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14. ABSTRACT
In many cases, clear mechanisms in areas of increased false alarm (FA) are unclear, although possible causes include rock outcrops and seafloor of mixed bottom type (e.g., mixed rock and sand). The long-term goals of this research program aim primarily to address this shortfall by providing knowledge of the exact mechanisms causing false alarms. This knowledge will be used to develop methods for simulating FA and predicting where high FA areas might occur and the influence of parameters such as slope or aspect on FA levels. Of equal importance, will be increasing our understanding of the relationship of the parameters of the K distribution, now being used for simulating clutter, to real features of the environment. Once mechanisms are established, this effort will also allow the performance of torpedo sonar systems to be predicted for seafloor environments, which will allow the negative impact of non-Rayleigh clutter on detection and classification to be minimized. Knowledge gained might also lead to methods for rapid environmental assessment techniques for the characterization of high false alarm/false target areas.

15. SUBJECT TERMS
clutter, false alarms, K distribution, seafloor scatter

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Principal Investigator	Anthony P. Lyons
Organization	The Pennsylvania State University Applied Research Laboratory

Technical Section

Technical Objectives

Long term goals:

The long-term goal of the present high-frequency scattering statistics work is to examine the links between environmental parameters of shallow water boundaries and the statistics of high frequency, broadband acoustic fields using a combination of at-sea measurements, ground truth and theoretical modeling. The influence of the properties of the boundaries to the scattered envelope statistics and noise fields will be examined in detail. The proposed project is designed to (1) examine experimental acoustic data to determine how environmental properties (e.g. roughness or bubble clouds) influence statistical distributions obtained with broadband, acoustic systems in shallow water including SAS and vector sensor systems; (2) test current models or develop models where none exist which link measured environmental parameters (e.g. roughness, bubble distributions) and system characteristics (e.g. bandwidth, frequency) to predict these statistics in realistic shallow-water ocean environments. The proposed effort will lead to methods for modeling and predicting properties that may be used to minimize the negative impact of the environment on: 1) detection and classification of targets on or near the seafloor in shallow water; and 2) processing of data taken with vector sensor arrays.

Objectives:

The importance of the present work lies in the ability to link scattered envelope distributions to measurable environmental properties such as seafloor patch size, composition or roughness. In conjunction with sonar system parameters, this link will provide the foundation necessary for solving several important problems related to the SAS detection of targets. The direct link between system and environmental parameters via scattering models to the statistical distributions will allow: performance prediction for different systems based on environmental properties, extrapolation of performance to other system/bandwidths, and optimization of sonar parameters to the local environment. Concisely the project objectives are:

1. Through analysis of experimental data and modeling, determine the frequency, bandwidth and grazing angle dependence of seafloor and sea surface scattered amplitude distributions observed in high-frequency sonar systems operating in shallow water.

2. Develop methods for predicting the effects on current and future high bandwidth sonar systems using ground truth and scattering models.

3. Define adaptive strategies to a given environment for mitigating the effects of the environment on sonar systems.

4. Collect vector active source and ambient noise data using vector sensors in a variety of environmental conditions.

Technical Approach

Experimental studies designed to link models of amplitude statistics to scattering models in order to improve predictive capabilities for high-frequency acoustic systems operating in shallow water areas are lacking. This research program will attempt to characterize the frequency and grazing angle dependence of clutter in the output of high-frequency sonar systems operating in shallow water and link the statistical characterization of returns to the environment through models which will aid in the prediction of environmental effects on future MCM acoustic systems. These goals were achieved through a combination of at-sea measurements and modeling primarily at frequencies between 20 and 200 kHz. Experimental acoustic data sets consisted of high-frequency narrow and broadband single beam collected as part of a Joint Research Project (JRP) with the NATO Undersea Research Centre (NURC), multi-beam data collected recently by ARL at Seneca Lake, as well as Synthetic Aperture Sonar (SAS) rail data that was collected by the Applied Physics Lab–University of Washington (APL-UW) as part of the SAX04 experiment and SAS data provided by NSWC-Panama City.

In order to measure vector ambient noise fields, two orthogonal arrays of vector sensors were deployed within the shallow water environment of AUTEC, Andros Island for a long term study of the acoustic ambient noise intensity as related to weather and waves. The long deployment period (8-12 months) will also allow for multiple opportunities to gather data sets with active sources and on isolated AUTEC vessel traffic (harbor security), as well as to investigate the ability to utilize surface generated noise to study the geo-acoustic characteristics of the ocean bottom. Deployment at AUTEC is unique in that there is no local industry, commercial traffic or significant sources of anthropogenic ambient noise in the 50Hz to 6 kHz region thereby allowing this study to provide baseline performance information on the natural characteristics of acoustic intensity fields in shallow water.

Work completed (FY07 – FY09)

In FY07 a predictive model for the statistical distribution of clutter resulting from scattering from two different contributing seafloor types within the same resolution cell was developed and compared with high-frequency acoustic scattering data collected with the NATO Undersea Research Centre (NURC) at Elba Island. The seafloors were modeled as being comprised of a finite number of homogeneous scattering patches (in contrast to the more traditional asymptotic derivation of the K-distribution) on a background (the area around the scattering patches) that was assumed to produce a Gaussian scattered return. In the statistical model, the impact of the relative scattering properties on the angle or frequency dependence of scattered PDFs can be naturally included. Predictions of the effective shape parameter of the K-distribution made using the model with realistic input parameters for several example seafloor descriptions were compared with estimates of the shape parameter obtained from the NURC data. The strength of the developed framework is that any number of different scattering mechanisms can be accommodated and the individual component scattering models can be changed as they improve. In conjunction with sonar system parameters, such as beam width, bandwidth, frequency and grazing angle, the clutter envelope distribution can be linked to measurable geo-acoustic properties.

The impact of propagation on scattering statistics through modeling, simulation, and data analysis of high-resolution Synthetic Aperture Sonar data was also examined in FY07. The K-distribution shape parameter was used to represent the reverberation statistics with large values indicating a trend toward Rayleigh-distributed reverberation. Prior to this work, research on the effects of multipath on reverberation statistics had been limited to theoretical studies predicting that multipath serves to make reverberation statistics more Rayleigh-like and experimental data analysis that did not conclusively demonstrate the effect without potentially confounding effects. Modeling and simulation of the SAX04 experiment configuration, sonar system, and local environment predicted a significant increase in the K-distribution shape parameter at the time of arrival of arriving multipath. Analysis of the SAX04 data illustrated a small shape parameter (on the order of 2) during times when the direct path dominated and a clear and significant increase in the shape parameter at the time of arrival of the fathometer-like multipath. The modeling made clear the requirement that the sonar system configuration and environment must act together to cause the multipath and direct-path power levels to be within approximately 10 dB of each other for multipath to have a significant impact on the reverberation statistics.

Work continued in FY08 on analysis of Synthetic Aperture Sonar (SAS) data acquired from the Applied Physics Laboratory -University of Washington during the ONR sponsored SAX04 experiment and SAS data obtained from NSWC - Panama City. Both of these data sets contributed to our understanding of non-Rayleigh envelope distributions as a function of the resolution of these kinds of high-frequency imaging systems and furthered the development of predictive models of the image statistics. We also looked at how SAS statistics depend on range and cross range resolution for seafloors where the seafloor acoustic response is anisotropic due to sediment ripples. The usefulness of techniques used in Synthetic Aperture Radar, such as multi-look processing, was also being explored.

Also in FY08, in conjunction with Dave Deveau of NUWC, installation and initial analysis was begun for data collected on arrays consisting of Wilcoxon TV-001 vector sensors. The arrays were in the form a 'T' shape and were mounted on a tripod assembly. The sensors were placed at $\lambda/2$ spacing at 3 kHz or approximately 25cm. The sensor system was deployed at a height of 2 meters off the bottom. A single 2000m length of armored electro-optical cable was run from a shore termination building to the array deployment location. The assembly was placed in approximately 20 meters water depth. Two active sources were positioned approximately 1-2 km from the array. Initial tests were performed to verify that the system was operational. Data was being acquired for 2 minutes, each hour, 24 hours a day using a 32 channel Nicolet Liberty data acquisition system and for 5 minutes, once a day for subsets of sensors in the array. AUTEC maintains a continuously operating wind/weather station that is less than 700 meters from the deployment area. This station's data was relayed through an existing RF network to a shore computer whose database was continually updated. The environmental data was extracted on a routine basis for correlation with the acoustic data.

Work was completed in FY09 on analysis of Synthetic Aperture Sonar (SAS) data acquired from the Applied Physics Laboratory -University of Washington during the ONR sponsored SAX04 experiment and SAS data obtained from NSWC - Panama City. Both of these data sets contributed to our understanding of non-Rayleigh envelope distributions and speckle as a function of the resolution of these high-frequency imaging systems and to furthering the development of predictive models of the image statistics. We specifically looked at how SAS image statistics depend on range and cross range resolution for seafloors where the seafloor acoustic response is anisotropic due to sediment ripples. The effect on SAS image statistics of ripple-induced amplitude variations was also examined. A student, Shawn Johnson, was involved with this work and has now graduated with a Ph.D. in Acoustics. Shawn is currently at the Applied Physics Laboratory – Johns Hopkins University and continues to work on related topics.

Impact/Applications

The scattering statistics research provided an improved understanding of the link between environmental parameters and system factors in causing clutter in high-frequency imaging systems. This study led to methods for modeling and predicting acoustic clutter that may be used to minimize the negative impact of clutter on detection and classification of targets on or near the seafloor in shallow water. Knowledge gained should help in the development of simulation tools, adaptive systems for sonar clutter reduction and rapid environmental assessment techniques for estimating the strength of clutter for a given area.

The study of the response of vector sensors to both active sources and noise fields has implications for the operation of future vector sensor sonar systems and methods used by the Navy. This study will lead to improved methods for modeling vector fields.

Transitions

The statistical models of clutter that have been explored and developed are being incorporated when possible into the ARL-PSU Technology Requirements Model (TRM), a high fidelity, physics-based digital simulator. Discussions are also under way to include models into simulations of Synthetic Aperture Sonar being developed at NSWC-Panama City. Vector sensor studies will yield guidance for future navy using arrays of these types of sensors.

Publications and technical presentations supported in whole or in part by this project:

Journal Articles (from September 2006):

Lyons, A.P., D.A. Abraham S.F. Johnson, 2010, Modeling the Effect of Seafloor Ripples on Synthetic Aperture Sonar Speckle Statistics, IEEE J. Ocean. Eng., in press.

Osler, J.C., D.M.F. Chapman, P.C. Hines, G.P. Dooley, and A.P. Lyons, 2010, Measurement and Modeling of Seabed Particle Motion using Buried Vector Sensors, submitted to IEEE J. Ocean. Eng.

Abraham, D.A. and A.P. Lyons, 2010, Reliable Methods for Estimating the K-distribution shape parameter, IEEE J. Ocean. Eng., Digital Object Identifier : 10.1109/JOE.2009.2025645.

Lyons, A.P., S.F. Johnson, D.A. Abraham and E. Pouliquen, 2009, High-Frequency Scattered Envelope Statistics of Patchy Seafloors, IEEE J. Ocean. Eng., **34**, 451-458.

Johnson, S.F., A.P. Lyons, D.A. Abraham and K.L. Williams, 2009, The Impact of Multi-Path on High-Resolution SAS Image Statistics, IEEE J. Ocean. Eng., **34**, 476-484.

Gerig, A.L., A.P. Lyons and E. Pouliquen, 2009, Comparison of Seafloor Roughness and Acoustic Temporal Decorrelation, IEEE J. Ocean. Eng., **34**, 423-430.

Jackson, D.R., M.D. Richardson, K.L. Williams, A.P. Lyons C.D. Jones, K.B. Briggs, and D. Tang, 2009, Acoustic Observation of the Time Dependence of the Roughness of Sandy Seafloors, IEEE J. Ocean. Eng., **34**, 407-422.

Weber, T.C., A.P. Lyons, and D.L. Bradley, 2007, Acoustic Propagation Through Bubble Clouds Exhibiting Spatial Structure," IEEE J. Ocean. Eng., **32**, 101-111.

Conference Proceedings (from September 2006):

Johnson, S.F., A.P. Lyons, and D.A. Abraham, 2008, Dependence of Synthetic Aperture Sonar Image Statistics on Resolution," in Proceedings of the International Symposium on Underwater Reverberation and Clutter, P.L. Nielsen, ed., Lerici, Italy, 9-12 September.

Lyons, A.P., T.C. Weber and M. Gustafson, 2007, An Experimental Study on the Causes of Non-Rayleigh Scattered Envelope Statistics, in Proceedings of 2nd Underwater Acoustic Measurements Conference: Technologies and Results CD-ROM, Heraklion, Crete, Greece, eds. John S. Papadakis and Leif Bjorno.

Lyons, A.P. and T.C. Weber, (Invited), 2007, A Multibeam Sonar Survey of a Benthic Lake Habitat: Assessing the Impact of Invasive Mussels in Seneca Lake, New York, Proceedings of 2nd Underwater Acoustic Measurements Conference: Technologies and Results CD-ROM, Heraklion, Crete, Greece, eds. John S. Papadakis and Leif Bjorno.

Weber, T.C., A.P. Lyons and D.L. Bradley, (Invited), 2007, Identifying bubble clustering: comparisons of the coherent and incoherent acoustic fields, invited paper, Proceedings of 2nd Underwater Acoustic Measurements Conference: Technologies and Results CD-ROM, Heraklion, Crete, Greece, eds. John S. Papadakis and Leif Bjorno.

Weber, T.C., and A.P. Lyons, 2006, A Multibeam Sonar Survey of Mid-Seneca Lake: Bathymetry, Backscatter, and Invasive Species, Finger Lakes Research Conference, Hobart and Smith College, Geneva, NY, 14 October.

Abraham, D.A. and A.P. Lyons, 2006. Bootstrapped K-Distribution Parameter Estimation, in Proceedings of the MTS/IEEE Oceans '06, Boston.

Abstracts (from September 2006):

Lyons, A.P., 2009, (Invited), Experimental Tests of Models for High-Frequency Scattered Envelope Statistics, 157th Meeting of the Acoustical Society of America, Portland, Oregon [J. Acoust. Soc. Am. Suppl. 1, 125, 2644].

Lyons, A.P., S.E. Parks, and T. C. Weber, 2007, An Experimental Test of a Model for Scattered Envelope Statistics, 154th Meeting of the Acoustical Society of America, New Orleans, Louisiana, [J. Acoust. Soc. Am. Suppl. 1, 122, 2975].

Johnson, S.F., A.P. Lyons, and D.A. Abraham, 2007, Effect of Resolution on Synthetic Aperture Sonar Statistics, 154th Meeting of the Acoustical Society of America, New Orleans, Louisiana, [J. Acoust. Soc. Am. Suppl. 1, 122, 3000].

Lyons, A.P., 2007, Scattered envelope statistics of patchy seafloors (and how this might possibly relate to fish schools), Office of Naval Research Fish Acoustics Review, Plymouth, MA, 1-2 November.