STUDY OF ONE- AND TWO-DIMENSIONAL FILTERING AND DECONVOLUTION ALGORITHMS FOR A STREAMING ARRAY COMPUTER

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The development of vector processing computers of the streaming array architectures has made possible a dramatic decrease in the time required for the solution of many problems. The largest improvement has come for those algorithms which readily lend themselves to sequential operations on long vectors.

There has concurrently been rapid growth in the applications of the techniques generally known as mathematical digital filtering, which are also called signal analysis, digital signal processing, time series analysis, and digital image processing. These techniques are applied to many kinds of data, but perhaps the most well-known applications are to seismic data and two-dimensional images. Many of the data types to which the techniques are applied consist of very large collections of numbers and a major limitation for these cases is the size and speed of the computer available. Often the analysis which is performed does not result in optimum improvement of the data because of this limitation. Therefore a move of the larger problems of mathematical digital filtering to the streaming array architecture can result in marked improvement in the data analysis techniques which may be employed. For this purpose it is useful to study both the nature of the digital filtering algorithms and their adaptability to the streaming array architecture.

This work is concerned with both the study of the filtering and deconvolution algorithms and their suitability for the streaming array architecture. It includes the theses of three graduate students at the University of New Orleans. Two of them, Mr. Mark Whitehorn and Ms. Kathleen Whitehorn, were supported in part by grant funds. The third, Ms. Karin Wright, did grant-related research, although not supported by grant funds. Her work was also related to a previous NASA grant of the principal investigator (NSF-1460) and was also submitted as a part of the final report of that grant. Her work is currently being extended by a graduate student, Mr. James Leclere, and Dr. Juliette Ioup and the principal investigator.

The work of Mr. Mark Whitehorn, included as Appendix 1, describes the application of always-convergent iterative noise removal and deconvolution techniques developed by the principal investigator (while supported in part by the grant) to two-dimensional image data. His work contains an examination of the effect of noise on the method.

Appendix 2 is the thesis of Ms. Karin Wright. In it she studies the optimization of Morrison's iterative noise removal method. Her results also apply to always-convergent iterative noise removal.

Ms. Kathleen Whitehorn's thesis, Appendix 3, concerns the application of transform domain derivative calculations in two dimensions and includes the effects of noise in the data. Sh: uses the Fourier transform derivative theorem and the FF. to calculate derivatives, correct to high order, quickly.

The two most commonly used operations of mathematical digital filtering are the convolution and the fast Fourier transform. Most filtering algorithms use these two operations as their building blocks, and they often comprise the most time-consuming components of the algorithms. Therefore we may divide the work done on this grant into the study of the use of the basic operations in the streaming array architecture on the one hand, and the incorporation of these operations into applications algorithms on the other.

The development of a fast Fourier transform algorithm for one- and two-dimensional data for a streaming array computer has been described by Korn and Lambiotte (1979). The algorithms have also been coded for the Cyber 200 series computer by these authors. Thus the work of this grant did not concern itself with the development of the fast Fourier transform (FFT) algorithm but rather with the filtering operations which might be performed on the transformed data. In this connection an introduction for users to the ideas of the discrete Fourier transform has been written (see Appendix 4). The discrete Fourier transform is the quantity being calculated in the fast Fourier transform program. It is also true that there is a great deal of confusion, especially for the two-dimensional users, among those new to ditigal image filtering, concerning the symmetries, coordinate axis labels, origin of coordinates, and redundancies in the transform. To help clarify these ideas, the discussion of Appendix 4 is presented. The ideas of this appendix have been incorporated into an algorithm which allows the user to perform various types of filtering and to manipulate the transform for display purposes in two dimensions.

The application of filtering in the function domain is performed using the convolution operation. The convolution was analyzed to see how it might be optimized for the streaming array architecture. The convolution for long arrays, especially for two-dimensional arrays, is notoriously slow compared to the performance of the same operation with the fast Fourier transform. When the arrays are adjusted, however, to do filtering with the fast Fourier transform without wraparound error (Oppenheim and Shafer, 1977), which arises from the cyclic nature of the DFT convolution theorem, the time trade-off is not as dramatic. It is still practical, therefore, to perform the convolution with a small filter in the function domain even for a large image. A very basic and important question in function domain filtering is whether to let the convolution expand the size of the input array on output or not. The convolution by its nature produces an output array which is larger than the input array, but the expanded part of the array is not always desired. The logical solution for avoiding inefficient use of computer time and memory is to have two convolution subroutines, one which performs an expanding convolution, and one which does not. We have studied two convolution algorithms for the streaming array architecture, one which leads to the expanded output, and one which only calculates that portion of the output which corresponds to the input array coordinates. To produce the correct results with these convolution algorithms, it is also important that the output arrays be dimensioned correctly. Therefore error checking for the defined array dimensions is incorporated into the algorithm.

Once the transform domain filtering and function domain convolution algorithms are available, what remains is the design of specific filters to be used in each domain. As has been mentioned previously, the discussion of some of these filters is included in the theses which appear as Appendices 1, 2, and 3.

The final appendix, Appendix 5, contains copies of some of the publications related to the grant, whether supported in part by grant funds or not, and current biographical data for the principal investigator. All papers, abstracts, and theses related to the grant, whether supported by grant funds or not, have been marked by an asterisk.