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Applied Research Division
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ATTN: Kam Ng, Code 4523

SUBJ: Annual Letter Report for FY93 on Contract N00014-91-J-4138

This letter and enclosure represents the Annual Letter Report for FY93 on the Wavelet Based Higher Order Spectal Processing efforts performed at ARL:UT under the above referenced ONR contract. This report summarizes progress and activities during the period 1 October 1992 to 30 September 1993.

Sincerely,

Gary R. Wilson
Signal Physics Group

Encl.

ANNUAL LETTER REPORT FOR FY93

I. ADMINISTRATIVE INFORMATION

Title:	Wavelet Based Cumulant Processing
Contract:	N00014-91-J-4138
P.I.:	Dr. Gary R. Wilson, ARL:UT, wilson@arlvs1.arlut.utexas.edu
Prog. Man.:	Kam Ng

II. TECHNICAL OBJECTIVES AND ISSUES

The objective of this program is to develop appropriate time-frequency signal processing methods for the analysis of the transient response of mechanical systems and structures. The focus of this program is on mid-frequency (2-20ka) target strength measurements. At higher frequencies, structures of interest respond primarily as rigid, or inelastic, scatterers. However, in these same structures at the mid-frequency and lower ranges, significant structural vibrations in the form of traveling waves can be created by the incident sound pressure. These traveling waves in turn cause sound to be reradiated from the structures in a rather complicated fashion at significant sound pressure levels. This reradiation is referred to as elastic scattering.

Typical measurements of the scattering of sound from submerged structures that have been developed for the high frequency, inelastic scattering case are for the purpose of determining the location of the dominant scatterers on the structure and their relative target strength. However, these measurement techniques for inelastic scattering are not as appropriate for elastic scattering because they do not provide the detailed insight into the more complicated structural response produced by elastic scattering. The predominant issue of mid-frequency target strength measurements is to determine the wave mechanisms established in the structure by the incident sound pressure and their contributions to the reradiated sound. Thus signal processing techniques are necessary that can examine in more detail the structure of the reradiated sound in order to infer the wave mechanisms in the structure.

III. TECHNICAL APPROACH

Typical mid-frequency target strength measurements record the acoustic amplitude of the transient sound reflected and reradiated from a structure as a function of time and position of the acoustic source and receiver with respect to the structure. These "raw" measurements can be processed by a series of analysis methods to provide an indication of various wave mechanisms in the structure, as summarized in Table I. In this program our approach has been to draw from our previous work in transient processing for full spectrum and condition based maintenance applications using wavelet and higher order spectral analysis to develop methods for measuring dispersion and damping properties of waves in structures. We have shown that in general a mechanical system with viscous damping and dispersion will respond to an impulsive excitation with a sum of traveling damped sinusoids that can be represented as a time-scale process. Our approach then has been to develop wavelet processing methods that are appropriate to the physics of mid-frequency target strength phenomena to help extract damping and dispersion characteristics. We have made use of existing scale model mid-frequency target strength data to develop and test wavelet processing methods.

IV. SUMMARY OF ACCOMPLISHMENTS

We have developed a wavelet function using a damped sinusoid model for the travelling waves in a mechanical structure due to a transient excitation. We conducted a simple experiment in which we provided a transient excitation to a metallic bar and used this model to determine the damping characteristics of the modes excited in this bar to demonstrate the validity of this method.

We have also acquired scale model target strength data from MIT and have determined how to process the data. We have applied the damped sinusoid wavelet to target strength data at a specific aspect angle. The resulting time-frequency representation of the data demonstrate the contribution of leaky shear waves in the structure to the reradiated acoustic data, but without the interfering contributions produced by a Wigner-Ville time-frequency representation of the data.

V. SIGNIFICANCE

The development of these signal processing methods can help give better insight into the physics of sound reradiation of structures in the mid-frequency range, specifically damping and dispersion characteristics of the travelling waves in the structure. The ultimate Naval objective of a better understanding of the physics of sound reradiation is to facilitate the design of new ships with reduced target strength and thus reduced vulnerability to detection by active sonar systems. Preceding work in wavelet processing of transient signals has transitioned to a 6.2 program (PE 060231, Block UN-3B, Project

Table I
Summary of Target Strength Analysis

Processed Measurement	Indicates	Analysis Method
Arrival time versus aspect angle	• Waves with different speeds in target	Time Series Analysis
Frequency versus aspect angle	• Resonances • Coincidence angle	Power Spectral Analysis
Arrival time versus axial location	• Location of scattering sources • Waves with different speeds in target	Focused Beamforming
Frequency versus wavenumber	• Waves with different speeds in target	Two-Dimensional Spectral Analysis
Arrival time versus frequency at fixed aspect angle	• Dispersion • Damping	• Wavelet • Quadratic Time-Frequency Representations (QTFR)

RJ-14-C33) sponsored by ONR 451 and NUWC-NL, Code 2121. The current work is being transitioned to Prof. Ira Dyer at MIT and thus to the ONR Structural Acoustics program.

VI. PLANNED EFFORTS

We will focus on the use of mid-frequency experimental scale model target strength data to test and refine the wavelet and time-frequency methods we have developed. Specifically, we will determine the extent to which the damped-sinusoid wavelet model needs to be modified based on the results from the existing scale model target strength data in order to determine the damping and dispersion characteristics of the data. Existing data sets for three different shell configurations that are expected to give different damping and dispersion characteristics, an empty shell, a ring stiffened shell, and a shell with complex internal structure, will be analyzed. In addition to wavelet methods, we will also examine other time-frequency representations that may be suitable. For non-linear dispersion, we recognize that the Cohen class of time-frequency representations may not be appropriate and will develop and test other types of time-frequency representations. We will approach the problem of the reduction of interference terms in the time-frequency representation by developing kernals for specific wave types in the shell based on the physics of elastic scattering.

VII. PRESENTATIONS AND PUBLICATIONS

Wilson, Gary R. and Wesley Ellinger, "Detection of Chaotic Processes in Gaussian Noise at Low Signal to Noise Ratios Using Higher Order Spectra," Proceedings of the IEEE Signal Processing Workshop on Higher-Order Statistics, South Lake Tahoe, CA, 7-9 June 1993.

Baugh, Kevin, "On Parametrically Phase-Coupled Random Harmonic Processes," Proceedings of the IEEE Signal Processing Workshop on Higher-Order Statistics, South Lake Tahoe, CA, 7-9 June 1993.

Wilson, Gary R., Mark D. Ladd, Russell D. Priebe, and Kevin W. Baugh,"Application of Wavelet Analysis to Machinery Diagnosis," presented at the 125th Meeting of the Acoustical Society of America, Ottawa, ON, Canada, 17-21 May 1993.

Barlett, Martin L., Kevin W. Baugh, and Gary R. Wilson, "Detection of Transients Using the Nonstationary Bispectrum," presented at the 125th Meeting of the Acoustical Society of America, Ottawa, ON, Canada, 17-21 May 1993.

Ladd, Mark D. and Gary R. Wilson, "Frequency Resolution Properties of the Wavelet Transform for Detecting Harmonically Related Narrowband Signals," Proceedings of the 1993 International Conference on Acoustics, Speech, and Signal Processing, Minneapolis, MN, 27-30 April 1993.

Wilson, Gary R. and Kevin Baugh, "Non-Parametric Detection of a Class of Cyclo Stationary Signals in Stationary Colored Non-Gaussian Noise Using Non-Stationary Higher Order Spectra," Proceedings of the IEEE Sixth Signal Processing Workshop on Statistical Signal and Array Processing, Victoria, BC, Canada, 7–9 October 1992.

Baugh, K. W., "Transient Signal Modeling and Detection Using Spectral Correlation," Proceedings of the IEEE Sixth Signal Processing Workshop on Statistical Signal and Array Processing, Victoria, BC, Canada, 7–9 October 1992.

Priebe, R. and G. Wilson, "Application of "Matched" Wavelets to Identification of Metallic Transients," Proceedings of the IEEE-SP International Symposium on Time-Frequency and Time Scale Analysis, Victoria, BC, Canada, 7-9 October 1992.

VIII. PARTICIPANTS

Dr. Gary R. Wilson, Research Scientist

Dr. Kevin W. Baugh, Research Scientist Associate

Prof. John Gilbert, Math Dept., University of Texas at Austin

Dr Joe Lakey, Instructor, Math Dept., University of Texas at Austin

Mark Ladd, PhD student, Electrical and Computer Engineering Dept., U. T.

Russell Priebe, PhD student, Electrical and Computer Engineering Dept., U. T.

Ens. David Ruth, Masters student, Mathematics Department, U.T.

1 student from the ARL:UT Honors Scholars Program