under moment constraints. Moment constraints and range of the data represent known information. Shannon's entropy is a measure of uncertainty; maximizing the entropy produces a pdf that is maximally noncommittal about what is not known.

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Co-PI Leon Sibul performed a key role in formulating the ME approach for modeling random signal and noise parameters, deriving the ML processor for detection of signals in random media, which is a generalized estimator-correlator and estimator-noise canceller structure, from a classic paper by Schwartz (1977), and in deriving mathematical expressions for pdfs of detection statistics. Graduate student John Camin began work on such as non-stationarity, spectrum shifts and spreading that are caused by time-varying systems. These results can be derived using linear system theory as discussed above.

The Bayesian approach incorporates random uncertainties in the environment, target and sonar as *a priori* pdf's, which are then incorporated into the signal processor (Haralabus et.al., 1993; Premus et. al., 1995; Richardson and Nolte, 1991). The critical issue of the Bayesian approach is how to obtain valid a priori pdf's. We propose obtaining them using MaxEnt method (Jaynes, 1968, 1982; Kapur and Kesavan, 1982; Kapur, 1989; Burg, 1967).

The model-based processor (MBP), as investigated by Candy and Sullivan (Candy and Sullivan 1995a, 1995b, 1994; Candy 1986), is a version of the matched field processor that utilized the normal-mode acoustic propagation model in state-space form. In this research, we will not consider matched field processing, but will incorporate several distinct advantages offered by the MBP: recursive implementation, inclusion of both noise and parameter uncertainties, relaxation of the assumption of stationary statistics, ability to estimate environmental parameters, and capability to monitor its own performance. Burkhardt (1992) has investigated robust adaptive processing for application to underwater acoustic array processing. His work is applicable to a wide class of robust signal processing techniques in uncertain acoustic channels. Williams (1989) has investigated robust signal subspace techniques for direction of arrival estimation in multipath environment.

Stochastic operator theory, dynamic modeling of uncertainty, and sequential estimation theory provide a theoretical formalism that is derived from fundamental physical principles and probabilistic characterizations of signals propagating through stochastic channels. In most cases, these approaches require more complete knowledge, e.g. a pdf, than is usually unavailable. The Maximum Entropy (MaxEnt) method uses the knowledge or data that is available, but is maximally noncommittal of what is unknown. The MaxEnt method is a well-developed scientific method that has been applied to many problems in physics, engineering, spectral estimation and Bayesian estimation. Our proposed application of this powerful method to signal processing in random/uncertain channels is the first of this type.

Recently there has been renewed interest in exploitation of environmental information for improvement of performance of detectors, estimators and classifiers. Abraham and Willett used the Page test for improved detection of time-spread active echoes (Abraham and Willett, 2002). Sun, Willett and Lynch fused constant frequency and linear frequency modulated signals to improve detection of reverberation-limited targets (Sun et. al., 2004). Proakis (2004) showed that using a sequentially estimated channel impulse model for the acoustic multipath channel reduced the bit error rate of a communication system by an order of magnitude.

WORK COMPLETED

There were two thrusts in FY06: (1) development of a method for predicting signal and noise statistics (deterministic and uncertain components) from available knowledge of the environment and environmental variability, and (2) derivation of a maximum likelihood detector capable of incorporating signal and noise statistics. Progress in these two areas is described in this section.

Predicting received signal and noise deterministic and uncertain components. Although knowledge of environmental parameters may be incomplete or uncertain, we have developed a method for obtaining parameter distributions that incorporate all available knowledge but do not make unwarranted assumptions, i.e. assumptions that are not justified by physical models, available data or known constraints (Camin et. al., 2006). Available knowledge of the environment is used with an acoustic propagation model and Monte Carlo simulation to obtain an ensemble of received signals, from whence parameters can be estimated. The problem of inferring parameter distributions from partial or incomplete information is a fundamental problem in statistics. Jaynes has applied the maximum entropy (MaxEnt) principle to the case where available information consists of sample moments of the unknown parameter (Jaynes, 1957). The MaxEnt principle states: *out of all probability density functions consistent with a set of constraints (moment constraints and physical constraints), choose the one that has maximum uncertainty* (Kesavan and Kapur, 1989). The measurement of uncertainty is Shannon's entropy $S(\mathbf{p}) = \sum p_i \ln p_i$, where $\mathbf{p} = (p_1, p_2, \ldots, p_n)$ is the vector of probabilities associated with a parameter vector; hence the name Maximum Entropy (Srikanth et. al., 2000).

The MaxEnt approach utilizes moments and physical constraints to produce a pdf that belongs to the exponential or Koopman-Pitman class of distributions. The moments can be calculated from data or derived from physical laws. A large number of pdfs used in statistical detection theory belong to the exponential class, including the gamma, beta, Gaussian, chi-squared, log normal, uniform, and Poisson density functions (Kapur and Kesavan, 1992; Lehmann, 1986; Schwartz, 1977).

Figure 2 shows the method developed in FY05-06 under the REVEAL project for incorporating environmental knowledge and variability into signal parameter predictions. The objective is to make use of knowledge of the spatio-temporal variability of the environment to predict the spatio-temporal variability of the received acoustic signals. Once the relevant ocean environment parameter distributions have been obtained, synthetic realizations of the environment are generated by random draw. An acoustic model is used to propagate acoustic energy through each realization to produce an ensemble of acoustic fields. This is referred to as Monte Carlo simulation.

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In order for the link between environmental and acoustic variability to be accurate, the physics that relate environment and source parameters to acoustic propagation must be incorporated. Various approximations to the wave equation are available to predict acoustic propagation given environmental and source/receiver parameters, e.g. normal modes, parabolic approximation (PE), and ray tracing. The best model for a particular application is influenced by factors such as the acoustic frequency, range dependence of the environment, the source-receiver range, and the signal parameters to be predicted.

In our approach, a large number of environmental realizations are used with an appropriate acoustic propagation code to calculate an ensemble of received acoustic signals (i.e. a Monte Carlo simulation). Therefore, statistics of the received signals are directly related to the environmental variability. Sample moments of received signal and noise parameters are calculated from the ensemble and the MaxEnt method used to produce an exponential class pdf. As discussed above, if received signal and noise pdfs are of the exponential class, the Maximum Likelihood detector has a useful estimator-correlator and noise estimator-canceller structure.

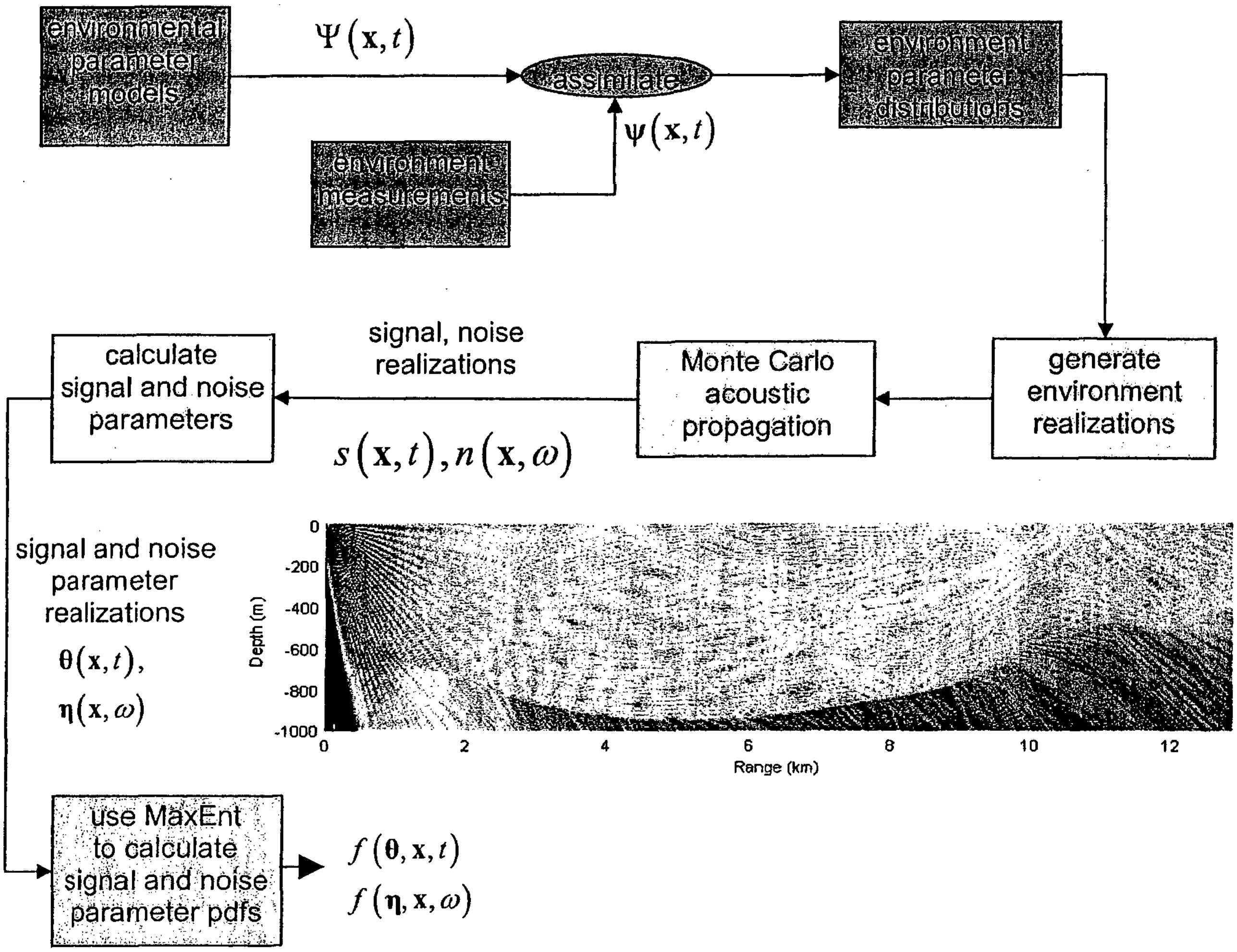

Figure 2: Method for calculating received acoustic signals using an environmental parameter model and in-situ measurements, Monte Carlo acoustic propagation simulation, and the Maximum Entropy (MaxEnt) method to obtain parameter pdfs from the ensemble of signals.

The method outlined above has been demonstrated using acoustic and environmental measurements made in the Strait of Gibraltar in 1996 (Camin et. al., 2006; Tiemann et. al., 2001a, 2001b). This is a dynamic region from an oceanographic standpoint due to strong tidally-driven flow and the presence of internal waves. The acoustic measurements utilized broadband acoustic pulses transmitted 13 km across the strait hourly over several days and many tidal cycles, and significant variation in received signal pressure was measured. Monte Carlo simulation was carried out using sound speed fields derived from a time and space-varying mean sound speed model combined with a large number of sound speed measurements. The MaxEnt method was used to obtain range- and depth-dependent pdf's of rms received pressure. The predicted pdfs are being compared with the measured pdfs in order to validate the method.

Derivation of the maximum likelihood detector. In FY05-06 the Maximum Likelihood (ML) detector was derived for signals that have propagated through a random or uncertain ocean environment (Ballard, et. al., 2006). To calculate the likelihood ratio, one must have the probability density functions (pdfs) of the certain parameters of the received signal and the noise. Received signal parameters pdfs can be calculated from incomplete knowledge of environmental and source parameters using the MaxEnt principle (Jaynes, 1957; Srikanth et. al., 2000) and an acoustic propagation program. This is discussed further below. The result important to this work is that the received signal parameter pdfs are of the exponential or Koopman-Pitman class, which includes the Gamma, Beta, Gaussian, Chi-Squared, log normal, Weibull, and many other density functions that have been used in statistical signal processing (Lehmann, 1986; Schwartz, 1977).

The ML detector for exponential class signal parameter pdfs was shown to amount to computing the mean of the parameter conditioned on the received signal, referred to as the conditional moment estimate (CME), and calculating a detection statistic by correlating the CME with the observation. The detector structure has been termed an "estimator-correlator" by Price (1956), and in application to ocean acoustic signal processing, following the terminology of Sha and Nolte (2005), the Estimated Ocean Detector (EOD). Kailath and Poor (1998) have pointed out that estimator-correlator detectors are often easier to implement than ML detectors. The general EOD structure, shown in Figure 3, also includes a noise canceller in which the noise component is estimated and subtracted from the observation.

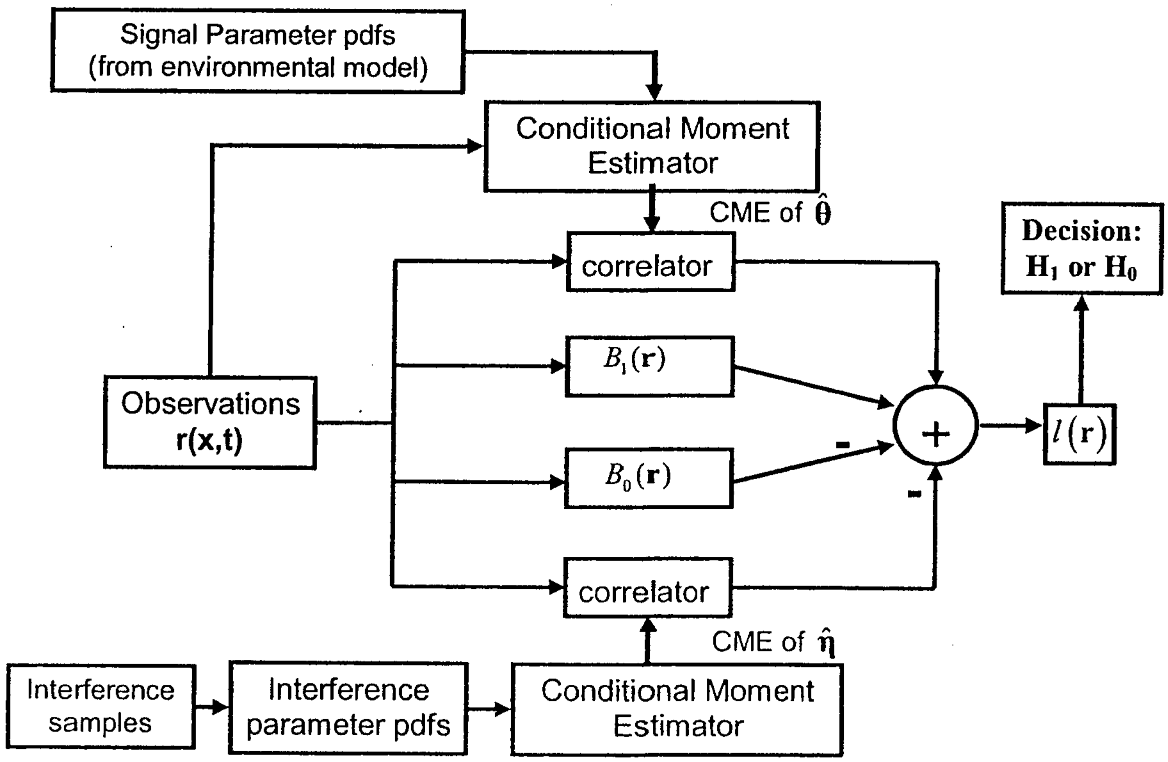

Figure 3: General structure of the Estimated Ocean Detector (EOD).

As a benchmark check of EOD implementation, the case of Gaussian signal and noise was investigated in detail. The resulting detector amounts to a weighted sum of an energy detector (ED) and a correlation detector (CD), with the weights determined by the noise and signal variances. This result is shown to produce receiver operating characteristics (ROC) that are equivalent to the classical case of the maximum likelihood detector of signals that has both deterministic and random components (Van Trees, 1968, Chapter 2, p 327).

Three cases were investigated for Gaussian signal and noise using a Monte Carlo numerical simulation for calculation of ROC. The "known ocean" refers to low signal variance, in which case knowledge of the signal is good, and the EOD is shown to reduce to a CD. The "unknown ocean" refers to high signal variance, in which case the signal is not well known, and the EOD reduces to an ED. The third case is for intermediate signal variance, and here the weighted sum of CD and ED formed by the EOD provides better performance than either detector by itself. In addition, the robustness of the Gaussian EOD to incorrect *a priori* knowledge of signal parameters was investigated. This investigation showed that EOD was robust to very wide range of incorrect prior knowledge of signal and noise variances.

Passive detection and classification is made particularly difficult by the many target-like interference sources. For this reason a receiver that incorporates an interference estimator-subtractor would be expected to provide major improvement to the passive sonar signal processors.

RESULTS

The results from the REVEAL project for FY06 are promising but preliminary. The overall goal of the project is to improve passive sonar detection and classification by taking advantage of knowledge of environmental variability, and the current work is best described as building components that will become part of the solution. Briefly, the components are:

- the <u>Maximum Entropy method</u>, with which we have learned how to construct probability density functions (pdfs) that incorporate what is known about the environment but are maximally uncertain about what is not known (or put another way, do not make unwarranted assumptions about what is not known). The resulting pdfs belong to the exponential class.

- <u>a received signal and noise statistics prediction</u> capability developed using RAM PE and Monte Carlo simulation. The method is being evaluated using acoustic and environmental measurements from the 1996 Strait of Gibraltar Acoustic Measurement.

- <u>a maximum likelihood receiver</u> formulated to accommodate prior distributions belonging to the exponential class. The receiver has been termed an Estimated Ocean Detector (EOD) because it possesses an estimator-correlator structure in which a conditional estimate of the parameter is obtained and then correlated with the observations.

The linkage of the MaxEnt method, which produces an exponential class pdfs, with the Estimated Ocean Detector, which can achieve optimal performance using an exponential class prior pdf, is an important result of this project.

Another significant result is that research by Ben Cotté in FY03-05 (MS Acoustics 2005) was accepted for publication in the Journal of the Acoustical Society of America (see Publications below for reference).

IMPACT/APPLICATIONS

The results of this research are expected to lead to new passive sonar detectors and classifiers that take advantage of knowledge of medium variability and uncertainty. The results are mainly applicable to passive processing. However, the active processor can be considered "*a detector matched to the estimated ocean.*" These results could have significant impact on Navy sonar system applications.

RELATED PROJECTS

The ONR Defense Research Initiative (DRI) on Capturing Uncertainty in the Common Tactical Environmental Picture (http://www.onr.navy.mil/sci_tech/ocean/321_sensing/cuwg/default.asp) This DRI, which completed in FY04, was concerned with including uncertainty associated with propagation channels, system parameters, and signal parameters into performance prediction of sonar systems. The present project is concerned with same issues and is drawing from progress made under the DRI. However, using MaxEnt principle to generate maximally uncertain pdfs is new and unique to the present project. Also, signal processing structures derived under this project were not considered in DRI. Sha and Nolte (Sha and Nolte, 2005) have analyzed and compared performance of a *matched ocean detector,* a *mean ocean detector* and an *unknown ocean detector.* In a similar vein, the detector developed under this project is termed the *estimated ocean detector.*

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PATENTS

None.

HONORS/AWARDS/PRIZES

Colin Jemmott, a PhD student in the Penn State Acoustics Graduate Program whose research is supported by the REVEAL project, was awarded the Best Paper by a Young Presenter in Signal Processing at the June 2006 Meeting of the Acoustical Society of America held in Provident, RI. The title of the paper was "Performance of the estimated ocean detector (EOD) against non-Gaussian signal and noise."