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BASIC RESEARCH IN UNDERWATER ACOUSTIC PROPAGATION STABILITIES AND RELATED SIGNAL PROCESSING

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This report summarizes the theoretical and laboratory work performed under contract N00014-75-C-0174 with the U.S. Navy, Office of Naval Research, during the period 1 January 1975 to 28 February 1977.

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1. LARGE COMPLEX DATA SETS

A major problem in underwater acoustic research is the search for better understanding of the effects of large scale oceanographic processes that either enhance or destroy coherence. The search for these effects requires the digestion of large complex data sets. The major efforts under this contract were in two areas of research aimed at enhancing our ability to extract information from such data.

1.1 Complex Information Display Using Color

This long term task was aimed at determining the spectral phase stability of noise and man-made signals. The color display facility is a 256 x 256 color point display under computer control. Although quite general in nature, its only use has been to study the spectrum as defined by 256 adjacent bins of an FFT analysis, displaying each analysis below the previous. The spectral magnitude is the displayed brightness, and the spectral phase is the color.

The hardware (electronics and mechanical) had been a major problem since the facilities conception, and it was not until early 1976 that the facility was deemed reliable, and the display free of artifacts. (For example, memory-timing problems caused vertical black lines.)

A modest operating system was written, tested, and completed for control of the display. An effective phase-to-color coding was developed by trial and refinement; this code contains no "white" as only one or two primary colors are excited for each display point. This code appears to be as effective in conveying phase and amplitude information as I had hoped it would be.

The data used for development were taken in January of 1974 in the MIMI Atlantic test. The most obvious conclusion was the need for time overlap (each FFT containing 25 percent new data and 75 percent old data). This agreed with the black and white "gram" display conclusion. Several of the test records showed remarkable signal phase stability; however, it was by chance that the signals' frequency coincided (nearly) with the center of an FFT bin, or this would not have been observed. Signal processing programs to correct this, allowing operator directed cueing and controlled fine-grain-tuning, were written at the close of the contract. This work is expected to continue under other ONR contracts.

1.2 A Data Processing Language

Work was begun under Dr. Gerald Cederquist on a general data processing language that would allow easier manipulation of large data bases, such as the January 1974 MIMI test, with greater assurance of accuracy. This development was discontinued when Dr. Cederquist neared the end of his post-doctoral stay. Unhappily, the concepts that were beginning to gel were not sufficiently well formulated to warrant reporting; we are, however, a bit smarter than we were. We understand how the use of more complete descriptors aid in analysis of data, and some of the complexities that must be overcome in descriptor transformations as data are processed.

2. SIGNAL PROCESSING

Extension of the theoretical basis for signal processing, and conversion of theory to practice have been low level, but continuing efforts, throughout this contract. Two such efforts warrant reporting here.

2.1 Factor Inverse Filtering

Under this contract and another ONR contract the basis for our previous success using pseudorandom linear maximal binary codes for propagation has been examined, and the techniques generalized. This has been a process that evolved over many years, and we developed and used the techniques before we understood them. Early in 1975 I began to crystallize this into "factor inverse filtering" and have tested it in three experiments. There will be both a report on this (under the other ONR contract) and papers, but the theory is essentially this:

Suppose a propagation experiment is to be conducted from one transmitter to one or more receivers, with the objective of measuring the channel transfer function $C(f,r)$ from the transmitter to the rth receiver. In principle we would like to transmit a short pulse, with spectrum $P(f)$, using due care to match to the transducer's transfer function $X(f)$. If we could measure the channel pulse response, $P(f)C(f,r)$, we would be happy, but the transducer cannot deliver sufficient energy in one short pulse to overcome the noise and forward scattered reverberation. Therefore we use a coded signal with spectrum $S(f)$ instead.

The key fact is that we have always used, and should use, a signal that contains the hypothetical pulse spectrum as a factor, and the actual signal has spectral zeros only where that pulse spectrum would be zero. Formally

$$S(f) = P(f)G(f) \quad , \; G(F) \neq 0 \text{ anywhere}$$

The actual received spectrum at the rth receiver is

$$R(f,r) = \left[P(f)G(f)\; X(f)\; C(f,r) + \sqrt{N(f,r)}\right] \quad A(f,r)$$

where $A(f,r)$ is the effect of the amplifiers and filters for the rth hydrophone, and the square root on the noise power spectrum, $N(f)$, indicates the Fourier transform of the actual noise on the rth receiver during the measurement. If there were no noise, we would simply solve for the desired result, $P(f)C(f,r)$. Do so.

$$\text{Estimated } [P(f)C(f,r)] = R(f,r) \;/\; G(f)X(f)A(f,r)$$

If a laboratory or "close in" test permits, measure the system without the ocean.

$$\text{Test: } T(f,r) = S(f)\; X(f)\; A(f,r)$$

The denominator in the estimation is $P(f)/T(f,r)$, which will have no zeros. If the signal is chosen carefully, G(f) will be fairly constant in magnitude, and so will this denominator. The phase function of this denominator is most important, as it undoes the "smearing" done by the transducer and the receiving filters. More important, if array work is being done, the phases of the individual hydrophones will be corrected for individual receiver channel differences. It's really simpler to use than it is to prove. The theory accounts for the signal-to-noise ratio gain due to increased transmission time and loss due to not matched-filtering, all in terms of the "flatness" of the factor spectrum, G(f) .

2 Power Spectrum Measurements

We have been wrestling with the theories and practice of power spectrum measurements for many years. Either our theory is inadequate or our practice is archaic, probably both. Under the previous ONR contract Dr. J. O. Gobien developed the theoretically optimum measurement method for wide sense stationary Gaussian processes with "poles-only" rational power spectra using continuous measurements (not sampled), and optimum in the Baysian sense. That work had some drawbacks: it required perfect analog differentiaters, and the stochastic theory claimed the high frequency falloff was "singularly estimatable," i.e., should be immediately obvious.

Under the present contract a doctoral study by Ron Carpinella analyses the practical implications of Gobien's work when applied to high-sampling-rate digital analysis, compared to Berg's "maximum entropy method" which applies to low-sampling-rate digital analysis. Berg's technique may be treated as assuming an auto-regressive process, which is very close in nature to that treated by Gobien.

This has been a difficult study. The mathematical models are elegant, obtuse, and difficult to manipulate; yet they appear to be inadequate for studying measurable features of underwater acoustic noise. The FFT and third-octave band analyses may be good practical techniques, but they have no support in stochastic theory. At the close of this contract Carpinella was beginning to sort the details from the principles. This work will continue unsupported, and any practical results will certainly show up in subsequent work under other ONR contracts.

Appendix A

TECHNICAL REPORTS AND MEMORANDUMS

The following technical report (thesis) and memorandums were produced wholly or in part under Contract N00014-75-C-0174.

1. G. N. Cederquist, The Use of Computer-Generated Pictures to Extract Information from Underwater Acoustic Transfer Function Data, Cooley Electronics Laboratory Technical Report No. 227, The University of Michigan, Ann Arbor, April 1975. ADA010 229.

2. G. N. Cederquist, CONSYS: A Collection of FORTRAN Subroutines to Produce Contour Maps of Data Surfaces Defined on Rectangular Grids, Cooley Electronics Laboratory Technical Memorandum No. 112, July 1976. ADA027 871

3. G. N. Cederquist, PERSYS: A Collection of FORTRAN Subroutines to Produce Perspective Views of Data Surfaces Defined on Rectangular Grids, Cooley Electronics Laboratory Technical Memorandum No. 113, August 1976. ADA030 152

Appendix B

CONFERENCE PAPERS AND SYMPOSIA

The following conference papers and symposium presentations were supported wholly or in part by Contract N00014-75-C-0174.

1. G. N. Cederquist, "The FLECS Preprocessor for FORTRAN," Computing Center, The University of Michigan, Ann Arbor, October 6, 1975.

2. G. N. Cederquist, "Program Microstructuring," Computing Center, The University of Michigan, Ann Arbor, January 15, 1976.

3. G. N. Cederquist, "A Survey of Recent Practical Developments in the Art of Program Construction," Western Michigan University, Kalamazoo, Southwestern Chapter of Association for Computing Machinery, February 18, 1976.

4. G. N. Cederquist, "An Interactive System for Time Series Analysis and Display of Water Quality Data," 5th International CODATA Conference, International Council of Scientific Unions, Denver, Colorado, June 28, 1976.

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