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We have created new tools for

- Developing a formalism in terms of shift and stride permutation operators and scalable tensor product kernels for modeling complex networks of multirate filter systems and an algebra for automatic manipulation of fundamental parameters including network topologies.
- Applying new mathematical tools to the theory of multidimensional multirate filter structure which bring out the fundamental role played by direct sum decompositions and short exact sequences and permit a unified treatment of both standard and new algorithms featuring new topologies, communication paths and data structures.
- Developing new algorithms for constructing families of unitary transforms (group trnasforms) from the Clifford theory of idempotents and studying the applications of these unitary transforms to multirate filtering and transform coding.

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This report consists of three parts: research, collaboration and academic.

Research

Rapid advances in system design tools and computer technologies offer the potential of parallel and distributed computing of highly complex and computationally intensive multirate filter systems. Typically applications to image processing, communications and automatic target recognition feature the need to process and analyze large quantities of data by a variety of sophisticated mathematical techniques. Usually an extensive special programming effort is required to achieve necessary levels of performance which must often be repeated for even small changes in system design or target architecture. This effort can be extremely time consuming and error prone greatly limiting and delaying the impact of these new technologies on the science and engineering community. During the last year we have created new tools which promise to utilize and extend these advances at minimal time and cost in software development by

- Developing a formalism in terms of shift and stride permutation operators and scalable tensor product kernels for modeling complex networks of multirate filter systems and an algebra for automatic manipulation of fundamental parameters including network topologies.

- Applying new mathematical tools to the theory of multidimensional multirate filter structure which bring out the fundamental role played by direct sum decompositions and short exact sequences and permit a unified treatment of both standard and new algorithms featuring new topologies, communication paths and data structures.

- Developing new algorithms for constructing families of unitary transforms (group trnasforms) from the Clifford theory of idempotents and studying the applications of these unitary transforms to multirate filtering and transform coding.

Some aspects of this research will be presented in an invited address at 102nd annual meeting of the Americal Mathematical Society in Orlando, FL in January 1996. Moreover this research has resulted in several papers and presentations at conferences.

- "Algebra of Multidimensional Multirate Structures," submitted for presentation.

- "Group Algebras and Orthogonal Decompositions," preprint.

- "Weyl-Heisenberg Systems and Finite Zak transform," accepted for publication, *Journal of Visual Communication and Image Representation*, Academic Press, Inc.

- "The Computation of Weyl-Heisenberg Coefficients for Critically Sampled and Over-sampled Signals," *SPAT ICSPAT94*, **2** pp824-829, Oct. 1994.

I expect and have verbal agreement that complete results of this research will appear in bookform to be published by Birkhauser.

Several student projects at CCNY have implemented codes analyzing and testing the efficiency of the algorithms developed in this research as well as thier applicability to transient signal detection, transform coding and signal analysis.

Collaboration

- With Professor Patrick Combettes of CCNY, a project is under way to combine time-frequency and time-scale analysis methods with convex projection methods for applications to large scale image processing. An NSF proposal has been submitted with professor Robert Alfano of CCNY as the principal investigator.

- With Professor A.J. Devaney of Northeastern University a project is underway to develop and implement wavelet based multirate filter algorithms for several projects including applications to ultrasound tomography and radar imaging.

- With Professor A.J. Devaney of Northeastern University a project is underway to study new physical models and algorithms to solve phase retrieval problems in imaging and crystallography. One aspect of this research in collaboration with Professor B. York of Northeastern University applys to the problem the new single isomorphic replacement methods introduced by Professor C. Giacovazzo of University of Bari, Italy. Several papers are in preparation including one which develops the role of data symmetry in reducing and organizing code for fundamental triplet calculations. This collaboration had resulted in submitted and plans for future proposals.

- Atlantic Aerospace Electronics Corporation has been developing algorithmic strategies for the efficient execution of SPW^{TM} programs and other system design tools in a multiprocessor environment. These system design tools have the capability of creating custom coded blocks and building complicated functionality by heirarchical block-nesting, but tools for translating complex system designs into efficient multiprocessor codes are still primitive. With Dr. R. Orr of Atlantic Aerospace Electronics Corporation a still pending SBIR to NSF has been written whose goal is to develop sophisticated tools for carrying out efficient multiprocessor implementations.

Grants and Contracts

FY 95 AFOSR MURI Topic: Computational Electromagnetics
Subcontract Topic: Mathematics of Computing

STTR, F49620-95-C-0073
Thermal Analysis of Multichip Modules Using Domain Decomposition and Wavelet-Capacitance Matrix

Academic

The graduate program in Electrical Engineering at CCNY has been subject to much criticism during the last few years as tuition increases and the difficulty of post graduate employment has greatly reduced the student body with a subsequent reduction in cost offerings. The program has a large minority enrollment having limited networking skills as to relevant fields of study and as to possible employment opportunities. One purpose of this sabbatical was to bring to these students a more focused program of digital signal processing based on an understanding of those fundamental courses, engineering culture and application areas which would best serve their intellectual and career potential. A related goal was to establish contact and possibly close relationships with potential sources of problems and employment so that students' research efforts could be better directed. Multirate filtering and multiprocessor algorithmic development were chosen as target areas as these tools are expected to be of long time significance to a wide range of applications to the DoD and medical imaging community. During this last year important contacts have been made at Northeastern University, Hanscom Air Force base and Atlantic Aerospace Electronics Corporation which have already born fruit as to employment opportunities. Moreover, at CCNY several new courses in DSP, multirate filter design and computer architecture have been introduced and serve as a basis to new courses and proposals in imaging, radar and multiprocessor implementation.

Publications during the Grant Period

1. "Algebra of Multidimensional Multirate Structures," submitted to *Journal of Applied Mathematics*, North-Holland.

2. "Group Algebras and Orthogonal Decompositions," preprint.

3. "Weyl-Heisenberg Systems and Finite Zak transform," accepted for publication, *Journal of Visual Communication and Image Representation*, Academic Press, Inc.

4. "The Computation of Weyl-Heisenberg Coefficients for Critically Sampled and Over-sampled Signals," *SPAT ICSPAT94*, **2** pp824-829, Oct. 1994.

5. with R. Orr, "Poisson Summation, the Ambiguity Function, and the Theory of Weyl-Heisenberg Frames," *The Journal of Fourier Analysis and Applications* **1** 3, 1995.

6. with A. Brodzik, "Weyl-Heisenberg Systems and the Finite Zak Transform," accepted for publication.

7. with I. Gertner, "Multiplicative Zak Transform", *Jour. Visual Comm. and Im. Rep.* **6** 1, March 1995, 89–95.

8. with M. An, Y Abdelatiff and N. Anupindi, "Group Invariant Fourier transform," *Adv. in Electronics and Electron Phys.,* **93**, P. Hawkes, Ed., Academic Press, 1995.

9. With G. Kechriotis, M. An, M. Bletsas and E. Manolakos, "A New Approach for Computing Multidimensional DFT's on Parallel Machines and its implementation on the iPSC/860 Hypercube," *IEEE Trans. on Signal Proc.* **43**1, 272-285, January, 1995.

10. with S. Qian, C. Lu and M. An, "Self-Sorting In-Place FFT Algorithm with Minimal Working Space," *IEEE Trans. on Signal Proc.* **42**10, 2835-2836, October, 1994.

11. with M. An and C. Lu, "DSP algorithm design and implementation on RISC architectures," presented at the first international conference on Electronics and Information Technology (ICEIT'94) held in Beijing, China.

12. with M. An C. Lu and S. Qian, "Self-sorting In-place FFT Algorithm with Minimum Working Space", *IEEE Trans. on Signal Processing,* **42**10, 1994.

13. with M. An and C. Lu, *Mathematics of Multidimensional Fourier Transform Algorithms*, October 1993, Springer-Verlag, New York.

14. with M. An, C. Lu adn S. Qian, "A Hybrid Parallel FFT Algorithm without Interprocessor Communication," *Proc. of IEEE Inter. Conf. on ASSP*, 1993.