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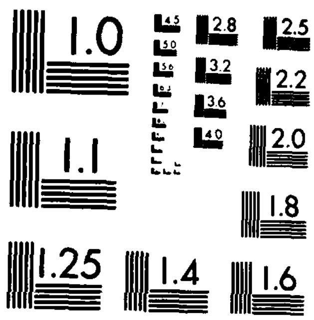

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Joint Services Electronics Program
DAAG29-81-K-0024
April 1, 1982 — March 31, 1983

TWO-DIMENSIONAL SIGNAL PROCESSING AND STORAGE AND THEORY AND APPLICATIONS OF ELECTROMAGNETIC MEASUREMENTS

June 1983

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

ANNUAL REPORT

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School of Electrical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

covers these

This is an annual report on research conducted under the auspices of the Joint Services Electronics Program. Specific topics covered are: digital signal processing, parallel processing architectures, two-dimensional optical storage and processing, hybrid optical/digital signal processing, electromagnetic measurements in the time domain, and automatic radiation measurements for near-field and far-field transformations.

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INTRODUCTION

This is an annual report on research carried out under Contract DAAG29-81-K-0024 during the period April 1, 1982 through March 31, 1983. The research activities were concentrated in two areas: 1) Two-Dimensional Signal Processing and Storage, and 2) Theory and Applications of Electromagnetic Measurements.

The research in two-dimensional signal processing and storage focuses on four major areas which overlap and reinforce one another. Digital Signal Processing research deals with the theory, design, and application of digital signal representations and digital signal processing algorithms and systems. The research in Parallel Processing Architectures is concerned with hardware and software problems in the use of multiport memories and multiple microprocessors for high-speed implementations of signal processing algorithms. The Two-Dimensional Optical Storage and Processing research efforts have focused upon holographic storage of information in electro-optical crystals and upon digital signal processing operations that can be incorporated with storage and retrieval functions. Hybrid Optical/Digital Signal Processing is concerned with the theory, implementation, and application of combined optical and electronic digital signal processing techniques. Details of the research in this general area are given under Work Units Number 1 through 6.

The research in electromagnetic measurements is focused upon two major areas. Research in Electromagnetic Measurements in the Time Domain has centered on the development of new methodology for making time domain measurements. The work involves both theoretical and experimental investigations of the use of transient signals to measure the charactertics of materials and electromagnetic systems. Research in Automated Rediation Measurements for Near- and Far-field Transformations has been concerned with assessing the accuracy of computed fields on the surface of lossy radomes and with compensating for probe effects when near-field measurements are made on arbitrary surfaces. Particular attention is devoted to spherical surfaces. This research is described under Work Units 7 and 8.

II. SIGNIFICANT RESEARCH ACCOMPLISHMENTS

The year covered by this report has produced many useful and potentially important results. These results are documented in the theses, the conference presentations, the journal articles, the book chapters and the patents listed in this report. The following accomplishments are, in the judgement of the laboratory directors, of particular significance and worthy of special consideration.

2.1 New Algorithms for Multidimensional Fourier Analysis

During the past year several optimal and programmable algorithms have been developed for evaluating a very general class of multidimensional discrete Fourier transforms. These algorithms should have a significant impact on the design and implementation of frequency domain beamformers, on the design and analysis of phased arrays, and in multidimensional spectrum estimation. (See Work Unit 2)

2.2 New Results on Directivity of Antennas Over a Material Half-Space

The directive properties of the horizontal circular-loop antenna for transmission into a material half-space have been examined in detail, both theoretically and experimentally. In a practical application, the half space might be the earth or the dielectric substrate for a printed circuit antenna. An important result of this study is that the resonant loop has a maximum directivity when it is slightly raised above the interface. A plane wave spectral analysis performed for a general antenna over a material half-space provided a physical explanation of the directive properties observed for the circular loop. This analysis should prove useful in the design and optimization of antennas for transmission through a material interface. (See Work Unit 7)

2.3 New Results on Imaging and Image Enhancement

Research on the modification of imaging systems in connection with hybrid optical-electronic signal processing has resulted in two significant developments: 1) the determination of the conditions under which coherent wave amplitude distributions can be imaged on a true linear-in-wave-intensity basis, and 2) the invention of a new class of imaging systems for pre-detection image enhancement. Linear-in-wave-intensity imaging has direct applicability to the problem of speckle reduction in laser radar imaging; the results of this study clarify issues raised in earlier work conducted by researchers at the MIRADCOM Research Directorate at Redstone Arsenal. The image enhancement technique, which is easily implemented by the insertion of complementary (often binary) masks in the source and pupil planes of a conventional imaging system, provides a convenient, low-noise, fully parallel method of improving contrast and enhancing structural detail in an image prior to input to a digital image processing system. (See Work Unit 6)

WORK UNIT NUMBER 1

TITLE: Constrained Iterative Signal Restoration Algorithms

SENIOR PRINCIPAL INVESTIGATOR

R. M. Mersereau, Professor
R. W. Schafer, Regents' Professor

SCIENTIFIC PERSONNEL

C. C. Davis, Graduate Research Assistant (Ph.D. candidate)
A. G. Katzaggelos, Graduate Research Assistant (Ph.D. candidate)
J. Hansen, Graduate Research Assistant

SCIENTIFIC OBJECTIVE

The objective of this research is to study a broad class of iterative signal restoration techniques which can be applied to remove the effects of many different types of linear and nonlinear distortions through knowledge of the distortion operator and prior knowledge of the set of allowable signals. Specific attention is directed towards problems in deconvolution, reconstruction from projections, bandlimited extrapolation, and shift varying deblurring of images.

RESEARCH ACCOMPLISHMENTS

Several of the techniques which have been investigated under this work unit are based upon iteration equations of the form

$$x_o(n) = \sum_{L=1}^{N} \lambda_i(n)*y_i(n)$$

$$\tilde{x}_k(n) = C[x_k(n)]$$

$$x_{k+1}(n) = \tilde{x}_k(n) + \sum_{i=1}^{N} \lambda_i(n)*(y_i(n)-D_i[\tilde{x}_k(n)]).$$

where $y_i(n) = D_i[x(n)]$, $C[\cdot]$ is a constraint operator, and the $\lambda_i(n)$ are linear operators which can be chosen to improve the convergence properties of the iteration. This restoration scheme assumes N signals $y_i(n)$ which are distorted versions of the same signal, $x(n)$.

One application of this iterative scheme is when the distortion operators are linear (i.e. convolutions). An example would be when several blurred versions of the same image are obtained with different blurring operators. It has been shown [1] that in situations where the frequency responses of the blurring operators have zeros, it is possible to restore the original signal if at least one of the frequency responses is nonzero at each frequency. Thus, information which is missing in one signal is provided by another signal. This multiple deconvolution algorithm has been studied with promising results [1] for simulated motion blurs. Future work will focus on noise effects and the extension of the basic principle to the shift-varying case.

Another application of the above iteration scheme is in reconstruction of a multidimensional signal from lower dimensional projections. In this case the distortion operators are projection operators. Using this approach a new algorithm has been developed for the reconstruction from projections problem.

Another approach to deconvolutions was formulated in terms of the principle of minimum entropy. This approach is based upon the assumption that for impulse-type signals which have been blurred by convolution with an unknown impulse response, the impulses can be uncovered by forcing the signal to be concentrated in a few isolated locations (i.e. the locations of the impulses). (R. A. Wiggins, "Minimum Entropy Deconvolution," Geoexploration, 16, pp. 21-35, 1978.) This technique leads to a set of nonlinear equations which must be solved iteratively. Initial results are not promising due to a tendency of the method tc produce unstable models for the unknown distortion impulse response.

The problem of extrapolating a bandlimited signal from known values of the signal has attracted considerable interest due to its implication in spectrum analysis. In the discrete case it has been shown [2] by two different constructive methods that a finite set of samples of a bandlimited signal cannot be uniquely extrapolated. The methods of proof are perhaps of interest in their own right since they show how to contruct a bandlimited sequence with an arbitrarily long interval of consecutive zero samples.

PUBLICATIONS

[1] A. G. Katsaggelos and R. W. Schafer, "Iterative Deconvolution Using Several Different Distorted Versions of an Unknown Signal," Proc. 1983 Int. Conf. on Acoustics, Speech, and Signal Processing, Boston, pp. 659-662, April 1983.

[2] M. H. Hayes and R. W. Schafer, "On the Bandlimited Extrapolation of Discrete Signals," Proc. 1983 Int. Conf. on Acoustics, Speech, and Signal Processing, Boston, pp. 1450-1453, April 1983.

[3] R. M. Mersereau, M. H. Hayes, and R. W. Schafer, "A Survey of Methods for Iterative Signal Restoration," Conf. Record, IEEE Int. Conf. on Communications, Philadelphia, pp. 3G.4.1-3G.4.5, June 1982.

WORK UNIT NUMBER 2

TITLE: Spectrum Analysis and Parametric Modelling

SENIOR PRINCIPAL INVESTIGATORS

R. W. Schafer, Regents' Professor
R. M. Mersereau, Associate Professor

SCIENTIFIC PERSONNEL

J. E. Bevington, Graduate Research Assistant (Ph.D. candidate)
A. Guessoum, Graduate Research Assistant (Ph.D. candidate)
P. A. Maragos, Graduate Research Assistant (Ph.D. candidate)

SCIENTIFIC OBJECTIVE

The objective of this research is to study and develop new techniques for spectrum analysis of one- and two-dimensional signals and to study the use of this analysis in the modelling of two-dimensional signals.

RESEARCH ACCOMPLISHMENTS

Research in this work unit has been concentrated in two major area-algorithms for processing multidimensional signals which are sampled on arbitrary periodic sampling lattices, and applications of linear predictive coding of images to image coding, image segmentation, and boundary detection.

The effort directed at algorithms for processing arbitrary sampled multidimensional signals has been ongoing for several years. During the past year we looked specifically at algorithms for evaluating the multidimensional discrete Fourier transform (DFT) [2]. We have successfully generalized to the multidimensional case the three most common algorithms for evaluating a one-dimensional DFT--the Cooley-Tukey FFT algorithm, Good's prime factor algorithm [1,3] and the Winograd Fourier transform algorithm. The latter two algorithms required the formulation and proof of a Chinese remainder theorem for arbitrary multidimensional lattices. In addition to formulating these algorithms, we have established bounds on their convergence, addressed several issues associated with their programming, and developed alternative aglorithms based on row column decompositions of the sampling lattices [1, 3].

The second major area of concentration concerns applications of linear predictive models for images to image coding, texture segmentation, and boundary detection. Our earlier work on monochrome coding of still images is being prepared for publication [5], and we have begun to generalize these results to the coding of color imagery. Our major effort, however, has been to use the predictor coefficients which result from the LPC model along with the prediction error as features for identifying regions of distinct texture within an image and the boundaries between them. We have applied fairly standard approaches from statistical pattern recognition using the prediction error as a distance measure in LPC feature space [4]. While this distance measure works reasonably well, a number of theoretical issues arise with its use. Our desire to be able to evaluate the LPC parameters over homogeneous regions, has also forced us to perform our analysis over regions with irregular shapes [4]. Our efforts at dealing with these problems are continuing.

PUBLICATIONS

[1] R. M. Mersereau, E. W. Brown, III, and A. Guessoum, "The Evaluation of Multidimensional DFTs on Arbitrary Sampling Lattices," Sixteenth Asilomar Conf. on Circuits, Systems, and Computers, Nov. 1982.

[2] R. M. Mersereau and T. C. Speake, "The Processing of Periodically Sampled Multidimensional Signals," IEEE Transactions on Acoustics, Speech, and Signal Processing, vol. ASSP-31, pp. 188-194, Feb. 1983.

[3] R. M. Mersereau, E. W. Brown, III, and A. Guessoum, "Row-Column Algorithms for the Evaluation of Multidimensional DFTs Defined on Arbitrary Sampling Lattices," 1983 IEEE Int. Conf. on Acoustics, Speech, and Signal Processing, pp. 1264-1267.

[4] P. A. Maragos, R. M. Mersereau, and R. W. Schafer, "Two-dimensional Linear Predictive Analysis of Arbitrary Shaped Regions," 1983 Int. Conf. on Acoustics, Speech, and Signal Processing, pp. 104-107.

[5] P. A. Maragos, R. M. Mersereau, and R. W. Schafer, "Two-Dimensional Linear Prediction and its Application to Adaptive Predictive Coding of Images," submitted to IEEE Trans. on Acoustics, Speech, and Signal Processing, May 1983.

WORK UNIT NUMBER 3

TITLE: Signal Reconstruction from Partial Phase and Magnitude Information

PRINCIPAL INVESTIGATOR

M. H. Hayes, Assistant Professor

SCIENTIFIC OBJECTIVE

Reconstructing a signal from only the phase or magnitude of its Fourier Transform are important problems which arise in a wide variety of different contexts and applications. Signal reconstruction from only magnitude information, for example, is a problem which naturally occurs in such diverse fields as crystallography, astronomy, and optics where the phase of an electromagnetic wave is either lost or impractical to measure, i.e., only intensity data is available. The ability to reconstruct a signal from only phase information, on the other hand, has potentially useful applications i such fields as seismics, ocean acoustics, radar and sonar signal processin and image processing. Specifically, phase-only signal reconstruction techn ques may be applied to the problems of deconvolution, time-delay estimatio system identification, spectral factorization, and phase unwrapping.

The long range goal of this research is to address some importa questions and practical issues related to the phase-only and magnitude-only reconstruction problems for discrete multidimensional signals. Included in this work will be an investigation into the importance of "amplitude" information in the representation of signals, the development of some new approaches for reconstructing a signal from its spectral magnitude, a study of the sensitivity of phase-only reconstruction algorithms to measurement errors and computational noise and, finally, an investigation into possible approaches for robust signal reconstruction in the presence of noise. As a result of this work, some practical and important signal processing problems such as deconvolution will be re-examined in the context of phase-only or magnitude-only reconstruction.

RESEARCH ACCOMPLISHMENTS

It was recently demonstrated that a one or two-dimensional signal is uniquely defined in terms of its spectral amplitude, i.e., spectral magnitude along with one bit of phase information, provided the signal is causal and has finite support. Following up on this result, some extensions which pertained to the recovery of signals from spectral magnitude and noisy phase were considered. Although no theoretical results are available at this time, some preliminary experimental results indicate that the phase accuracy necessary for signal recovery given exact spectral magnitude information is minimal.

Following up on some earlier work concerned with the importance of boundary conditions in the phase retrieval problem, some generalizations of the conditions required for off-axis holography were developed. Specifically, for two-dimensional discrete fields $x(m,n)$ with rectangular regions of support, the two-dimensional (m,n)-plane was divided up into eight different regions consisting of four quarter planes and four semi-infinite stri ps. It was then shown that if a single point source is located in any one of these quarter planes and is positioned arbitrarily close to the 2-D field x(m,n) then it is possible to reconstruct the boundary values of this field from its autocorrelation (spectral magnitude) and, consequently to recursively reconstruct the entire field. Alternatively, it was shown that if two of the semi-infinite strips contained a single point source, again positioned arbitrarily close to the 2-D field, then is again possible to reconstruct the boundary values and, hence, the entire 2-D field from its autocorrelation.

Finally, using some of the mathematical machinery acquired in the development of some of the theoretical results related to this work, a constructive proof that the band-limited extrapolation of a discrete band-limited sequence is not unique was developed. (See Work Unit Number 1.)

PUBLICATIONS

[1] P. L. Van Hove, M. H. Hayes, J. S. Lim, and A. V. Oppenheim, "Signal Reconstruction From Fourier Transform Amplitude," to appear in IEEE Trans. Acoust., Speech, and Signal Proc.

[2] M. H. Hayes and T. F. Quatieri, "Recursive Phase Retrieval Using Boundary Conditions," to appear in Journal of the Optical Society of America.

[3] M. H. Hayes, "The Representation of Signals in Terms of Spectral Amplitude," Proc. 1983 Int. Conf. on Acoust., Speech, and Signal Proc., pp. 1446-1449, April 1983.

[4] M. H. Hayes and R. W. Schafer, "On the Bandlimited Extrapolation of Discrete Signals," Proc. 1983 Int. Conf. on Acoust., Speech, and Signal Proc., pp. 1450-1453, April 1983.

[5] R. M. Mersereau, M. H. Hayes, and R. W. Schafer, "A Survey of Methods for Iterative Signal Reconstruction," Proc. 1982 Int. Conf. on Comm., pp. 3G4.1-3G4.5.

WORK UNIT NUMBER 4

TITLE: Multiprocessor Architectures for Digital Signal Processing

SENIOR PRINCIPAL INVESTIGATOR

T. P. Barnwell, III, Professor

SCIENTIFIC PERSONNEL

C. J. M. Hodges, Research Engineer
Peter Yue, Graduate Research Assistant (Ph.D. candidate)
David Schwartz, (Ph.D. candidate)
Z. H. Tumeh, Graduate Research Assistant
Y. S. Lee, Graduate Research Assistant
M. J. T. Smith (Ph.D. candidate)

SCIENTIFIC OBJECTIVES

The objective of this research is to develop techniques for the automatic generation of optimal and near-optimal implementation of a large class of digital signal processing (DSP) algorithm on digital machines composed of multiple processors.

RESEARCH ACCOMPLISHMENTS

This research is centered on the problem of generating efficient implementations for a large class of DSP algorithms using multiple programmable processors. This problem is fundamental in many areas including implementations using VLSI design; implementations using arrays of state machines, signal processing chips, or microprocessors; and implementations using networks of general purpose computers.

DSP algorithms are unique in the sense that they usually have very high computational requirements and relatively simple control requirements. For this reason, it is often possible to use the system synchrony and the system architecture to intrinsically implement the control functions and to allow optimal utilization of the processors on the pure arithmetic tasks. Traditionally, this problem has been approached from two poles: SIMD structures, where all the processors execute exactly the same program in lock-step; and graph-structured machines, such as data flow computers, where the architecture is configured to the graph structure. The SIMD approach leads to very efficient implementations, but it is very inflexible. In contrast, fully implemented graph-structured machines achieve the maximum attainable throughput (for a particular algorithm and processor), but are generally inefficient.

More recently, there has been considerable interest in a class of multiprocessors called Systolic Arrays. These machines are simply synchronous MIMD structures with highly constrained communications. Such machines are well matched to the constraints of VLSI design both because they use multiple processors which only differ in their control (store) functions and because their limited communications are well matched to the realities of VLSI design. Like SIMD machines, systolic arrays use the system snychrony to realize the central function, and can result in very efficient implementations. The main problem with systolic array implementations is that they present the system designer with a different complex multidimensional pipeline problem to solve for every algorithm to be implemented. By centering on the architecture rather than the algorithms, the commonalty between the fundamental constraints imposed by the algorithms has not been properly explored. As a result, the solutions to individual problems remain pragmatic and ad hoc.

Our approach can be considered to be a set of techniques for compiling DSP algorithms for optimal implementation on systolic arrays, although we do not encourage this interpretation. A far better interpretation is to state that we are working on a general theory and a corresponding set of techniques which are applicable to the problem of optimally implementing DSP algorithms on synchronous multiprocessors. Our work is centered on understanding the general relationships between the algorithmic constraints and the architectural constraints. Stated simply, our work is centered on the algorithm, and the details of the architecture/implementation are a result and not the starting point. The fact that our design techniques often appear to be aimed at systolic arrays is simply a reflection of the fact that the concept of systolic arrays is a good encapsulation of the constraints imposed by many hardware environments.

Our initial approach has been to study the overlap of a class of algorithms, a class of multiprocessors, and a class of implementations. The algorithms are all those techniques which can be specified by single-time-index signal flow graphs, and all algorithms which can be transformed into single-time-index signal flow graphs by restructuring or decimation. This class of algorithms includes all single and multiple dimension digital filters, time varying filter structures, sequential matrix operations, and many more. The class of multiprocessors consists of all machines composed of identical, synchronous, programmable processors. The class of implementation is all those attainable using the Skewed Single Instruction Multiple Data (SSIMD) approach which attains the efficiency of SIMD while being nearly as flexible as the graph-structured approach.

In this context, efforts this year have produced several note worthy results. First, many of the theoretical results from last year,s work with regard to optimal implementations with SSIMD have been implemented in the form of a multiprocessor computer. During the same period, the multiprocessor computer hardware has been augmented with a disk based control processor, and a new (revision 3) operating system has been completed. These two developments are currently being combined to form a fully automatic SSIMD multiprocessor compiler and loader. These are largely the work of Mr. Lee and Mr. Hodges, respectively.

In the theoretical area, advances have been made in understanding the bounds and implementation issues associated with block filter realizations. It has been clearly demonstrated that block filters have advantages for filter implementation in situations where speed is of great importance. This is largely the work of Mr. Schwartz.

In the multiprocessor application area, a new high-speed co-processor based on the TMS-320 Texas Instruments' signal processing chip has been designed and is currently being implemented by Mr. Tumeh. This design replaced a previous design which has been made obsolete by the advent of the TMS-320.

Finally, in the area of time-frequency representation of signals, it has been shown that there exist analysis-reconstruction filter banks which allow for high quality filter banks, require the same number of frequency domain samples as time domain samples, and which allow exact reconstruction. This work, which was done largely by Mr. Smith, appears to be of considerable importance.

PUBLICATIONS

[1] T. P. Barnwell, III and C. J. M. Hodges, "A Synchronous Multi-processor System for Implementing Digital Signal Processing Algorithms," Professional Program Session Record 21 of Southcon-82, pp. 21:4-1-21:4:6, March 1982 (invited).

[2] T. P. Barnwell, III, C. J. M. Hodges, and M. Randolph, "Optimum Implementation of Single Time Index Signal Flow Graphs on Synchronous Multiprocessor Machines," Proceedings of ICASSP-82, Paris, France, pp. 687-690, May 1982.

[3] T. P. Barnwell, III and C. J. M. Hodges, "Optimal Implementation of Signal Flow Graphs on Synchronous Multiprocessors," Professional Program Session Record 22 of Electro/82, June 1982 (invited).

[4] T. P. Barnwell, III, "Synchronous Techniques for Signal Flow Graph Implementation," NSF Workshop on Digital Signal Processing, Washington, DC, June 1982.

[5] T. P. Barnwell, III and C. J. M. Hodges, "Optimal Implementation of Signal Flow Graphs on Synchronous Multiprocessors," Proceedings of the 1982 International Conference on Parallel Processing, Belaire, MI, August 1982.

[6] T. P. Barnwell, III and C. J. M. Hodges, "Optimal Implementation of DSP Algorithms on Synchronous Multiprocessors," Proc. of Workshop on Algorithmically Specialized Computer Organizations, Oct. 1982.

WORK UNIT NUMBER 5

TITLE: Two Dimensional Optical Storage and Processing

SENIOR PRINCIPAL INVESTIGATOR

Thomas K. Gaylord, Professor

SCIENTIFIC PERSONNEL

M. G. Moharam, Assistant Professor
W. E. Baird (Instructor)
C. C. Guest, Graduate Research Assistant (Ph.D. Candidate)
M. Mirsalehi, Graduate Research Assistant (Ph.D. Candidate)

SCIENTIFIC OBJECTIVE

The scientific objective of this research is to develop broadly-based, theoretical and experimental knowledge of high-capacity two-dimensional optical digital processing and two-dimensional optical information storage. This brings together a range of concepts from basic physics to signal processing in its most generalized form. Optical digital parallel processing in forms such as a word/signature detector, multiport memories, and a parallel numerical processor are being investigated.

RESEARCH ACCOMPLISHMENTS

The rigorous coupled-wave theory was developed under Joint Services Electronics Program sponsorship. This year, we were invited to publish a review paper on this new theory and how it relates to previous approximate theories. This invited paper was published in the May 1982 issue of Applied Physics [1]. Our method provides, for the first time, a straightforward method to analyze diffraction from gratings accurately. This approach has been adopted by numerous companies (I.B.M., Bausch and Lomb, Perkin Elmer, Marconi Avionics, etc.), laboratories (Bell Labs, Systems Research Laboratories, Battelle Columbus Laboratories, etc.), and universities (University of Southern California, Tel-Aviv University, University of South Flordia, etc.). Applications include laser beam deflection, modulation, coupling, filtering, distributed feedback, holographic beam combining, wavelength multiplexing and demultiplexing, optical digital parallel processing, acousto-optic signal processing, spectrum analysis, diffractive optics, and head-up displays. In the last year the rigorous coupled-wave analysis has been extended by us to surface-relief (corrugated) gratings [2]. This is the case most often used in making diffractive optical elements. In addition, the theory has been extended to any general polarization incident upon the grating together with the possibility of losses in the medium [3]. The only case that cannot be analyzed by rigorous coupled-wave theory is that of a pure reflection grating (with grating fringes parallel to the surface). We have, however, developed a rigorous chain-matrix approach to handle this case [4].

A patent was issued to us this year for "optical holographic content-addressable memory system for truth-table look-up processing" [5]. This is an extension of the basic system that we are investigating under JSEP sponsorship. Presently, we are analyzing our system experimentally and theoretically to determine the probability of a false alarm and the probability of miss for the operations of addition and multiplication performed using binary and residue number systems in the presence of laser beam amplitude and phase errors.

New research into the logical reduction of truth-tables for both look-up optical processors and VLSI programmable logic arrays has been started. A program written in ALGOL has been generated to determine the minimum number of logical function minterms for each output bit that are needed for addition and multiplication using binary and residue arithmetic. Some simple cases have been finished.

PUBLICATIONS

[1] Gaylord, T. K. and Moharam, M. G., "Planar Dielectric Grating Diffraction Theories," Applied Physics B, vol. 28, pp. 1-14, 1982. (invited)

[2] Moharam, M. G. and Gaylord, T. K., "Diffraction Analysis of Dielectric Surface-relief Gratings," Journal of the Optical Society of America, vol. 72, pp. 1385-1392, October 1982.

[3] Moharam, M. G. and Gaylord, T. K., "Rigorous Coupled-wave Analysis of Grating Diffraction -- E Mode Polarization and Losses," Journal of the Optical Society of America, vol. 73, pp. 451-455, April 1983.

[4] Moharam, M. G., and Gaylord, T. K., "Chain-matrix Analysis of Arbitrary-thickness Dielectric Reflection Gratings," Journal of the Optical Society of America, vol. 72, pp. 187-190, February 1982.

[5] C. C. Guest and T. K. Gaylord, "Optical Holographic Content-Addressable Memory System for Truth-Table Look-Up Processing," U. S. Patent No. 4,318,581, issued March 9, 1982.

WORK UNIT NUMBER 6

TITLE: Hybrid Optical/Digital Signal Processing

SENIOR PRINCIPAL INVESTIGATOR

William T. Rhodes, Professor

SCIENTIFIC PERSONNEL

Mr. Joseph Mait, Graduate Research Assistant (Doctoral candidate)

Mr. Robert Stroud, Graduate Research Assistant (Doctoral candidate)

SCIENTIFIC OBJECTIVE

The overall goal of this work is the development of hybrid optical/electronic techniques for 2-D signal processing that complement existing and projected digital methods. Major areas of activity include (1) a theoretical investigation and experimental implementation of incoherent optical systems for bipolar spatial filtering; (2) the development of hybrid optical/electronic Fourier scanning techniques for highspeed image processing; (3) the investigation of partially coherent optical methods for adaptive fully parallel image enhancement; and (4) the investigation of hybrid techniques for shift-variant 2-D signal processing.

RESEARCH ACCOMPLISHMENTS

Bipolar Incoherent Spatial Filtering. Conceptual and analytical aspects of multiple-objective constrained 2-D iterative processing were developed as they applied to joint pupil function specification. Initial progress has been made in applying techniques of LaGrange multipliers to the global optimization of pupil functions for hybrid processors.

Fourier Transform Scanning Image Processor. After considerable effort, remaining bugs in the electronic control system for the processor have been eliminated. Preparations are now being made for basic proof-of-principal experiments. A newly installed oven-stabilized etalon on the argon laser is expected to reduce system noise.

Partially Coherent Image Processing. Work has continued on the investigation of partially coherent imaging systems, which use complementary source and pupil distributions, for the enhancement of photographic and similar recorded imagery. Results obtained in a preliminary experimental evaluation of the basic method are extremely promising. Tests to be conducted this spring are expected to show the great potential of these methods in the pre-processing of low-contrast imagery for input to digital processors.

Space-Variant Image Processing. A hybrid time- and space-integration technique for holographic signal recording has been invented that has potential application to space-variant image processing. Study of high-speed acousto-optic methods for algebraically-oriented signal processing has continued.

PUBLICATIONS AND PRESENTATIONS

Conference Presentations (No Proceedings):

[1] W. T. Rhodes, "Acousto-optic Algebraic Signal Processing," 1982 Gordon Research Conference on Optical Processing and Holography, Plymouth, NH, June 1982.

[2] W. T. Rhodes and M. Koizumi, "Linear-in-intensity Imaging of Coherent Wave Fields," 1982 Annual Meeting of the Optical Society of America, Tucson, October 1982.

Conference Presentations (Proceedings):

[1] J. N. Mait and W. T. Rhodes, "Dependent and Independent Constraints For A Multiple Objective Iterative Algorithm," in Signal Recovery and Synthesis with Incomplete Information and Partial Constraints, Optical Society of America, Incline Village, Nevada, January 1983, THA14-1 through THA14-4.

[2] W. T. Rhodes, A. Tarasevich, N. Zepkin, "Complex Covariance Matrix Inversion with a Resonant Electro-optic Processor," Two-Dimensional Image and Signal Processing, G. Morris, ed., Los Angeles, January, 1983 (Proc. SPIE, Vol. 3888, pp. xx-xx, 1983).

[3] W. T. Rhodes and M. Koizumi, "Image Enhancement by Partially Coherent Imaging," 10th International Optical Computing Conference, H. J. Caulfield, ed., Boston, March 1983 (IEEE Pub. No. , 1983).

Chapters in Books:

[1] W. T. Rhodes, "The Falling Raster in Optical Signal Processing," in Transformations in Optical Signal Processing, W. T. Rhodes, J. R. Fienup, and B. E. A. Saleh, eds. (SPIE, Bellingham, 1983).

WORK UNIT NUMBER 7

TITLE: Electromagnetic Measurements in the Time Domain

SENIOR PRINCIPAL INVESTIGATOR

G. S. Smith, Associate Professor

SCIENTIFIC PERSONNEL

Dr. J. D. Norgard, Professor
Mr. W. Scott, Graduate Research Assistant (Ph.D. candidate)

SCIENTIFIC OBJECTIVE

The broad objective of this research is to develop new methodology for making electromagnetic measurements directly in the time domain or over a wide bandwidth in the frequency domain. This research includes the development of theoretical analyses necessary to support the measurement techniques. One aspect of the research is the systematic study of radiating structures placed near or embedded in material bodies. In a practical situation the radiator might serve as a diagnostic tool for determining the geometry, composition or electrical constitutive parameters of the body.

RESEARCH ACCOMPLISHMENTS

The research on the directive properties of coaxial arrays of circular-loop antennas near a material interface was completed during this period. The results are described in a conference paper and journal article submitted for publication [2]. This work showed that a single loop or an array of loops in a dielectric half space 1 could have a very directive field pattern into the adjacent dielectric half space 2; the directively at a point directly below the loop increasing with the ratio of permittivities ϵ_2/ϵ_1. The directivity has a peak when the loop is close to the interface.

A general analysis to explain the unusual directive properties of antennas near a material interface, including the circular loop, is in progress. The analysis uses the plane wave spectral representation of the electromagnetic field. The research accomplished to date provides a general physical picture of the factors that produce the directive properties of the antennas like the circular loop [3].

The electrically short monople antenna is being studied as a diagnostic probe for determining the electrical constitutive parameters of materials. Methods for inverting the measured admittance to determine the constitutive parameters have been developed, and an experimental program to validate the method by measuring the permittivity of temperature controlled liquids is in progress.

The monopole of general electrical length excited by a transient signal is also being studied as a probe for measuring the electrical constitutive parameters over a broad band of frequencies. During the past year, the errors associated with the inversion procedure have been studied. These include the errors due to the inaccuracies of the instrumentation as well as the errors caused by the multi-valuedness of the inversion.

Publications and Presentations

[1] L. N. An and G. S. Smith, "The Horizontal Circular-loop Antenna Near a Planar Interface," Radio Science, vol. 17, pp. 483-502, May-June 1982.

[2] G. S. Smith and L. N. An, "Loop Antennas For Directive Transmission into a Material Half-space," presented at the 1982 URSI Symposium, Albuquerque, New Mexico, May 1982; also submitted for publication.

[3] G. S. Smith, "Directive Properties of Antennas for Transmission into a Material Half-space," to be presented at the 1983 URSI Symposium, Houston, Texas, May 1982; also submitted for publication.

WORK UNIT NUMBER 8

TITLE: Automated Radiation Measurements for Near and Far-Field Transformations

SENIOR PRINCIPAL INVESTIGATOR

Edward B. Joy, Professor

SCIENTIFIC PERSONNEL

G. K. Huddleston, Associate Professor
W. M. Leach, Jr., Associate Professor
T. E. Brewer, Instructor
L. E. Corey, Graduate Research Assistant (Ph.D., December 1980)
B. E. Eisenman, Graduate Research Assistant (M. S., December 1980)
T. G. Picard, Graduate Research Assistant (M. S., June 1981)
R. E. Wilson, Graduate Research Assistant
G. R. Scott, Graduate Research Assistant
J. M. Rowland, Graduate Research Assistant
K. Hsu, Graduate Research Assistant

SCIENTIFIC OBJECTIVE

The objectives of this work are:

1. Development of a general theory for probe position error compensation for near field measurements performed on arbitrary surfaces.

2. Development of an indirect measurement method to determine the fields on the surface of a dielectric shell enclosing a radiating antenna to serve as an analytical tool in isolating deficiences in analysis methods.

3. Development of a computationally efficient near field coupling equation between a test antenna and a measuring probe when the probe is used to sample the field radiated by the test antenna over the surface of a sphere.

RESEARCH ACCOMPLISHMENTS

An approximate technique for probe position error was formulated, computer implemented and demonstrated. Accuracy for small probe position errors was shown to be very good. This approximate technique known as "K-correction" is a phase only correction and based on the assumption of all near field energy propagating in the K-direction of the main beam peak. This technology was transferred to the RCA, U. S. Navy Aegis program and is now in use. Alignment of the Aegis phased array was judged impossible without this technology. Current efforts are underway on two approaches of near-field-probe position-error-compensation for spherical surface measurements.

The desired coupling equation, when the field radiated by the test antenna and the field radiated by the measuring probe are expressed in the form of plane wave spectrum expansions, has been derived and is being documented for submission for publication. The final solution for the spherical wave mode coefficients is not complete. When this is completed, the theoretical work will be complete.

Efforts have been directed to the preparation of the Automated Radiation Laboratory for the measurement of electromagnetic fields on a sphere near a radome-enclosed antenna. (Spherical wave expansions will be used in a far-field and to near-field transformation to determine the fields on the radome surface. These fields will be compared with those computed using existing algorithms and the radiating characteristics of the antenna without radome). All interface hardware has been constructed and bench-tested. Current efforts are directed toward development of the computer software to control the positioning of the test antenna, to sample and record the amplitude and phase of the antenna responses as measured by the network analyzer, and to transmit the voluminous measured data to the central computer for processing.

PUBLICATIONS AND PRESENTATIONS

[1]. E. B. Joy and G. R. scott, "Shape Effects on Optimal Radome Wall Design," Proceedings of the Sixteenth Symposium on Electromagnetic Windows, June 1982, Atlanta, Georgia.

[2]. G. K. Huddleston, "Effects of Ray Refraction and Reflection on Radome Boresight Error Calculations Using Geometrical Optics and Lorentx Reciprocity," Proceedings of Sixteenth Symposium on Electromagnetic Windows, June 1982.

[3]. E. B. Joy and R. E. Wilson, "A Simplified Technique for Probe Position Error Compensation in Planar Surface Near Field Measurements," Proceedings of the Antenna Measurements Technique Association 1982 Meeting, Las Cruces, NM, October 5-7, 1982, pp. 14-1 through 14-10.

[4]. G. K. Huddleston, "Simplified Scattering Models for Polarimetric Processing Radar," 2nd Workshop on Polarimetric Radar Technology, Redstone Arsenal, May 1-3, 1983.

[5]. V. V. Jory, E. B. Joy, W. M. Leach, Jr., "Current Antenna Near-Field Measurement Research at the Georgia Institute of Technology," Proceedings of the 13th European Microwave Conference, Nurnberg, West Germany, September 5-8, 1983.

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