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13. ABSTRACT *(Maximum 200 words)*

The study of digital signal processing is to a large extent the study of algorithms, but there is a natural classification into algorithms for design and algorithms for actual processing. Our research has been mainly concerned with the latter classification and has addressed structural constraints which arise because of resource limits and/or a desire for efficiency. This has led in a number of problems to some algebraic decomposition of algorithms with the intent of achieving parallelism and quality, as measured by the degree of approximation (bias) and roundoff noise and similar errors (variance). More recently, we have been studying problems which involve both classes of algorithms; for example, what is a good design (filter function or window) which must conform to structural constraints dictated by processing considerations. This has proven to be a rich area of application.

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Final Report Summary

High-speed parallel processing has made possible many real-time applications of digital signal processing. Our research has been mainly concerned with the design of algorithms within this context. We shall summarize the problems studied and the contributions made below. Detailed descriptions of our findings will be found in the references listed in Part II of this report.

In references [2], [3], and [6], adaptive array processing problems are studied with the goal of finding numerically efficient updates of the singular value decomposition of the data matrix. This problem is important in the tracking of time-varying subspaces, a generalization of the notion of separating a time series into signal and noise components. The main contributions include a numerical stabilization technique which eliminates the error buildup problem in a computationally efficient manner within the context of practical, real-time computation.

In references [1], [7], and [8], the classical problem of spectral factorization is addressed using a Newton-Raphson algorithm. By enforcing symmetry, a special Euclidian algorithm with some remarkable properties emerges. It involves updates which are formally equivalent to a backwards Levinson algorithm, which may have inherent parallelism. Furthermore, the set of minimum phase polynomials is preserved under the update.

In references [4], [5], [10], and [13], another classical problem is studied. A quite general theory of what is possible in the bias/variance tradeoff in using quadratic estimators for the power spectrum is developed. A very interesting time-frequency localization bound can be found in [4]. In [13], a new multiple-window quadratic estimator with some remarkable algebraic properties is described. The windows involve a form of time division multiplexing with circular shift constraints. These constraints allow for an algebraic decomposition of the problem of finding orthogonal, time-shifted windows with maximum frequency selectivity. While the estimator requires the computation and storage of only one window function, its performance is very simlar to that of the Thomson estimator, which uses the Slepian window set.

In references [14] and [15], a problem of designing wavelets with maximum frequency selectivity subject to a constraint involving the length of the underlying FIR filter and the regularity (or number of zeros at $z = -1$) is characterized and solved. The solution involves characterizing extremal wavelets in terms of their zeros on the unit circle and then finding the zeros of the extremal filter via a generalization of the classical problem of numerical quadrature. A doubly symmetric Euclidian algorithm for the robust determination of the magnitude of the wavelet frequency function is also developed.

In references [9], [11], and [12], some parametric modeling problems are addressed. In [9], a unified approach to low-order modelling which involves projections within high-order models is found to include several of the classical model reduction methods.

List of manuscripts submitted or published under ARO sponsorship during this period, including journal references:

1. C. J. Demeure and C. T. Mullis, "Fast Newton-Raphson Method for Moving Average Spectral Factorization." *Proc XIIth GRETSI Colloque*, Juan-Les-Pins, France (June 1989).
2. K. A. Byerly and R. A. Roberts, "Output Power Based Partial Adaptive Array System," *Proceedings of the 23rd Asilomar Conference on Signals, Systems, and Computers*, Pacific Grove, CA (November 1989).

3. M. P. Clark and R. A. Roberts, "Real-Time Adaptive Beamforming Using Rank-One Eigenstructure Updating," *Proceedings of the 23rd Asilomar Conference on Signals, Systems, and Computers*, Pacific Grove, CA (November 1989).

4. L. L. Scharf and C. T. Mullis, "Quadratic Estimators of the Power Spectrum," Chapter One of *Advances in Spectrum Estimation*, Ed. Simon Haykin (Englewood Cliffs, NJ: Prentice Hall, 1990).

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6. R. A. Roberts and R. D. DeGroat, "Efficient, Numerically Stabilized Rank-One Eigenstructure Updating," *IEEE Trans on ASSP* **ASSP-38**:2 (February 1990).

7. C. J. Demeure and C. T. Mullis, "Generalized Moving Average Spectral Factorization," *Proc Vth EUSIPCO Conference*, Barcelona, Spain (September 1990).

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9. B. Derras and C. T. Mullis, "A Unified Approach to System Approximation," *AMSE Journal* **23**:1 (1991).

10. M. Clark, C. T. Mullis, and L. L. Scharf, "Quadratic Estimators of the Frequency-Wavenumber Spectrum," *Proc 1991 ICASSP Conf*, Toronto, Ont (May 1991).

11. C. Fajre, "Application of Hankel Forms in the L^∞ Approximation Problem," M.S. Thesis, University of Colorado at Boulder (1991).

12. C. Fajre and C. T. Mullis, "The L^∞ Wiener Problem: An Application of the L^∞ Extension Problem," *Proc EUSIPCO 92 Conf*, Brussels, Belgium (August 1992).

13. M. Clark and C. T. Mullis, "Quadratic Estimation of the Power Spectrum Using Orthogonal Time-Division Multiple Windows," *IEEE Trans Signal Proc* **SP-41**:1 (January 1993).

14. K. Aas, "Analysis and Synthesis of Filter Banks for Wavelet Decompositions and Subband Coding," Ph.D. Thesis, University of Colorado at Boulder (May 1993).

15. K. Aas, K. Duell, and C. T. Mullis, "Characterization and Design of Wavelet Generating Filters," submitted to *IEEE Trans Signal Proc* (1991).

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Report of inventions (by title only):

None.