AD-A271 181 [...]TION PAGE

Form Approved OMB No. 0704-0188

(2)

1.	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 19, 1993	FINAL REPORT: 4/13/90 to 4/12/93

4. TITLE AND SUBTITLE

High Resolution Signal Processing

5. FUNDING NUMBERS

DAAL03-90-G-0106

6. AUTHOR(S)

Donald W. Tufts

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

The University of Rhode Island
Electrical Engineering Department
Kelley Annex
Kingston, R.I. 02881

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U. S. Army Research Office
P. O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

ARO 27620.13-MA

11. SUPPLEMENTARY NOTES

The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

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.

14. SUBJECT TERMS Fourier Analysis, Spectrum Analysis, Direction of Arrival (DOA) Estimation, Interference Suppression, Signal Parameter Estimation, Frequency Estimation, & Signal Estimation

15. NUMBER OF PAGES 5

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to ***stay within the lines*** to meet ***optical scanning requirements***.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	- Contract	**PR**	- Project
G	- Grant	**TA**	- Task
PE	- Program Element	**WU**	- Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."
DOE - See authorities.
NASA - See Handbook NHB 2200.2.
NTIS - Leave blank.

Block 12b. Distribution Code.

DOD - Leave blank.
DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
NASA - Leave blank.
NTIS - Leave blank.

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

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

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