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13. ABSTRACT (Maximum 200 words) Motivated by the goal of efficient, effective, high-speed integrated-circuit realization, we have discovered an algorithm for high speed Fourier analysis called the Arithmetic Fourier Transform (AFT). It is based on the number-theoretic method of Mobius inversion, a method that is well suited for integrated-circuit realization. The computation of the AFT can be carried out in parallel, pipelined channels, and the individual operations are very simple to execute and control. Except for a single scaling in each channel, all the operations are additions or subtractions. Thus, it can reduce the required power, volume and cost. Also, analog switched-capacitor realizations of the AFT have been studied. We have also analyzed the performance of a broad and useful class of data-adaptive signal estimation algorithms. This in turn has led to our proposed improvements in the methods. We have used perturbation analysis of the rank-reduced data matrix to calculate its statistical properties. The improvements made have been demonstrated by computer simulation as well as by comparison with the Cramer-Rao Bound.	
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High Resolution Signal Processing

Final Report

**By
Donald W. Tufts**

August 23, 1993

U.S. Army Research Office

Proposal No. 27620-MA-SDI

The University of Rhode Island

**Approved for Public Release;
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Part A: Statement of the Problem Studied

Future theater-defense systems must be designed to reliably locate, identify and track enemy missiles and aircraft, and static and mobile radar installations, more rapidly than presently possible. The desired information regarding a missile, aircraft etc. is encoded in the signal which is observed by a radar receiver or in the outputs measured at an array of antenna elements or Infra Red (IR) sensors. The observed signals are often weak and are contaminated by background noise and strong jamming signals. Using the observed data we wish to extract parameters of interest such as the angles of arrival of electromagnetic waves impinging on an array of antenna elements, the Doppler frequencies and Doppler rates of chirp signals and the time delays between received signals. It is important to be able to use this information to determine and track the locations and velocities of moving and fixed targets.

Part B: Summary of the most Important Results

We are working to overcome the algorithmic and computational difficulties of obtaining high resolution optical and radar imagery. The motivation is to provide discrimination of decoys from targets and to provide better classification and tracking of targets. The needed large apertures operating at short wavelengths can suffer from aberration which will cause a blurring of the imagery.

Motivated by the goal of efficient, effective, high-speed integrated-circuit realization, we have discovered an algorithm for high speed Fourier analysis called the Arithmetic Fourier Transform (AFT). It is based on the number-theoretic method of Mobius inversion, a method that is well suited for integrated-circuit realization. The computation of the AFT can be carried out in parallel, pipelined channels, and the individual operations are very simple to execute and control. Except for a single scaling in each channel, all the operations are additions or subtractions. Thus, in addition to significantly speeding up an FFT-based approach, it can reduce the required power, volume and cost. Also, analog switched-capacitor realizations of the AFT have been studied.

The AFT has also been modified to compute the Discrete Cosine Transform (DCT) and extended to calculate two-dimensional Fourier coefficients. Thus, the AFT can be applied to the representation and processing of images and to multi-dimensional array processing.

We have also proposed an iterative AFT. This method overcomes the difficulty of dense Farey-fraction sampling that is inherent in the original algorithm. The disadvantage of the original AFT algorithm has been turned into an advantage and dense frequency domain samples are obtained without any additional interpolation or zero-padding. The iterative AFT has been extended to 2-D signals as well.

We have also analyzed the performance of our previously proposed data-adaptive signal estimation algorithm. This in turn has led to our proposing an improvement in the technique. We have used perturbation analysis of the rank-reduced data matrix to unveil its statistical properties. The improvements made over our original technique have been demonstrated by computer simulation as well as by comparison with the Cramer-Rao bound.

We have investigated a multi-stage procedure to achieve good local resolution of significantly overlapping components in a transient signal. At each stage we coarsely identify (as compared to the next stage) broad regions in the time-frequency plane that have significant energy. In each sub-region, detection of signal components is done in the presence of interference from neighboring regions using our previously proposed technique of employing signal eigenfilters.

We have also proposed a new fractionally-spaced equalizer (FSE) for adaptive, digital communication whose time span is a single symbol period. Also, a sub-optimal minimum mean-squared error (MMSE) receiver has been developed. Its performance is shown to be good at reasonable input SNRs and for short training periods as well. This receiver has been developed for a linear, time-invariant (or slowly varying) channel.

Part C: List of Publications and Technical Reports

- * " The Effects of Perturbations of Matrix-Based Signal Processing", by Donald Tufts, *Proceedings of the IEEE, Fifth Acoustic Speech and Signal Processing, Workshop on Spectrum Estimation and Modeling*, pp.159-162, October 10-12, 1990.
- * " One-Dimensional and Two -Dimensional Discrete Cosine Transforms Using the Iterative Arithmetic Fourier Transform", by Haiguang Chen and Donald Tufts *Proceedings of the Third Biennial ASSP Mini conference*, April 19-20, 1991.

- * " On Improving the Detection of Gabor Components of Transient Signals", by G.F. Boudreaux-Bartels, Donald Tufts, and S. Umesh, *Proceedings of the Third Biennial Mini conference on Acoustics Speech and Signal Processing, ASSP*, April 19-20 1991.
- * " A Suboptimum Linear Receiver Based on a Parametric Channel Model", by Melbourne Barton and Donald Tufts, *IEEE Transactions on Communications*, Vol. 39, No. 9, September 1991.
- * " Computation of the Discrete Cosine Transform Using the Iterative Arithmetic Fourier Transform", By Haiguang Chen and Donald Tufts , *Journal of Visual Communication and Image Representation*, Vol.2, No. 4 PP.395-404, December 1991
- * "Iterative Realization of the Arithmetic Fourier Transform", by Donald Tufts and Haiguang Chen, *IEEE Transactions on Signal Processing*, January 1992.
- * " A Low Rank Weighted Matrix Approximation Method for Robust Estimation of Sinusoid Parameters", by Geoffrey Edelson, Ramdas Kumaresan, and Donald Tufts, *IEEE Proceedings of the International Conference on Acoustics Speech and Signal Processing*, 1992, March 23-26, 1992.
- * " Resolving the Components of Transient Signals by a Multistage Procedure", by S. Umesh and Donald Tufts, *Proceedings of the International Conference on Acoustics Speech and Signal Processing*, 1992, March 23-26, 1992.
- * "Estimation of the Signal Component of a Data Vector: Analysis of Old and New Matrix Based Methods", by Abhijit Shah and Donald Tufts, *Proceedings of the International Conference on Acoustics Speech and Signal Processing*, 1992, March 23-26, 1992.
- * " Resolving the Components of Transient Signals using the Neural Networks and Subspace Inhibition Filter Algorithms, by E. Wilson, S. Umesh, and D.W. Tufts, *Proceedings of the International Joint Conference on Neural Networks, IJCNN*, Vol.4, pp. 283-288, June 1992
- * "Estimation of a Signal Waveform from Noisy Data Using Low-Rank Approximation to a Data Matrix", by Donald Tufts and Abhijit Shah *IEEE Transactions on Signal Processing*, Vol.41., No.4, April 1993.

- * " Blind Wiener Filtering: Estimation of a Random Signal in Noise Using Little Prior Knowledge", by Donald Tufts and Abhijit Shah, *IEEE Proceedings of the International Conference on Acoustics Speech and Signal Processing, 1993*, Vol.4, pp.236-239, April 1993.
- * " Multistage Neural Networks Structure for Transient Detection and Feature Extraction", by Beth Wilson, S. Umesh and Donald Tufts, *IEEE Proceedings of the International Conference on Acoustics Speech and Signal Processing, 1993*, Vol. 1, pp. 489-492, April 1993
- * " Computation of the Discrete Cosine Transform Using the Iterative Arithmetic Fourier Transform", By Haiguang Chen and Donald Tufts , *Journal of Visual Communication and Image Representation*, Vol.2, No. 4 PP.395-404, December 1991.
- * " Fast Maximum Likelihood Estimation of Signal Parameters Using the Shape of the Compressed Likelihood Function", by Donald Tufts, Hongya Ge, & S. Umesh, *Invited Paper to Appear in the IEEE Journal of Oceanic Engineering*, October 1993.
- * " Estimating the Frequencies of Two Sinusoids using only the Phase Angles of Complex-Valued Data, by Hongya Ge and Donald Tufts, *IEEE Transactions on Signal Processing*, Vol.41, No.5, pp. 1982-1986, May 1993.

Report of Patents

- 1) U.S. Patent Number #4,999,799. March 12, 1991
" Signal Processing Apparatus for Generating a Fourier Transform"
- 2) Patent applied for :
"Signal Processing Apparatus and Method for Interactively Determining Arithmetic Fourier Transforms", January 1992

Part D: Scientific Personnel:

Professors:

Professor Donald W. Tufts
Professor Ramdas Kumaresan
Professor Richard Vaccaro
Professor James Cooley

Support Staff:

Scientific Research Grant Assistant: Mark Kenyon
Scientific Research Grant Assistant: Andrea Quist
Secretary Patricia Watkins

Graduate Students:

Degrees Granted:

Haiguang Chen PhD 1991
Daniel Moonan MS 1992

Unfinished Degrees:

Nagesh Anupindi
Hongya Ge
Faezeh Haddad Goha
Shubasish Kundu
Craig Macinnes
Thulasinath Manickam
Victor Manzella
Abhijit Shah
S. Umesh

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