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AN INTERACTIVE ANALYSIS PROGRAM FOR A DIGITAL IMAGE PROCESSING --ETC(U)
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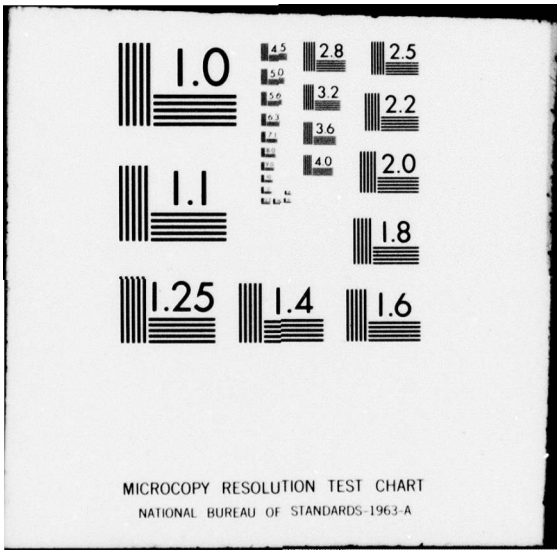
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AN INTERACTIVE ANALYSIS PROGRAM FOR A DIGITAL IMAGE PROCESSING LABORATORY

THESIS

AFIT/GE/EE/78S-16 Dennis A. McGaugh
Capt USA

(14) AFIT/GE/EE/78S-16

(6) AN INTERACTIVE ANALYSIS PROGRAM FOR A DIGITAL IMAGE PROCESSING LABORATORY

THESIS

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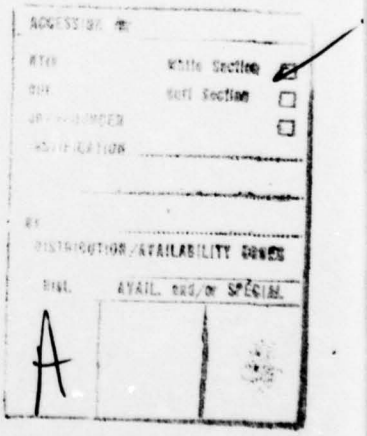

by

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Preface

This work attempts to provide the solution to a problem first identified by Major J. W. Carl of the Air Force Institute of Technology, School of Engineering. The basic problem was to design and implement the software necessary to allow two-dimensional linear filter and two-dimensional Discrete Fourier Transform (DFT) to be performed on an existing minicomputer-based image processing system. With the addition of the routines described in this thesis, true linear filtering of images is now available on the DICOMED Image Processing System. It is hoped that with its filtering capability, and with its 64x64 DFT capability that this new image analysis software will indeed provide a useful analytical tool.

I would like to take this brief opportunity to thank the people without whom this project would have been virtually impossible. Thanks to Captain Fred Barney for his making the DICOMED equipment available and for his patient explanations on the intracacier of same.

A special thanks to my thesis advisor, Major Carl for his saint-like patience and profound guidance during some very trying times. And lastly, but by no means least, thanks to my wife Marla for her typing the thesis rough draft and for her inspirational moral support.

Dennis A. McGaugh

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Abstract

A FORTRAN program is presented that will interactively prepare digitized images (pictures) for experimental analysis. The digital preparation includes the ability to Discrete Fourier Transform (DFT), Inverse Fourier Transform (IDFT), threshold image power spectral density, and to perform two-dimensional image filtering. Further, a brief discussion of image distortion measurements, optimal image size for experimental presentation, and image aliasing is provided. A sample of typical processed image results is also supplied.

AN INTERACTIVE ANALYSIS PROGRAM FOR A DIGITAL IMAGE PROCESSING LABORATORY

I. Introduction

There currently exists, located in the Air Force Avionics Laboratory, image processing hardware and software capable of digitizing and performing limited statistical calculations of pictorial imagery. There also exists a requirement to perform certain image processing with this equipment in preparation for a visual experiment. However, the software needed to conduct the processing did not formerly exist. The types of computations needed to perform this processing and analysis are well-known. But these computations needed to be developed in software and implemented on the particular small computer system that is available.

The image processing functions that are needed include: two-dimensional linear filtering, calculation of a two-dimensional image power spectrum, ability to specify a threshold for this power spectrum, and the Mean-Square-Error (MSE) and Bandwidth (BW) of an image constrained to occupy only those frequencies at which the power spectrum is above a specified threshold. Additionally, it is desired that these functions be interactively controlled and specified to the program during run time.

The problem is to develop and provide a software program capable of accomplishing the above functions, and still

be compatible with the existing equipment. Additionally, part of this thesis work is to determine what is the minimum size of picture digitization (e.g. 64x64, 128x128, 256x256) that will produce pictures suitable for the experiment; that is, a picture that creates an image of no less quality than 30 lines per 1° of visual angle subtended during viewing. The picture digitization will also impact on the computer resources needed to perform the filtering. The experiment currently calls for the use of up to 24 different pictures. These pictures are available in positive or negative form, and have been digitized (2048x2048) and stored on magnetic tape. The sampling resolution may also cause image aliasing problems, and this effect must also be discussed.

The material presented in this thesis follows roughly the same order as discussed above. Chapter II discusses the constraining environment, its effect on program development, and the digital domain for implementation of the required functions. Chapter III briefly describes the laboratory hardware/software and the final project software. Chapter IV presents a sample of processed image results, and Chapter V closes with summary remarks and mention of areas for future work. The appendix contains a program user's guide and complete program documentation.

II. Discussion

During the development of the image analysis program, several important questions had to be answered. The answers to some are rather straight-forward; the answers to others were influenced by answers to previous questions. The answer to each question, and its impact on the design of the image analysis program is presented in the section that follows. After reading these sections, it is hoped that there will be clear understanding of the program constraint environment.

A Question of Image Resolution

The requirement exists to conduct visual experiments with pictorial presentation to human subjects. The images should fall within the subjects' regions of foveal vision; that is, the images should not exceed a visual angle of 2 degrees during viewing. In discussions with (then) Captain Larry Goble of the US Air Force Flight Dynamics Laboratory at Wright-Patterson AFB, Ohio, the point was made that the industry standard for images on graphics and television displays is a twelve-inch square picture viewed at a distance of thirty inches with a resolution of no less than sixty lines per inch. It was also decided that this should be the resolution standard for the analysis program. After some basic geometrical calculations, this works out to be 30 lines of resolution per 1 visual degree (vis). Additionally, the experimental displays require that each visual presentation

consist of two different pictures placed side-by-side. Considering the overall limit of 2° vis vertically and horizontally, this means that for square pictures, each picture can only subtend 1° vis.

The answer to the question of image resolution is that each picture, in order to subtend 1° vis, must be 1/2 inch x 1/2 inch at 30 inches distance from the viewer, and each picture must have a minimum of 30 lines of resolution both horizontally and vertically. Imagery of this quality is obtainable through the use of the laboratory DICOMED image processing equipment. It should be noted, however, that the requirement for number of lines of resolution increases when considering the question of aliasing.

A Question of Aliasing in Digitized Images

The DICOMED image processing equipment digitizes a given picture with a sequential horizontal scanning action. It begins at the top of the picture to be digitized with a horizontal scan the width of the picture. It then proceeds incrementally down the picture with successive, picture width, horizontal scans until it stops at the picture bottom. Both horizontal and vertical directions are discretely sampled with an adjustable number of samples per picture widths (independently chosen in each direction). The result of this scanning process is the mapping of the entire picture into a MxN matrix of M·N discrete pixel values, where M and N are both powers of two. In this application, M was equal

to N. For the DICOMED machine, the value of each pixel can be any one of 256 gray scale levels, from white (377_8) to black (000_8). When referring to the resolution of this resulting digitized picture, it is said to have N lines of resolution, with a sampling rate of N (where $N=2^P$).

The answer to the question of aliasing can be found by referring to the Nyquist sampling theorm (12:68). Restated, it simply says: to eliminate spectrum aliasing in the discrete domain, sample at a rate greater than or equal to twice the spectral width. Therefore, for the previous case of an NxN sampled image, in order to prevent aliasing after discrete Fourier transformations, there must not be any spatial-frequency content above $\frac{N}{2}$ cycles per picture width. The experimental requirement is for a minimum of 30 lines resolution per picture. This means that a digitized picture with this resolution can display up to 30 full oscillations (cycles) between white and black per picture in either the horizontal or vertical direction. Therefore, the display resolution criterion is satisfied if $\frac{N}{2} \geq 30$. Since a DFT/FFT computer algorithim (discussed later) will be used to transform into the Fourier domain, and powers of two run fastest in that algorithim, and since the DICOMED image processing system samples at powers of two, a sampling rate of 64 was selected as the minimum convenient value that N can have and still meet the display resolution criteria. This requires a 64x64 digitization of each image to be processed, and insures that, at this digitization level, the

resolution limits of human observers will be met under the cited viewing conditions.

Now, to insure no image aliasing, it must be guaranteed that there is no spatial frequency, in the image being transformed, above 32 cycles per picture width. To provide this guarantee, all 64x64 digital images used in this work were derived from pictures sampled at a rate much higher than 64 samples per line. The original pictures were first digitized into 2048x2048 images. Then by considering 64x64 blocks of 32x32 pixels, each 32x32 pixel block was averaged into one pixel value. The resultant averaged pixel values produce the required 64x64 digital image. In essence, this procedure performs a two-dimensional, digital low-pass filtering operation on a picture that may contain spatial frequencies of up to 1024 cycles. Although this type of low-pass filtering results in a $\frac{\sin x}{x}$ form for the filter in the frequency domain, and such filters are not particularly good in the stop-band of the filter (considerable side-lobe structure), these effects were ignored since relatively low spatial frequencies are anticipated in the original pictures. This procedure is essentially a digital simulation of the low-pass filtering operation necessary to avoid aliasing.

The Question of Linear Filtering Implementation

The functional requirement for linear filtering implies spatial convolution of the form (10:440):

$$y(n_1,n_2) = x(n_1,n_2) * h(n_1,n_2) = \sum_{m_1=-\infty}^{\infty} \sum_{m_2=-\infty}^{\infty} x(m_1,m_2) \cdot h(n_1-m_1,\ n_2-m_2)$$

where $y(n_1,n_2)$ is the output image result of the $x(n_1,n_2)$ input image that has been filtered by a linear filter with an impulse response of $h(n_1,n_2)$. As noted by Rabiner and Gold (Ref 10), this calculation in the spatial domain with images is not usually soluable in closed form except for the most trivial filters. However, a more tractable form of this convolution equation occurs in the frequency domain. It is well-known (Ref 8) that the convolution equation takes the form:

$$Y(k_1,k_2) = X(k_1,k_2) \cdot H(k_1, k_2)$$

where $Y(k_1,k_2)$, $X(k_1,k_2)$, and $H(k_1,k_2)$ are the Fourier transform coefficients of the image output, image input, and image filter impulse response respectively. Now, the filter computations become readily manageable and almost trivial. They simply involve multiplying each Fourier transform coefficient of the input image with each respective Fourier transform coefficient of the impulse response of the filter. The result is then inverse Fourier transformed back into the spacial domain as the resultant linearly filtered output image.

The transfer function furnished for the linear filtering process is given as a one dimensional equation. Before it can be used to filter an image, however, it must be converted into two-dimensional form. It has been shown by Huang (Ref 6) that a good circularly symmetric two-dimensional linear filter can be obtained from a good one-dimensional

linear filter via the relation:

$$H(k_1,k_2) = \hat{H}(\sqrt{k_1^2 + k_2^2})$$

where $\hat{H}$ is the one-dimensional filter impulse response at the appropriate frequency values of k_1 and k_2. For the situation involving the previously cited 64x64 image matrices, this requires Fourier domain frequency values (k_1,k_2), along both the real and imaginary axis, ranging from -32 cycles to +32 cycles. Due to the circular symmetry of the filter, only one 32x32 quadrant need be calculated from the equation. Once calculated, it is appropriately copied into the other three quadrants of the filter matrix. A more complete explanation of this operation appears in Appendix A.

The Question of Operating in Two Dimensions

The most obvious problem of processing in two-dimensions is simple: it takes longer, and uses more computer memory. For the one-dimensional case, the discrete Fourier transform of a sequence of N samples takes N^2 complex addition and multiplications; in two-dimensions, it takes N^4 operations by brute force. For the one-dimensional case, the filtering process in the Fourier domain requires $2 \cdot N$ complex coefficients to be stored in computer memory; in two-dimensions $2 \cdot N^2$ complex coefficients must be stored. To help reduce these increased requirements associated with two-dimensional processing, certain processing modifications were made.

First was the implementation of the well-known (Ref 8)

Fast Fourier Transform (FFT) technique. This reduces the number of addition and multiplications from N^4 (64^4=16,77,216) to $2N \cdot N\log_2 N$ ($128 \cdot 64 \cdot 6 = 49,152$), a reduction of over 10 to 1. The program implementation of the FFT algorithim is via the FORTRAN subroutine called FOURT. It is a program written by Norman Brenner from the basic program by Charles Rader of MIT Lincoln Laboratory. It is a very versatile program, and offers more options than are required for the particular image processing application. But its very versatility was the reason it was selected, as it will allow calculation of odd sizes of FFT's for images other than the present 64x64 size. A more complete discussion of FOURT appears with the program listing in the appendix.

The second modification was to use disk files to store the images and complex FFT coefficients. In the existing IPS/DICOMED image processing systems each complex number occupies 4 words of storage. For one 64x64 FFT coefficient matrix to be entirely loaded into computer memory it would require 16K words. If, as in a filtering operation, two matrices were to be used at once, then 32K words would be needed; the existing minicomputer core storage is only 28K words. A technique suggested by Oppenhein (Ref 8) to reduce the requirement for two-dimensional core storage is to perform the two-dimensional FFT as a series of one-dimensional FFT's. Further, by first storing the images on random access disk files then reading in only one row or column from each appropriate disk file, the FFT operates on only those two

pieces of data at one time, and the core required to operate the program is dropped to a realizeable size. Although the processing scheme involves huge amounts of computer I/O, the time to compute and store a 64x64 point complex FFT is less than 4 minutes, and the time to accomplish filtering (matrix multiplication) is less than 2 minutes. Additionally, there is an option to have the FFT coefficients normalized by dividing all coefficients by the zero-frequency or DC term, or to have the FFT coefficients remain with their unnormalized values.

A Question of Power Spectrum Thresholding

Once the digitized image is in the Fourier domain, the calculation of the power spectrum is straight-forward. The power spectral density of an image is related to the squares of the absolute value of the Fourier coefficients and is given by:

$$\Phi(u,v) = E\left\{\left|X(u,v)\right|^2\right\}$$

where the expectation is over an ensemble of image transforms. The program implementation for estimating the power spectrum of a set of images is obvious from this equation, and a discussion can be found in Appendix A, Operating Procedures, 5c. The analysis program provides the capability to average up to 24 different image spectrums. These 24 images may be the same ones that are mentioned in the introduction to this paper. It is on this resultant averaged power spectrum that

the thresholding function is expected to be used.

The thresholding function was originally requested to be used with only the power spectrum. However, to provide more flexibility, it is implemented in a manner to allow its use with any specified 64x64 matrix of complex data (i.e. FFT coefficients, or power coefficients). By using the thresholding function, the analysis program user is able to interactively specify a 64x64 complex valued matrix, and to enter a real valued number against which the absolute value of every complex point is compared. The result of this thresholding operation is the creation of a 64x64 matrix which contains (in complex format) the value one for every point above the threshold and a complex zero for every point below the threshold. Both the original matrix and the threshold matrix are then available for further processing.

Since the thresholding is done in the Fourier domain, values that are linearly related (Ref 1:138-141) to spatial bandwidth (BW) and mean-square-error (MSE) are easily calculated. The BW value is simply the number of points above threshold in the Fourier domain. In the spatial domain, these above-threshold values correspond to the image pixels that would be transmitted over a digital channel with relative bandwidth BW. The MSE value is simply the sum of the power values below threshold. In the spatial domain, the MSE corresponds to the error of the image transmitted over a digital channel, with bandwidth BW described above.

The Question of Images and Image File Generation

Originally, the only requirement for image output was to generate a completely processed image ready for experimental testing. However, in an effort to make the analysis program applicable for more general use, the ability to display intermediate results is also provided. A 64x64 image file displaying the results for each of the following functional operations is prepared and stored in DICOMED/IPS format on disk: (1) the reduction of a 2048x2048 image to a 64x64 image; (2) the two-dimensional FFT calculation; (3) the power spectrum calculation; and (4) a fully processed image (either thresholded, linearly filtered, or FFT'd).

Since the images are in DICOMED/IPS format, post-processing with the IPS system is trivially implemented (Ref 7). A sample image file format appears in the appendix.

III. Laboratory Hardware and Software

The imagery equipment used for this work is located in the Avionics Laboratory on Wright-Patterson AFB, Ohio. A detailed description of the equipment is included in Reference 7. Briefly, it consists of a PDP-11/45 minicomputer with 28K of core memory and many peripherals. Included are: one RPØ3 diskpack disk drive, two RKØ5 diskcartridge disk drives, one MTU1Ø tape drive, one 132 column line printer, a Conrac video monitor, and one Tektronix 4000 series graphics terminal. Additionally, the system is interfaced to a DICOMED image scanner/recorder. With this equipment, the capability exists to perform up to a 2048x2048 point digitization of pictures. As the DICOMED digitizes the picture, it is stored on magnetic tape for follow-on processing by the PDP-11/45 Image Processing System (IPS). A description of the IPS software is also included in Reference 7.

A full description of the software written for this thesis appears in the appendix. It is written for interactive use and provides the following capabilities:

1. Image reduction from 2048x2048 to 64x64.
2. FFT of a 64x64 image.
3. Calculation of $\Phi_i(u,v)$ for one image, or an average $\hat{\Phi}(u,v)$ of a standard set of 24 images.
4. Ability to threshold a 64x64 image as previously discussed.
5. Ability to generate a 64x64 filter from a user supplied impulse response equation.

6. Inverse FFT of Fourier coefficients.

By running this program, any one of the above processes can produce an image file that is stored on the RPØ3 disk for display by the IPS system, or hardcopy picture generation by the DICOMED system.

IV. Results

Figure 1 presents some samples of output from the digital image preparation program. It should be noted that Figure 1 was generated with an arbitrary high-pass filter whose transfer function has the form:

$$H(f) = 0.5(1 + \ln(f/10 + 0.1), \text{ for } 0 \leq f \leq 32$$

Also note, that the slight graininess of the 64x64 pictures is due to a blow-up factor of two (4 new points for each original point). This was done solely to provide larger pictures for Figure 1.

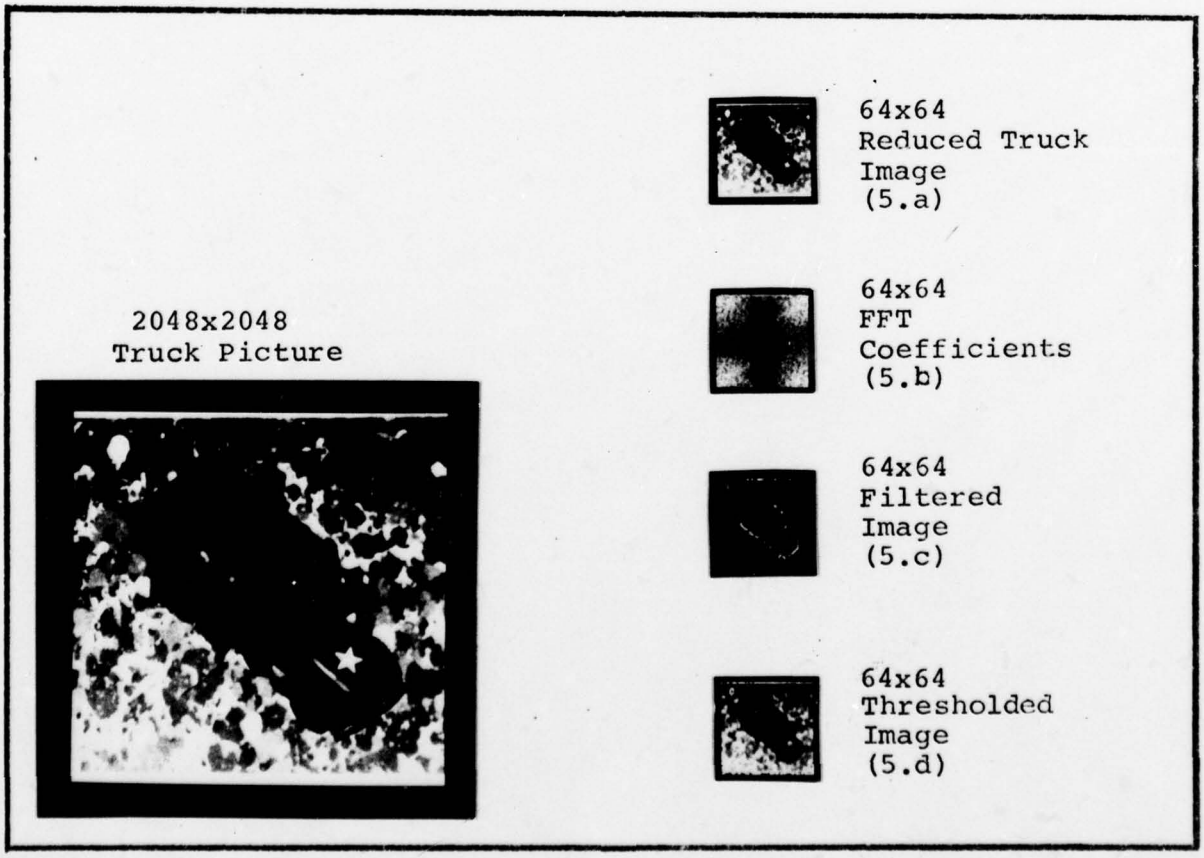

Figure 1. Sample Images

V. Summary and Recommendations

This thesis has presented a computer program to digitally process images, and in this case the processing is motivated by a desire to generate stimuli for a particular psychometric experiment. Additionally, as can be verified by reading the program description in the appendix, a general purpose routine is now made available to tailor digital processing of pictures for a large number of image filtering based applications.

Areas for future work would include modifying the program to process pictures other than the 64x64 size, and an on-line interactive tie-in between the IPS system and the processing program.

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Appendix A

User's Guide for RAZMA.TAZ

Appendix A

User's Guide for RAZMA.TAZ

Introduction

This program allows a user to perform the following functions on IPS/DICOMED images:

1. A reduction of a 2048x2048 image file to a 64x64 image file.
2. A two-dimensional fast-fourier transform (FFT) of a 64x64 image with either normalized or unnormalized coefficients.
3. Calculation of a two-dimensional power spectrum of one 64x64 image file, or the two-dimensional average power of 24, 64x64 images.
4. Specification of a high-pass threshold on either the FFT file or the power file.
5. Generation of a two-dimensional filter (FFT domain) from a user specified impulse response equation.
6. Multiplication of any threshold or filter files with any image or FFT or power files.
7. Calculation of the two-dimensional inverse FFT transform on any modified FFT file.

Reference Material

1. The DOS/BATCH Handbook: Monitor Operating System Version Ø9. Digital Equipment Corporation, Maynard,

Mass. DEC-11-ODBHA-A-D, April 1974.

2. Image Processing Software Conversion, Vol. I & II. Development Center, Air Force Systems Command, Grifiss AFB, New York 13441. February 1977. (ADA038136 & ADA038137).

Operating Procedures

This gives the ordinary routine for running RAZMA.TAZ. Specialized uses and procedures are covered under sub-heading Miscellaneous Operations.

1. Program materials you will need include:

   User's Guide.

   IPS diskcartridge (RKØ5) (AAT Lab-blue label).

   "Scratch" diskcartiridge (RKØ5) (AAT Lab-#6).

   ROLLIN magtape with RAZMA.TAZ program and 24 picture data sets.

   IPS/DICOMED PDP-1445 computer and associated hardware (AAT lab).

2. How to 'power-up':

   a. Place PDP-11/45 console HALT switch down, turn key of console clock-wise to the 'on' position.

   b. Load IPS diskpack in RKØ5 unit #Ø. Load 'scratch' diskpack in RKØ5 unit #1. Do not use 'write protect' switch. Wait until 'on-cylinder' light comes on.

   c. Mount ROLLIN tape on tape drive. This can be omitted if program and data files are already on the scratch diskcartridge or the RPØ disk drive.

   d. Turn on RAMTEK graphics display box.

   e. Slowly turn on line printer, then toggle 'master clear', and toggle 'on-line' switches. This can be omitted if no printer output is expected (normally none is).

f. Open door to RPØ disk drive to see if diskpack #1 (DOS) is installed. If not, retrieve it from the lower cabinet and install it. Turn on power switch and wait until yellow light comes on.

g. Turn on Tektronix 4014 terminal and place it in 'local' mode. Type 'ESC' key, then ':' key. Type in that order, and only once each. This reduces the display front size. Place terminal 'on-line'.

h. Turn on CONRAC video display.

i. Return to the PDP-11/45 console SWR. Set in 000776_8 ('one' is up) and toggle 'load ADR' switch. Set in 000777_8 and toggle 'DEP' switch. Move switch from 'HALT' to 'ENABLE' and hit the 'RUN' switch.

j. Place the thumbwheel of the AED8000 to the 'MAINTENANCE' display and to ADDR CODE = 776732. Push the red IPL switch once. The LED's above the display should begin flashing. If not, go back and try again.

k. Return to the Tektronix terminal and type RKØ: Do not type a carriage return. Enter the date and time in the format shown.

l. Login with $ L0 11,11.

m. Type $ RUN DK1: RAZMA.TAZ, or $ RUN DPØ: RAZMA.TAZ.

n. Follow the yellow brick road.

3. How to 'power-down':

a. To end RAZMA.TAZ, type the 'CTRL' key and the 'C' key simultaneously, followed by 'K' and 'I'. This exits to the DOS monitor. This may also be used to stop the program at any time. Next, type 'FI' to log-out from the IPS/DOS system.

b. Place the terminal in 'LOCAL' mode, give the screen display several RESET's, and turn off the terminal.

c. Turn off the CONRAC video monitor.

d. Return to the PDP-11/45 console and hit the 'HALT' switch.

e. Toggle the switches on both RKØ5 diskcartridge drives to the UNLOAD position. The doors will remain locked until the 'LOAD' light comes on. This will take about a minute. Then the cartridges can be removed.

f. Meanwhile, the following steps may be performed.

g. Toggle the Line printer to 'OFF LINE' and turn it off.

h. Turn off the RAMTEK graphics display box.

i. Push the red IPL switch on the AED8000 once. Push, then release, the yellow power switch on the RPØ disk drive. The yellow light will slowly go out. After it goes out the diskpack can be removed if desired.

j. Unload/dismount the ROLLIN magtape, if it was loaded on the magtape drive, and turn off the magtape drive.

k. Return to the RKØ5 diskcartridge drives and remove the diskcartridges.

l. Turn the key on the PDP-11-45 console fully counter-clockwise to the off position.

4. Running the RAZMA.TAZ. The actual operation of the program is straight forward. A menu of functions is presented first and the user selects the desired function. All prompts are self-explanatory. The format for all ASSIGN commands is given prior to each request for user assignment. Any error in syntax will be caught by the monitor system. However, be very careful to note the device unit number used in the command format. Failure to use the same number when typing in the command can destroy certain necessary stored program files along with the user's specified input file. Should the wrong number be typed, simply retype the command before typing 'CO'. If 'CO' has already been typed, do a 'CNTRL/C', 'KI' immediately. This closes all files and returns control to the DOS monitor. By running FILDMP or

PIP (see DOS/BATCH handbook), the user's files can be verified and/or restored. For verification of program files, see Special Procedures. After file verification or restoration, RAZMA.TAZ can be started normally.

Other than prompts and asking for file assingments there should be no other messages, except when using the FFT, POWER, and IFFT functions. In these cases, an error message will be printed about an overflow on a real to integer conversion. This is normal. It occurs during the generation of each function's image file, and refers to the DC term of the FFT coefficients. It does not affect any in ternal processing calculations. The error merely means that the value of the DC term is greater than 16,384 and exceeds the allowable 256 level gray scale of the DICOMED image processor. The DC pixel value will be zero (black pixel), in the upper left hand corner of any picture created from the image file.

Errors of any other type should not occur. If they do, it is most likely due to processing a bad data from an input file. As before, use FILDMPT or PIP to check input files for correct data.

5. RAZMA.TAZ functions. This briefly describes what each function does and what files are used or generated.

a. REDUCTION. Takes a user specified 2048x2048 image file and averages it's pixels into a 64x64 image file. The routine takes a 32x32 pixel block from the specified file and averages the entire 1024 points into one point of the 64x64 image. The output file is called AVG.IMG.

b. FFT. Performs a two-dimensional fast fourier transform (FFT) on either a user specified image file or the AVG.IMG. file. The resultant coefficients can be either normalized (FFTCOF.NRM file) or unnormalized (FFTCOF.UNN file) as requested by the user. The routine performs the FFT by using the subroutine FOURT, first on each image row, and then on each image column. An image file of the resultant FFT coefficients is also made (FFT.IMG). The DC term is in the upper left-hand corner. This image file may be accessed in the normal manner under the IPS/DICOMED system.

c. POWER. Uses the FFT coefficients to generate a two-dimensional power spectrum. The input file can be a single user specified FFT file, or FFTCOF.NRM, or FFTCOF.UNN. Additionally, the function will calculate the average power spectrum of the 24 storage picture coefficients. The power calculation is simply the squaring of the FFT coefficients. The resultant output file is PWRFFT.COF. An image file is also created (PWRFTT.IMG) for use on the IPS/DICOMED system.

d. THRESHOLD. This function looks a user specified coefficient file, or PWRFFT.COF, or FFTCOF.NRM, or FFTCOF.UMM and creates a file that when used with the MULT function will pass only coefficients above a certain threshold value. This value is entered, interactively, by the user. In addition, the routine counts the number of points above the threshold and calculates a "bandwidth" number; i.e., PTS.ABOVE ÷ 4096 = BW. Also, if the coefficients were POWER coefficients and normalized, it finds the mean-square-error of the thresholded power spectrum; i.e., the amount of power below the threshold setting. The output file contains only a mask of 1's and Ø's at the appropriate location and is called THRHLD.FIL.

e. FILTER. This function takes a user specified filter transfer function equation and computes a two-dimensional mask file which can be used in the MULT program. The value of the mask points are based on the radial distance from the upper left-hand corner of a 32x32 square (Fig 2).

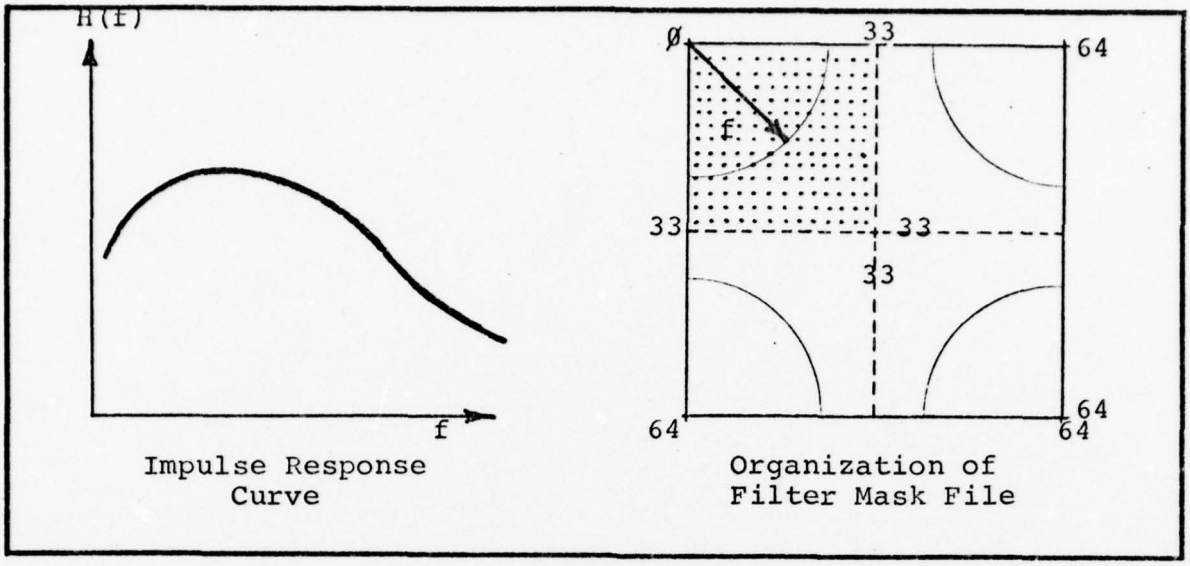

Figure 2. User Specified Filter Impulse Response

The equation is specified on line 515 of the RAZMA.TAZ program listing. To change the equation, the program must be edited and reassembled (see Miscellaneous Operations, b). The resultant output file is FILTER.COF.

f. MULT. This functional routine takes one user specified coefficient file, or THRHOLD.COF, or FILTER.COF and multiplies it point-by-point times another user specified coefficient file, or FFTCOF.NRM, or FFTCOF.UNN, or PWRFFT.COF. It's output file is MULT.DAT.

g. IFFT. This function performs an inverse FFT on the MULT.DAT file. The user cannot directly specify input to this file. But he can however, input indirectly. By giving the THRESHOLD function a threshold of zero, a mask of all one's will be generated. Then, using this mask with MULT and specifying the other MULT input file, the input to IFFT is assured. The output is an image file named PROCSD.IMG. As with all other image files, this is operable on the IPS/DICOMED system.

6. FLOWCHART. The flowchart in Figure 3 shows the processing flow and options available in RAZMA.TAZ.

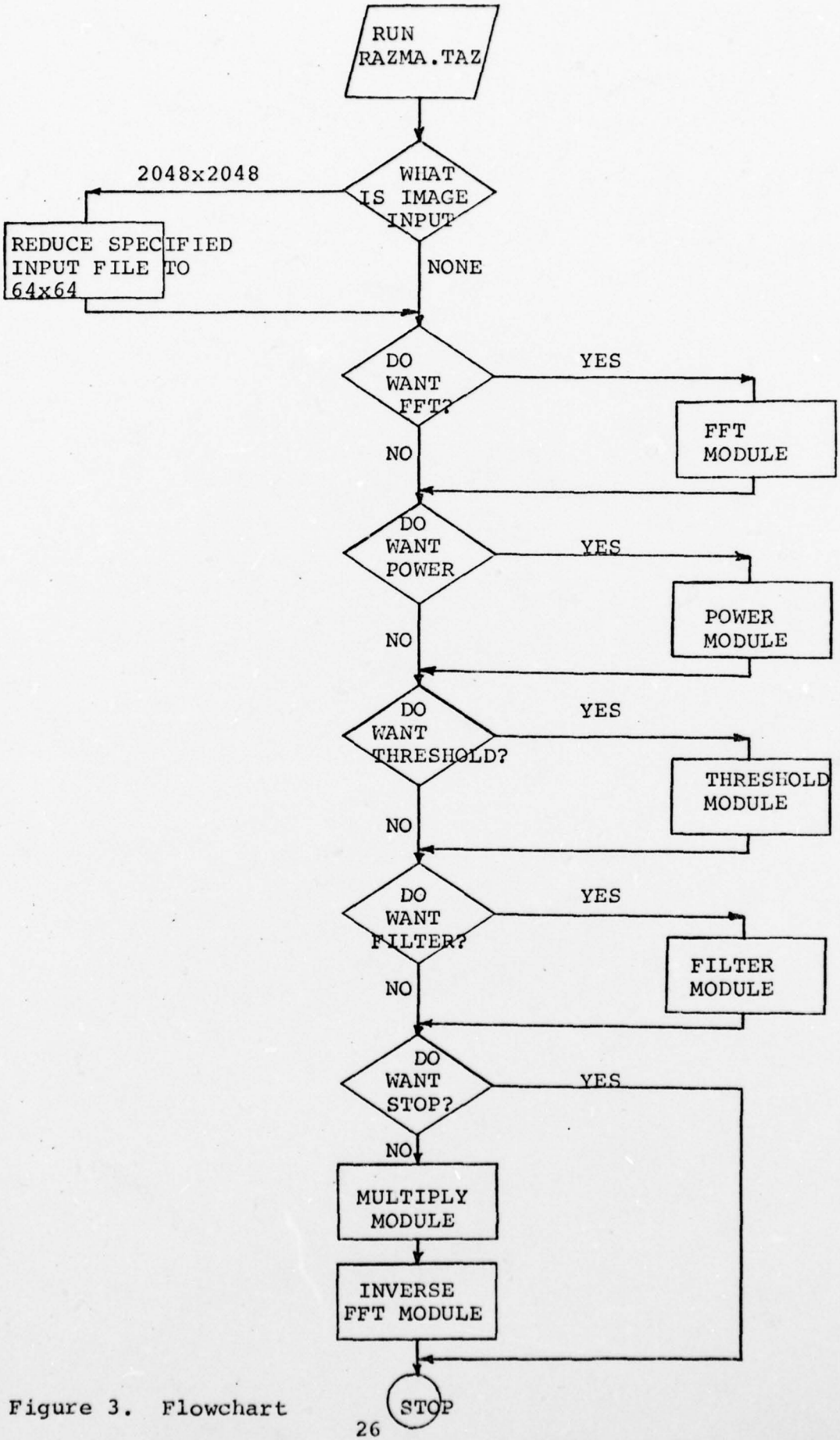

Figure 3. Flowchart

Special Procedures

1. NO FILE! After the $LO and $RUN the monitor answers with NO FILE! When this occurs, run the DOS/BATCH PIP program (see the handbook) and see if RAZMA.TAZ is on the disk you specified in the $RUN command. If not, check the other disk. Remember, you must be logged-in under UIC=11,11. If not on either disk, use the ROLLIN tape and ROLLIN program (in handbook) to restore the RKØ5 diskcartridge on unit #1 (DK1:). Then start POWER-UP procedures

2. UNABLE TO OPEN FILE. This can occur any time during the running of the RAZMA.TAZ program. This usually means that an expected input file (specified by ASSIGN) or one of the 24 standard picture files does either not exist on DPØ: or two files exist with the same name. In either case, run PIP to get a listing of all files on DPØ: to see if all required files are there, and perform file manifulation as appropriate. If file cannot be found on DPØ: or DK1:, it may be necessary to ROLLIN the magtape as in the above step and start again. A minimum of the following files are required:

```
DIRECTORY DK1: [ 11,11 ]

15-SEP-78

ART%1 .COF     64C 13-SEP-78 (233)
ART%2 .COF     64C 13-SEP-78 (233)
ART%3 .COF     64C 13-SEP-78 (233)
ART%4 .COF     64C 13-SEP-78 (233)
APC1  .COF     64C 13-SEP-78 (233)
APC2  .COF     64C 13-SEP-78 (233)
APC3  .COF     64C 13-SEP-78 (233)
APC4  .COF     64C 13-SEP-78 (233)
CVRTK1.COF     64C 13-SEP-78 (233)
CVRTK2.COF     64C 13-SEP-78 (233)
CVRTK3.COF     64C 13-SEP-78 (233)
CVRTK4.COF     64C 13-SEP-78 (233)
OPNTK1.COF     64C 13-SEP-78 (233)
OPNTK2.COF     64C 13-SEP-78 (233)
OPNTK3.COF     64C 13-SEP-78 (233)
OPNTK4.COF     64C 13-SEP-78 (233)
SHER1 .COF     64C 13-SEP-78 (233)
SHER2 .COF     64C 13-SEP-78 (233)
SHER3 .COF     64C 13-SEP-78 (233)
SHER4 .COF     64C 13-SEP-78 (233)
M60A1 .COF     64C 13-SEP-78 (233)
M60A2 .COF     64C 13-SEP-78 (233)
M60A3 .COF     64C 13-SEP-78 (233)
M60A4 .COF     64C 13-SEP-78 (233)
ART%1 .IMG     10C 13-SEP-78 (233)
ART%2 .IMG     10C 13-SEP-78 (233)
ART%3 .IMG     10C 13-SEP-78 (233)
ART%4 .IMG     10C 13-SEP-78 (233)
APC1  .IMG     10C 13-SEP-78 (233)
APC2  .IMG     10C 13-SEP-78 (233)
APC3  .IMG     10C 13-SEP-78 (233)
APC4  .IMG     10C 13-SEP-78 (233)
CVRTK1.IMG     10C 13-SEP-78 (233)
CVRTK2.IMG     10C 13-SEP-78 (233)
CVRTK3.IMG     10C 13-SEP-78 (233)
CVRTK4.IMG     10C 13-SEP-78 (233)
OPNTK1.IMG     10C 13-SEP-78 (233)
OPNTK2.IMG     10C 13-SEP-78 (233)
OPNTK3.IMG     10C 13-SEP-78 (233)
OPNTK4.IMG     10C 13-SEP-78 (233)
SHER1 .IMG     10C 13-SEP-78 (233)
SHER2 .IMG     10C 13-SEP-78 (233)
SHER3 .IMG     10C 13-SEP-78 (233)
SHER4 .IMG     10C 13-SEP-78 (233)
M60A1 .IMG     10C 13-SEP-78 (233)
M60A2 .IMG     10C 13-SEP-78 (233)
M60A3 .IMG     10C 13-SEP-78 (233)
M60A4 .IMG     10C 13-SEP-78 (233)
RAZMA .TAZ     88  15-SEP-78 (233)
RAZMA .FTN     120 15-SEP-78 (233)

TOTL BLKS:  1084
TOTL FILES:  60
```

3. EXPONENT OVERFLOW or OVERFLOW DURING REAL TO INTEGER CONVERSION. This can occur during the operation of all functions except FILTERING or THRESHOLDING. It is the result of processing with invalid data in the assigned input files, or bad data from one of the 24 stored image files. In either case, the contents of files can be inspected using the DOS/BATCH program FILDMP (see handbook). The organization and contents of typical image and coefficient files are shown in Appendix C. If bad data is suspected in any of the 24 noted image files, the best procedure is to use the DOS/BATCH program PIP to restore the files; an example of how to do this is shown in the next section.

4. UNABLE TO READ SPECIFIED FILE FORMAT or END OF FILE-END OF MEDIUM. This occurs when the RAZMA.TAZ program encounters files with improper file organization or length. Again, as above, use FILDMP or PIP to verify and transfer files.

Miscellaneous Operations

1. Generating Files. There are three catagories of files associated with the RAZMA.TAZ program.

   a. Programming operating files. These are files generated by the program for it's own use. A discussion of these files is found in the comments of the program listing.

   b. Twenty-four standard picture file sets. Each picture set consists of an image file and a normalized FFT coefficient file. These picture sets have already been generated and are stored for use by the program in the POWER function. A copy of these files is on the ROLLIN magtape.

   c. User impact files. These are files specified by the user with the ASSIGN command. The file will be either the image or the FFT coefficient type.

      The origin of the image files can be from the IPS/DICOMED system (2048x2048 or 64x64) or the RAZMA.TAZ program (64x64). Directions for creating image files under the IPS/DICOMED system can be found in Volume 1 of Reference 2. Creating a 64x64 image file under RAZMA.TAZ can be accomplished by using the reduction function, and then exiting to use PIP to rename the newly generated AVG.IMG file to whatever name the user desires. To save these files on magtape, PIP and ROLLIN are used. For

each file, the PIP command is: #DK1: name.extn/CO<DPØ: name.extn. Then, ROLLIN is used (DOS/BATCH handbook) to copy DK1: and create a new ROLLIN tape.

The origin of the FFT coefficient files must be from running RAZMA.TAZ. The file is simply created by running the FFT function, and then exiting to use PIP to rename the newly created FFTCOF.NRM or FFTCOF.UNN file to whatever name the user desires. The file can then be saved in the same manner as the image files.

2. Restoring files. For RAZMA.TAZ to operate, all files must be on DPØ:. If they are not (a minimum listing appears in Special Procedures), or for some reasons the files become invalid, the files must be restored. A permanent copy of all files is on the ROLLIN magtape. This tape can be loaded onto DK1: (DOS/BATCH handbook), and then the appropriate file transferred under PIP to DPØ:. The proper PIP command is: #DPØ: name.extn/CO< DK1: name.extn.

3. Changing RAZMA.TAZ. Best advice: DON'T. However, for the brave and/or foolhardy, a bubble chart and program listing is given in Appendix B. Once the changes have been made under EDIT (see handbook), the proper Fortran assembly must be made. The proper command after $RUN FORTRAN is: #DK1: RAZMA, LP:< DK1: edit file name. extn / ON; or, #DPØ: RAZMA, LP:< DK1: edit file name. extn/ON. (Assuming EDIT was done on DK1:). This is important because RAZMA.TAZ uses single word integer variables. When the assembly is done, the linker command after $RUN LINK is: #DK1: RAZMA.TAZ<DK1: RAZMA/CC, DKØ: FTNLIB/L/E; or: #DPØ: RAZMA.TAZ<DK1: RAZMA/CC, DKØ: FTNLIB/L/E as appropriate.

User's Guide

Sample Sessions

EDIT

FORTRAN

PIP

ROLLIN

RAZMA.TAZ

```
RJ EDIT
EDIT-11  V07-03

*DK1:RAZMA.FTN<DK1:RAZMA.FTN
*F
*500AL
            DATA(N)=0.5*(1.0+ALOG(RADIAL*0.1+1.0))
*I.515.U
515         DATA(N)=0.5*(1.0+ALOG(RADIAL*0.1+1.0))
*3L
            DATA(N)=0.5*(1.0+ALOG(RADIAL*0.1+1.0))
520         CONTINUE
*-AA2L
515         DATA(N)=0.5*(1.0+ALOG(RADIAL*0.1+1.0))
520         CONTINUE
*E
*EX

*^C
.KI

$
```

```
$RU FORTRN
FORTRAN  V06.13
*DK1:RAZMA,LP:<DK1:RAZMA.FTN/ON
  C
.KI

$RU LINK

LINK V01-04
*DK1:RAZMA.TAZ<DK1:RAZMA/CC,DK0:FTNLIB/L/E


SPACE USED 030420, SPACE FREE 061132
*^C
.KI

$
```

```
$RU PIP
PIP  V10-02
*DK1:FILTER.IMG/CO<DP0:PROCSD.IMG
*DP0:FILTER.IMG/CO<DK1:FILTER.IMG
*DK1:FILTER.IMG/DI

DK1:

E 11,11 ]

FILTER.IMG     10C 15-SEP-78 <233>


*DP0:FILTER.IMG/DI

DP0:

E 11,11 ]

FILTER.IMG      5C 15-SEP-78 <233>


$^C
.KI

$
```

← RENAMING FILE & STORING FILE

← RESTORING FILE

```
ROLLIN V07

$^'MT0:RAZMA<DK1:/RW/DATE:13-SEP-78
$^'MT0:RAZMA<DK1:/DATE:13-SEP-78
$
```

SAVE TWO COPIES of DISK ON MAGTAPE

```
ROLLIN V07

$DK1:<MT0:RAZMA/FI
$
```

RESTORING DISK FROM MAGTAPE

```
$PU DK1:RAZMA.TAZ

GREETINGS AND SOLUTIONS
SPEAK TO ME ABOUT IMAGE INPUT

TYPE: B FOR BIGGIE /2048X2048/
      J FOR JUNIOR /64X64/
      S FOR STANDARD SET OF 24
      N FOR NONE
J

THE INPUT IMAGE FILE MUST BE SPECIFIED.
IF NOT YET ASSIGNED, PLEASE DO SO NOW, THE FORM IS:
$AS DP0:NAME.EXT,7
THEN TYPE CO TO CONTINUE.
#005 000000
$AS DP0:COURTK4.IMG,7
$CO

TYPE:  N FOR NORMALIZED FFT COEFF
       U FOR UNNORMALIZED COEFF
N

FFT WORKING

FORT003022 REAL OUTSIDE RANGE ON REAL TO INTEGER CONVERSION
NAME    SEQ
MAIN.   00179

DONE FFT

TYPE C TO CONTINUE, TYPE S TO STOP
C

TYPE P FOR POWER, F FOR FILTER, T FOR THRESHOLD
P

TYPE: O, FOR ONLY ONE FFT INPUT, S, FOR STD 24 FFT COEFF
S

SQUARING FFT/S/
FORT003022 REAL OUTSIDE RANGE ON REAL TO INTEGER CONVERSION
NAME    SEQ
MAIN.   00321

DONE POWER

TYPE N TO MAKE NEW THRESHOLD FILE,TYPE O TO USE OLD FILE
N

TYPE:  V FOR VANILLA PLAIN FFT COEFF
       A FOR AVERAGED/SQUARED FFT INPUT
A

SPECIFY A REAL VALUE FOR THE THRESHOLD OF
 THE FORM = 0.0000 /UP TO 15 TRAILING DIGITS/
0.000001

THRESHOLD WORKING

THIS THRHLD.FIL USED A REAL THRESHOLD OF  0.000000[illegible]7
THE ABSOLUTE MSE WAS =  0.000034680684621
AND THE BANDWIDTH WAS= 2022/4096 OR  0.493652344

END THRESHOLD

TYPE C TO CONTINUE,TYPE S TO STOP
C

IF FFT COEFF WERE JUST NOW MADE, THE FILE IS
ALREADY ASSIGNED.  TYPE CO TO CONTINUE.
IF NOT YET ASSIGNED, PLEASE DO SO NOW.  THE FORM IS:
$AS DP0:NAME.EXT,3
THEN TYPE CO TO CONTINUE.
#005 000000
$CO

MULTIPLYING
HA-HA....THINK YOU CAN FOOL MOTHER NATURE EH!
DONE MULT

IFFT WORKING
DONE IFFT
$
```

```
$PU DK1:PAZMA.TAZ

GREETINGS AND SOLUTIONS
SPEAK TO ME ABOUT IMAGE INPUT

TYPE: B FOR BIGGIE /2048X2048/
      J FOR JUNIOR /64X64/
      S FOR STANDARD SET OF 24
      N FOR NONE
J

THE INPUT IMAGE FILE MUST BE SPECIFIED.
IF NOT YET ASSIGNED, PLEASE DO SO NOW. THE FORM IS:
$AS DP0:NAME.EXT,7
THEN TYPE CO TO CONTINUE.
A005 000000
$AS DP0:CUPTK4.IMG,7
$CO

TYPE:  N FOR NORMALIZED FFT COEFF
       U FOR UNNORMALIZED COEFF
N

FFT WORKING

FORT003022 REAL OUTSIDE RANGE ON REAL TO INTEGER CONVERSION
NAME    SED
MAIN.   00179

DONE FFT

TYPE C TO CONTINUE, TYPE S TO STOP
C

TYPE P FOR POWER, F FOR FILTER, T FOR THRESHOLD
T

TYPE N TO MAKE NEW THRESHOLD FILE,TYPE O TO USE OLD FILE
O

THE OLD THRESHOLD FILE MUST BE SPECIFIED.
IF ALREADY ASSIGNED, TYPE CO TO CONTINUE.
IF NOT YET ASSIGNED, PLEASE DO SO NOW. THE FORM IS:
$AS DP0:NAME.EXT,1
THEN TYPE CO TO CONTINUE.
A005 000000
$AS DP0:THRHLD.FIL,1
$CO

IF FFT COEFF WERE JUST NOW MADE, THE FILE IS
ALREADY ASSIGNED.  TYPE CO TO CONTINUE.
IF NOT YET ASSIGNED, PLEASE DO SO NOW.  THE FORM IS:
$AS DP0:NAME.EXT,3
THEN TYPE CO TO CONTINUE.
A005 000000
$CO

MULTIPLYING
AH-HA....THINK YOU CAN FOOL MOTHER NATURE EH!
DONE MULT

IFFT WORKING
DONE IFFT
$
```

```
$PU DK1:PAZMA.TAZ

GREETINGS AND SOLUTIONS
SPEAK TO ME ABOUT IMAGE INPUT

TYPE: B FOR BIGGIE /2048X2048/
      J FOR JUNIOR /64X64/
      S FOR STANDARD SET OF 24
      N FOR NONE
J

THE INPUT IMAGE FILE MUST BE SPECIFIED.
IF NOT YET ASSIGNED, PLEASE DO SO NOW, THE FORM IS:
$AS DP0:NAME.EXT,7
THEN TYPE CO TO CONTINUE.
A005 000000
$AS DP0:CURTIS4.IMG,7
$CO

TYPE:  N FOR NORMALIZED FFT COEFF
       U FOR UNNORMALIZED COEFF
N

FFT WORKING

FORT003022 REAL OUTSIDE RANGE ON REAL TO INTEGER CONVERSION
NAME    SEQ
MAIN.   0017

DONE FFT

TYPE C TO CONTINUE, TYPE S TO STOP
C

TYPE P FOR POWER, F FOR FILTER, T FOR THRESHOLD
F

TYPE:  C TO USE CURRENT FILTER EQUATION FOR FILE
       O TO USE AN OLD FILTER FILE
C

MAKING FILTER
DONE FILTER

TYPE C TO CONTINUE, TYPE S TO STOP
C

IF FFT COEFF WERE JUST NOW MADE, THE FILE IS
ALREADY ASSIGNED.  TYPE CO TO CONTINUE.
IF NOT YET ASSIGNED, PLEASE DO SO NOW.  THE FORM IS:
$AS DP0:NAME.EXT,3
THEN TYPE CO TO CONTINUE.
A005 000000
$CO

MULTIPLYING
AH-HA....THINK YOU CAN FOOL MOTHER NATURE [H'

DONE MULT

IFFT WORKING
DONE IFFT
$
```

User's Guide

Program Bubble Chart

Program Listing

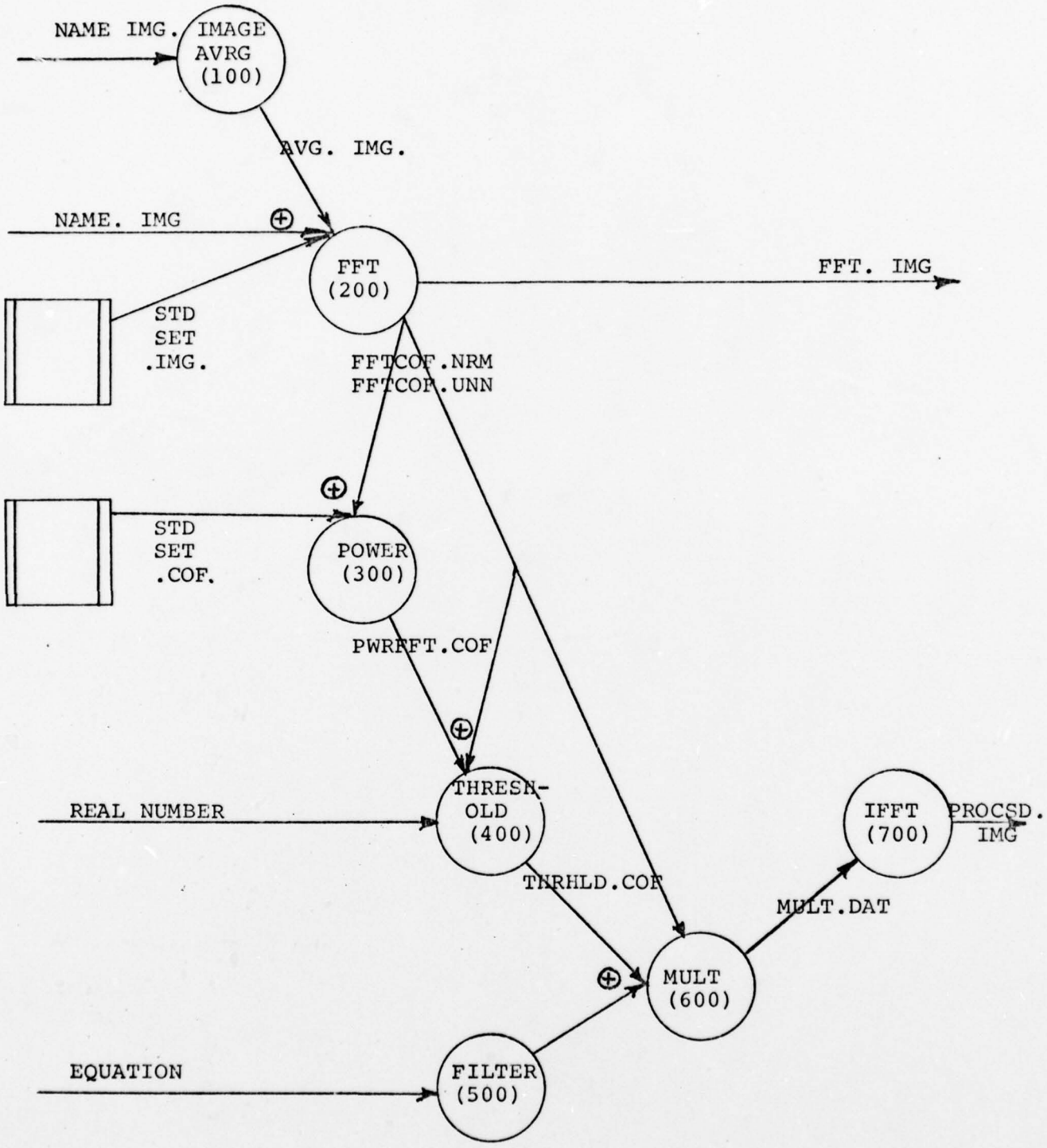

Figure 4. Program Bubble Chart

```
C       ****************************************************************
C                    PROGRAM  RAZMA,TAZ
C       ****************************************************************
C
C
C       THIS PROGRAM HAS THE FOLLOWING DISK (DP0:) RANDOM ACCESS FILE
C       ASSIGNMENTS:

C       AVG    .IMG = OUTPUT OF REDUCE, INPUT TO FFT
C       SCRATC.DAT = USED IN FFT
C       FFTCOF.NRM = OUTPUT OF FFT, INPUT TO POWER
C       (FFTCOF.UNN)                INPUT TO THRESHOLD
C                                   INPUT TO MULT
C       FFT    .IMG = OUTPUT OF FFT
C       ------.COF =                  INPUT TO POWER
C       PWRFFT.COF = OUTPUT OF POWER, INPUT TO THRESHOLD
C       PWRFFT.IMG = OUTPUT OF POWER
C       THRHLD.FIL = OUTPUT OF THRESHOLD, INPUT TO MULT
C       FILTER.COF = OUTPUT OF FILTER, INPUT TO MULT
C       MULT   .DAT = OUTPUT OF MULT, USED IN IFFT
C       PROCSD.IMG = OUTPUT OF IFFT
C
C       THE FOLLOWING DEVICES ARE INTERACTIVELY ASSIGNED TO THESE
C       FILES DURING THE RUNNING OF THE INDICATED MODULES:
C
C       FILE          1     2     3     4     5     6     7     8
C       BIG    .IMG                                      REDUCE
C       AVG    .IMG                                       FFT
C       FFTCOF.---                MULT  THRES  POWER
C       POWFFT.COF                      THRES
C       FILTER.COF   MULT
C       THRHLD.COF   MULT
C
C       ANY I/O REFERENCE MADE TO DEVICE NUMBERS AFTER THE DEVICES HAVE
C       BEEN INTERACTIVELY ASSIGNED DURING THE MODULES SPECIFIED ABOVE,
C       WILL OPERATE ON THE FILE DATA EQUATED WITH THAT DEVICE NUMBER.
C
C
C
C
C

        COMPLEX DATA(64),DATBUF(64),DCVAL,NOFILS,MSE
        BYTE HEADER(64,8),BUFFER(2048),BBUF(2),BCOL(128),NULLS(64,8)
        INTEGER INPTR,AVGPTR,DAT3PT,DAT2PT,FFTPTR,DAT7PT,DAT8PT
        INTEGER SUM,BUF,OFFSET,COL(64),UNIT,COFPTR,COFIMG,AVGFFT
        INTEGER THRSPT,OUTBW,BW,IERR,DAT1PT,DAT5PT,DAT4PT,ASGD7,PWRON
        EQUIVALENCE (BCOL(1),COL(1)),(BBUF(1),BUF)
        DATA HEADER/0,0,79,58,64,0,64,505*0/
        DATA NULLS/512*0/

1       WRITE (6,5)
        WRITE (6,6)
        WRITE (6,11)
2       WRITE (6,7)
        WRITE (6,8)
```

```
      WRITE (6,9)
      WRITE (6,10)
      WRITE (6,11)
5     FORMAT(' GREETINGS AND SOLUTIONS ')
6     FORMAT(' SPEAK TO ME ABOUT IMAGE INPUT ')
7     FORMAT(' TYPE: B FOR BIGGIE /2048X2048/ ')
8     FORMAT('       J FOR JUNIOR /64X64/ ')
9     FORMAT('       S FOR STANDARD SET OF 24 ')
10    FORMAT('       N FOR NONE ')
11    FORMAT('  ')
      READ (6,12) INBJSN
12    FORMAT(A)
      IF(INBJSN.EQ.1HJ) GOTO 200
      IF(INBJSN.EQ.1HB) GOTO 100
      IF(INBJSN.EQ.1HN) GOTO 30
      IF(INBJSN.NE.1HS) GOTO 2
20    WRITE (6,25)
      WRITE (6,26)
      WRITE (6,27)
22    WRITE (6,28)
      WRITE (6,11)
25    FORMAT(' THE STANDARD SET OF 24 PICTURES IS ALREADY STORED ')
26    FORMAT(' IN IMAGE FILES & IN NORMALIZED FFT COEFF FILES ON DP0: ')
27    FORMAT(' IF WISH TO PROCEED TO DO POWER, FILTER, OR THRESHOLD, ')
28    FORMAT(' TYPE C TO CONTINUE, TYPE S TO STOP, ')
      READ (6,12) INCS
      IF(INCS.EQ.1HS) GOTO 900
      IF(INCS.NE.1HC) GOTO 22
30    WRITE (6,35)
      WRITE (6,36)
      WRITE (6,37)
      WRITE (6,38)
      WRITE (6,11)
35    FORMAT(' TYPE: 1 TO DO FFT ')
36    FORMAT('       2 TO DO POWER ')
37    FORMAT('       3 TO DO THRESHOLDING ')
38    FORMAT('       4 TO DO FILTERING ')
      READ (6,12) IWHERE
      IF(IWHERE.EQ.1H1) GOTO 200
      IF(IWHERE.EQ.1H2) GOTO 300
      IF(IWHERE.EQ.1H3) GOTO 400
      IF(IWHERE.NE.1H4) GOTO 30
      GOTO 500

C     ****** REDUCTION MODULE *****
100   WRITE (6,105)
      WRITE (6,107)
      WRITE (6,108)
      WRITE (6,109)
105   FORMAT(' THE INPUT IMAGE FILE MUST BE SPECIFIED, ')
107   FORMAT(' IF NOT YET ASSIGNED, PLEASE DO SO NOW,  THE FORM IS: ')
108   FORMAT(' SAS DP0:NAME.EXT,7 ')
109   FORMAT(' THEN TYPE CO TO CONTINUE, ')
      ASGD7='Y'
      PAUSE
      DEFINE FILE 7(4097,512,U,INPTR)
```

```
            CALL SETFIL(8,'AVG,IMG',IERR,'DP',0)
            DEFINE FILE 8(80,32,U,AVGPTR)
            WRITE (6,110)
  110       FORMAT(' AVERAGE WORKING ')
            INPTR=2
            AVGPTR=1
            DO 115 J=1,8
  115       WRITE (8'AVGPTR) (HEADER(I,J),I=1,64)
            DO 116 J=1,8
  116       WRITE (8'AVGPTR) (NULLS(I,J),I=1,64)

            DO 170 I=1,64
              DO 120 K=1,64
  120         COL(K)=0
              DO 150 J=1,32
              READ (7'INPTR) (BUFFER(N),N=1,1024)
              READ (7'INPTR) (BUFFER(N),N=1025,2048)
                DO 140 K=1,64
                OFFSET=(K-1)*32
                SUM=0
                  DO 130 L=1,32
                  INDX=L+OFFSET
                  BBUF(1)=BUFFER(INDX)
                  SUM=SUM+BUF
  130             CONTINUE
                COL(K)=SUM/32+COL(K)
  140           CONTINUE
  150         CONTINUE
              DO 160 K=1,64
              COL(K)=COL(K)/32
  160         CONTINUE
            WRITE (8'AVGPTR) (BCOL(N),N=1,128,2)
  170       CONTINUE
            ENDFILE 7
            ENDFILE 8
  190       WRITE (6,195)
            WRITE (6,11)
  192       WRITE (6,196)
            WRITE (6,11)
  195       FORMAT(' DONE IMAGE AVERAGING ')
  196       FORMAT(' TYPE C TO CONTINUE, TYPE S TO STOP ')
            READ (6,12) INCS
            IF(INCS.EQ.1HS) GOTO 900
            IF(INCS.NE.1HC) GOTO 192
            GOTO 30

      C     ***** FFT MODULE *****
  200       CALL SETFIL(8,'AVG,IMG',IERR,'DP',0)
            DEFINE FILE 8(80,32,U,AVGPTR)
            IF(ASGD7.EQ.1HY) GOTO 215
            WRITE (6,205)
            WRITE (6,207)
            WRITE (6,208)
            WRITE (6,209)
  205       FORMAT(' THE INPUT IMAGE FILE MUST BE SPECIFIED, ')
  207       FORMAT(' IF NOT YET ASSIGNED, PLEASE DO SO NOW, THE FORM I8: ')
```

```
    208     FORMAT(' $AS DP0:NAME.EXT,7 ')
    209     FORMAT(' THEN TYPE CO TO CONTINUE. ')
            PAUSE
            DEFINE FILE 7(80,32,U,AVGPTR)
    210     WRITE (6,215)
            WRITE (6,216)
            WRITE (6,11)
    215     FORMAT(' TYPE:  N FOR NORMALIZED FFT COEFF ')
    216     FORMAT('        U FOR UNNORMALIZED COEFF ')
            READ (6,12) NORMUN
            DEFINE FILE 3(64,256,U,DAT3PT)
            CALL SETFIL(3,'SCRATC.DAT',IERR,'DP',0)
            DEFINE FILE 2(64,256,U,DAT2PT)
            IF(NORMUN.EQ.1HN) CALL SETFIL(2,'FFTCOF.NRM',IERR,'DP',0)
            IF(NORMUN.EQ.1HU) CALL SETFIL(2,'FFTCOF.UNN',IERR,'DP',0)
            IF(NORMUN.NE.1HU.AND.NORMUN.NE.1HN) GOTO 210
    217     DEFINE FILE 1(80,32,U,FFTPTR)
            CALL SETFIL(1,'FFT.IMG',IERR,'DP',0)
            WRITE (6,219)
    219     FORMAT(' FFT WORKING ')
            AVGPTR=17
            DAT2PT=1
            DAT3PT=1
            FFTPTR=1
            SCALE=1.0/64.0
            DO 220 J=1,8
    220     WRITE (1'FFTPTR) (HEADER(I,J),I=1,64)
            DO 225 J=1,8
    225     WRITE (1'FFTPTR) (NULLS(I,J),I=1,64)
            DO 230  K=1,64
    230     COL(K)=0

            DO 250 I=1,64
            IF(ASGD7.EQ.1HY) READ(8'AVGPTR) (BCOL(N),N=1,128,2)
            IF(ASGD7.NE.1HY) READ(7'AVGPTR) (BCOL(N),N=1,128,2)
              DO 240  J=1,64
              DATA(J)=COL(J)
    240       CONTINUE
            CALL FOURT(DATA,64,1,-1,1,0)
            WRITE (3'DAT3PT) (DATA(N),N=1,64)
    250     CONTINUE
            DO 290  K=1,64
            DAT3PT=1
              DO 260 I=1,64
              READ (3'DAT3PT) (DATBUF(N),N=1,64)
              DATA(I)=DATBUF(K)
    260       CONTINUE
            CALL FOURT(DATA,64,1,-1,1,0)
            IF(NORMUN.EQ.1HU) GOTO 270
            SCALE=256.0*64.0
            J=1
            IF(K-1) 265,265,266
    265     DCVAL=DATA(1)
            J=J+1
    266       DO 267 I=J,64
              DATA(I)=DATA(I)/DCVAL
```

```
    267       CONTINUE
    270     WRITE (2'DAT2PT) (DATA(N),N=1,64)
            DO 280 I=1,64
            COL(I)=(CABS(DATA(I)))*SCALE
    280     CONTINUE
            WRITE (1'FFTPTR) (BCOL(N),N=1,128,2)
    290     CONTINUE
            ENDFILE 1
            ENDFILE 2
            ENDFILE 3
            ENDFILE 7
            ENDFILE 8
            WRITE (6,296)
            WRITE (6,11)
    295     WRITE (6,297)
            WRITE (6,11)
    296     FORMAT(' DONE FFT ')
    297     FORMAT(' TYPE C TO CONTINUE, TYPE S TO STOP ')
            READ (6,12) INCS
            IF(INCS.EQ.1HS) GOTO 900
            IF(INCS.NE.1HC) GOTO 295
    298     WRITE (6,299)
            WRITE (6,11)
    299     FORMAT(' TYPE P FOR POWER, F FOR FILTER, T FOR THRESHOLD ')
            READ (6,12) IPFT
            IF(IPFT.EQ.1HF) GOTO 500
            IF(IPFT.EQ.1HT) GOTO 400
            IF(IPFT.NE.1HP) GOTO 298
            GOTO 300

    C       ***** POWER MODULE *****
    300     CALL SETFIL(8,'PWRFFT.IMG',IERR,'DP',0)
            DEFINE FILE 8(80,32,U,DAT8PT)
            DAT8PT=1
            DO 301 J=1,8
    301     WRITE(8'DAT8PT) (HEADER(I,J),I=1,64)
            DO 302 J=1,8
    302     WRITE(8'DAT8PT) (NULLS(I,J),I=1,64)
    303     WRITE(6,304)
            WRITE (6,11)
    304     FORMAT(' TYPE: O, FOR ONLY ONE FFT INPUT; S, FOR STD 24 FFT COEFF ')
            READ (6,12) INOS
            PWRON='Y'
            IF(INOS.EQ.1HS) GOTO 312
            IF(INOS.NE.1HO) GOTO 303
            IF(NORMUN.EQ.1HN) CALL SETFIL(5,'FFTCOF.NRM',IERR,'DP',0)
            IF(NORMUN.EQ.1HU) CALL SETFIL(5,'FFTCOF.UNN',IERR,'DP',0)
            IF(NORMUN.EQ.1HN.OR.NORMUN.EQ.1HU) GOTO 308
            WRITE (6,305)
            WRITE (6,306)
            WRITE (6,307)
    305     FORMAT(' FFT INPUT MUST BE SPECIFIED.  PLEASE DO SO NOW. ')
    306     FORMAT(' THE FORM IS:     $AS DP0:NAME.EXT,5 ')
    307     FORMAT(' THEN TYPE CO TO CONTINUE. ')
            PAUSE
    308     DEFINE FILE 5(64,256,U,DAT5PT)
```

```
      CALL SETFIL(1,'PWRFFT.COF',IERR,'DP',0)
      DEFINE FILE 1(64,256,U,DAT1PT)
      WRITE (6,309)
309   FORMAT(' SQUARING FFT/S/ ')
      DAT1PT=1
      DAT5PT=1
      DO 311 I=1,64
      READ (5'DAT5PT) (DATA(N),N=1,64)
        DO 310 J=1,64
        DATA(J)=DATA(J)*DATA(J)
        COL(J)=(CABS(DATA(J)))
310     CONTINUE
      WRITE (1'DAT1PT) (DATA(N),N=1,64)
      WRITE(8'DAT8PT) (BCOL(N),N=1,128,2)
311   CONTINUE
      ENDFILE 1
      ENDFILE 5
      ENDFILE 8
      GOTO 390

312   WRITE (6,309)
      CALL SETFIL(5,'PWRFFT.COF',IERR,'DP',0)
      DEFINE FILE 5(64,256,U,DAT5PT)
      SCALE=64.0**3
      NOFILS=(24,0,24,0)
      DO 313 I=1,64
      DATBUF(I)=(0,0,0,0)
313   CONTINUE
      DAT5PT=1
      DO 314 I=1,64
      WRITE (5'DAT5PT) (DATBUF(N),N=1,64)
314   CONTINUE
      UNIT=5
      DO 360  I=1,24
      DAT5PT=1
      COFPTR=1
      IF(UNIT-4) 319,315,317
315     DO 316 J=1,4
316     ENDFILE J
317     DO 318 J=1,4
318     DEFINE FILE J(64,256,U,COFPTR)
      UNIT=0
319   UNIT=UNIT+1
320   IF(I-1) 322,321,322
321   CALL SETFIL(1,'APC1.COF',IERR,'DP',0)
      CALL SETFIL(2,'APC2.COF',IERR,'DP',0)
      CALL SETFIL(3,'APC3.COF',IERR,'DP',0)
      CALL SETFIL(4,'APC4.COF',IERR,'DP',0)
322   IF(I-5) 335,323,324
323   CALL SETFIL(1,'ARTY1.COF',IERR,'DP',0)
      CALL SETFIL(2,'ARTY2.COF',IERR,'DP',0)
      CALL SETFIL(3,'ARTY3.COF',IERR,'DP',0)
      CALL SETFIL(4,'ARTY4.COF',IERR,'DP',0)
324   IF(I-9) 335,325,326
325   CALL SETFIL(1,'CVRTK1.COF',IERR,'DP',0)
      CALL SETFIL(2,'CVRTK2.COF',IERR,'DP',0)
```

```
            CALL SETFIL(3,'CVRTK3.COF',IERR,'DP',0)
            CALL SETFIL(4,'CVRTK4.COF',IERR,'DP',0)
  326       IF(I-13) 335,327,328
  327       CALL SETFIL(1,'OPNTK1.COF',IERR,'DP',0)
            CALL SETFIL(2,'OPNTK2.COF',IERR,'DP',0)
            CALL SETFIL(3,'OPNTK3.COF',IERR,'DP',0)
            CALL SETFIL(4,'OPNTK4.COF',IERR,'DP',0)
  328       IF(I-17) 335,329,330
  329       CALL SETFIL(1,'M60A1.COF',IERR,'DP',0)
            CALL SETFIL(2,'M60A2.COF',IERR,'DP',0)
            CALL SETFIL(3,'M60A3.COF',IERR,'DP',0)
            CALL SETFIL(4,'M60A4.COF',IERR,'DP',0)
  330       IF(I-21) 335,331,335
  331       CALL SETFIL(1,'SHER1.COF',IERR,'DP',0)
            CALL SETFIL(2,'SHER2.COF',IERR,'DP',0)
            CALL SETFIL(3,'SHER3.COF',IERR,'DP',0)
            CALL SETFIL(4,'SHER4.COF',IERR,'DP',0)
  335       CONTINUE
              DO 350 J=1,64
              READ(5'DAT5PT) (DATBUF(N),N=1,64)
              READ(UNIT'COFPTR) (DATA(N),N=1,64)
                DO 337 K=1,64
  337           DATA(K)=DATA(K)*DATA(K)
                DO 340 K=1,64
                DATBUF(K)=DATBUF(K)+DATA(K)
  340           CONTINUE
              DAT5PT=DAT5PT+1
              WRITE(5'DAT5PT) (DATBUF(N),N=1,64)
  350         CONTINUE
  360       CONTINUE
  365       DAT5PT=1
            DO 380 I=1,64
            READ(5'DAT5PT) (DATA(N),N=1,64)
              DO 370 J=1,64
              DATA(J)=DATA(J)/NOFILS
              COL(J)=(CABS(DATA(J)))*SCALE
  370         CONTINUE
            DAT5PT=DAT5PT+1
            WRITE(5'DAT5PT) (DATA(N),N=1,64)
            WRITE(8'DAT8PT) (BCOL(N),N=1,128,2)
  380       CONTINUE
            DO 385 I=1,5
  385       ENDFILE I
            ENDFILE 8
  390       WRITE (6,395)
            WRITE (6,11)
  395       FORMAT(' DONE POWER ')
            GOTO 400

  C         ***** THRESHOLD MODULE *****
  400       WRITE (6,405)
            WRITE(6,11)
  405       FORMAT(' TYPE N TO MAKE NEW THRESHOLD FILE,TYPE O TO USE OLD FILE ')
            READ (6,12) INNO
            IF(INNO.EQ.1HO) GOTO 600
            IF(INNO.NE.1HN) GOTO 400
```

```
  410     WRITE (6,415)
          WRITE (6,416)
          WRITE (6,11)
  415     FORMAT(' TYPE:  V FOR VANILLA PLAIN FFT COEFF ')
  416     FORMAT('        A FOR AVERAGED/SQUARED FFT INPUT ')
          READ (6,12) INVA
          IF(INVA.EQ.1HA) CALL SETFIL(4,'PWRFFT.COF',IERR,'DP',0)
          IF(INVA.EQ.1HV.AND.NORMUN.EQ.1HN)
          1CALL SETFIL(4,'FFTCOF.NRM',IERR,'DP',0)
          IF(INVA.EQ.1HV.AND.NORMUN.EQ.1HU)
          1CALL SETFIL(4,'FFTCOF.UNN',IERR,'DP',0)
          IF(INVA.NE.1HA.AND.INVA.NE.1HV) GOTO 410
          IF(NORMUN.EQ.1HN.OR.NORMUN.EQ.1HU.OR.PWRON.EQ.1HY) GOTO 430
          WRITE (6,424)
          WRITE (6,425)
          WRITE (6,426)
          WRITE (6,427)
          WRITE (6,428)
  424     FORMAT(' THE FILE TO BE THRESHOLDED MUST BE SPECIFIED. ')
  425     FORMAT(' IF NOT YET ASSIGNED, PLEASE DO SO NOW. ')
  426     FORMAT(' THE FORM IS: ')
  427     FORMAT(' $AS DP0:NAME.EXT,4 ')
  428     FORMAT(' THEN TYPE CO TO CONTINUE ')
          PAUSE
  430     DEFINE FILE 4(64,256,U,DAT4PT)
          CALL SETFIL(1,'THRHLD.FIL',IERR,'DP',0)
          DEFINE FILE 1(64,256,U,THRSPT)
          WRITE (6,431)
  432     WRITE (6,433)
          WRITE (6,11)
  431     FORMAT(' SPECIFY A REAL VALUE FOR THE THRESHOLD OF ')
  433     FORMAT('  THE FORM = 0.0000 /UP TO 15 TRAILING DIGITS/ ')
          READ (6,435,ERR=432) THRES
  435     FORMAT(F18.15)
          WRITE(6,439)
          WRITE (6,11)
  439     FORMAT(' THRESHOLD WORKING ')

          DAT4PT=1
          THRSPT=1
          BW=0
          MSE=(0.0,0.0)
          DO 470 I=1,64
          READ (4'DAT4PT) (DATA(N),N=1,64)
            DO 460 J=1,64
            DATBUF(J)=(1.0,0.0)
            BELOW=CABS(DATA(J))-THRES
  450       IF(BELOW) 451,453,453
  451       MSE=MSE+DATA(J)
            OUTBW=OUTBW+1
            DATBUF(J)=(0.0,0.0)
  453       CONTINUE
  460       CONTINUE
          WRITE(1'THRSPT) (DATBUF(N),N=1,64)
  470     CONTINUE
          ENDFILE 1
```

```
            ENDFILE 4
            BW=4096-OUTBW
            ABSMSE=CABS(MSE)
            FRACBW=FLOAT(BW)/4096.0

            WRITE(6,480) THRES
            WRITE (6,482) ABSMSE
            WRITE (6,484) BW,FRACBW
            WRITE (6,11)
  480       FORMAT(' THIS THRHLD,FIL USED A REAL THRESHOLD OF ',F18.15)
  482       FORMAT(' THE ABSOLUTE MSE WAS = ',F18.15)
  484       FORMAT(' AND THE BANDWIDTH WAS= ',I4,'/4096 OR ',F12.9)
  490       WRITE (6,495)
            WRITE (6,11)
  491       WRITE (6,496)
            WRITE (6,11)
  495       FORMAT(' END THRESHOLD ')
  496       FORMAT(' TYPE C TO CONTINUE,TYPE S TO STOP ')
            READ (6,12) INCS
            IF(INCS.EQ.1HS) GOTO 900
            IF(INCS.NE.1HC) GOTO 491
            GOTO 600

  C         ***** FILTER MODULE *****
  500       WRITE (6,505)
            WRITE (6,506)
            WRITE (6,11)
  505       FORMAT(' TYPE:  C TO USE CURRENT FILTER EQUATION FOR FILE ')
  506       FORMAT('        O TO USE AN OLD FILTER FILE ')
            READ (6,12) INCO
            IF(INCO.EQ.1HO) GOTO 600
            IF(INCO.NE.1HC) GOTO 500
  510       WRITE (6,512)
  512       FORMAT(' MAKING FILTER ')
            DEFINE FILE 1(64,256,U,DAT1PT)
            CALL SETFIL(1,'FILTER.COF',IERR,'DP',0)
            KAPA1=0
            KAPA2=0
            SIGMA1=0.
            SIGMA2=0.
            DAT1PT=1
            IFOLD=34
            DO 530  M=1,64
            MM=M
              DO 520 N=1,64
              NN=N
              IF(M.GE.IFOLD) MM=66-M
              I=MM-1
              IF(N.GE.IFOLD) NN=66-N
              J=NN-1
              SQIJ=I**2+J**2
              RADIAL=SQRT(SQIJ)
  515         DATA(N)=0.5*(1.0+ALOG(RADIAL*0.1+1.0))
  520         CONTINUE
            WRITE (1'DAT1PT) (DATA(N),N=1,64)
  530       CONTINUE
```

```
            ENDFILE 1
            WRITE (6,545)
            WRITE (6,11)
    540     WRITE (6,546)
            WRITE (6,11)
    545     FORMAT(' DONE FILTER ')
    546     FORMAT(' TYPE C TO CONTINUE, TYPE S TO STOP ')
            READ (6,12) INCS
            IF(INCS.EQ.1HS) GOTO 900
            IF(INCS.NE.1HC) GOTO 540
            GOTO 600


    C       ***** MATRIX MULT MODULE *****
    600     IF(INNO.EQ.1HN) CALL SETFIL(1,'THRHLD.FIL',IERR,'DP',0)
            IF(INCO.EQ.1HC) CALL SETFIL(1,'FILTER.COF',IERR,'DP',0)
            IF(INNO.NE.1HO.AND.INCO.NE.1HO) GOTO 620
            IF(INNO.EQ.1HO) WRITE (6,605)
            IF(INCO.EQ.1HO) WRITE (6,606)
    605     FORMAT(' THE OLD THRESHOLD FILE MUST BE SPECIFIED, ')
    606     FORMAT(' THE OLD FILTER FILE MUST BE SPECIFIED, ')
            WRITE (6,607)
            WRITE (6,608)
            WRITE (6,609)
            WRITE (6,610)
    607     FORMAT(' IF ALREADY ASSIGNED, TYPE CO TO CONTINUE, ')
    608     FORMAT(' IF NOT YET ASSIGNED, PLEASE DO SO NOW, THE FORM IS: ')
    609     FORMAT(' $AS DP0:NAME,EXT,1 ')
    610     FORMAT(' THEN TYPE CO TO CONTINUE, ')
            PAUSE
    620     DEFINE FILE 1(64,256,U,DAT1PT)
            IF(NORMUN.EQ.1HU) CALL SETFIL(3,'FFTCOF.UNN',IERR,'DP',0)
            IF(NORMUN.EQ.1HN) CALL SETFIL(3,'FFTCOF.NRM',IERR,'DP',0)
            WRITE (6,625)
            WRITE (6,626)
            WRITE (6,627)
            WRITE (6,628)
            WRITE (6,629)
    625     FORMAT(' IF FFT COEFF WERE JUST NOW MADE, THE FILE IS ')
    626     FORMAT(' ALREADY ASSIGNED,  TYPE CO TO CONTINUE, ')
    627     FORMAT(' IF NOT YET ASSIGNED, PLEASE DO SO NOW,  THE FORM IS: ')
    628     FORMAT(' $AS DP0:NAME,EXT,3 ')
    629     FORMAT(' THEN TYPE CO TO CONTINUE, ')
            PAUSE
            DEFINE FILE 3(64,256,U,DAT3PT)
            IF(NORMUN.EQ.1HU.OR.NORMUN.EQ.1HN) GOTO 640
    630     WRITE (6,635)
            WRITE (6,11)
    635     FORMAT(' TYPE N FOR NORM FFT COEFF, TYPE U FOR UNNORMALIZED COEFF ')
            READ (6,12) NORMUN
            IF(NORMUN.NE.1HU.AND.NORMUN.NE.1HN) GOTO 630
    640     CALL SETFIL(2,'MULT.DAT',IERR,'DP',0)
            DEFINE FILE 2(64,256,U,DAT2PT)
            WRITE (6,645)
    645     FORMAT(' MULTIPLYING ')
            DAT1PT=1
```

```
              DAT2PT=1
              DAT3PT=1
              DO 680  I=1,64
              READ (3'DAT3PT) (DATA(N),N=1,64)
              READ (1'DAT1PT) (DATBUF(N),N=1,64)
              IF(NORMUN.EQ.1HU) GOTO 665
              K=1
              IF(I-1) 650,650,655
     650      WRITE (6,651)
     651      FORMAT(' AH-HA....THINK YOU CAN FOOL MOTHER NATURE EH! ')
              DCVAL=DATA(1)
              K=K+1
     655        DO 660 J=K,64
                DATA(J)=DATA(J)*DCVAL
     660        CONTINUE
     665        DO 670 J=1,64
                DATA(J)=DATA(J)*DATBUF(J)
     670        CONTINUE
              WRITE (2'DAT2PT) (DATA(N),N=1,64)
     680      CONTINUE
              ENDFILE 1
              ENDFILE 2
              ENDFILE 3
              WRITE (6,695)
              WRITE (6,11)
     695      FORMAT(' DONE MULT ')
              GOTO 700

     C        ***** INVERSE FFT MODULE *****
     700      CALL SETFIL(2,'MULT.DAT',IERR,'DP',0)
              DEFINE FILE 2(64,256,U,DAT2PT)
              CALL SETFIL(8,'PROCSD.IMG',IERR,'DP',0)
              DEFINE FILE 8(80,32,U,DAT8PT)
              WRITE (6,730)
     730      FORMAT (' IFFT WORKING ')
              DAT2PT=1
              DAT8PT=1
              SCALE=1.0/4096.0
              DO 740 J=1,8
              WRITE (8'DAT8PT) (HEADER(I,J),I=1,64)
     740      CONTINUE
              DO 745 J=1,8
              WRITE (8'DAT8PT) (NULLS(I,J),I=1,64)
     745      CONTINUE
              DO 750 I=1,64
              READ (2'DAT2PT) (DATA(N),N=1,64)
              CALL FOURT(DATA,64,1,1,1,0)
              DAT2PT=DAT2PT+1
              WRITE (2'DAT2PT) (DATA(N),N=1,64)
     750      CONTINUE

              DO 780  K=1,64
              DAT2PT=1
                DO 760 I=1,64
                READ (2'DAT2PT) (DATBUF(N),N=1,64)
                DATA(I)=DATBUF(K)
```

```
760         CONTINUE
          CALL FOURT(DATA,64,1,1,1,0)
            DO 770 I=1,64
            COL(I)=(REAL(DATA(I)))*SCALE
770         CONTINUE
          WRITE (8'DAT8PT) (BCOL(N),N=1,128,2)
780       CONTINUE
          ENDFILE 2
          ENDFILE 8
          WRITE (6,795)
795       FORMAT(' DONE IFFT ')
900       END


ROUTINES CALLED:
SETFIL, FOURT , CABS  , FLOAT , SQRT  , ALOG  , REAL


OPTIONS =/ON,/OP:3

BLOCK        LENGTH
MAIN,   9645   (045532)*

**COMPILER ----- CORE**
   PHASE       USED  FREE
DECLARATIVES 00963 14349
EXECUTABLES  03343 11969
ASSEMBLY     04731 15221
```

```
      SUBROUTINE FOURT(DATA,NN,NDIM,ISIGN,IFORM,WORK)
C
C     THE COOLEY-TUKEY FAST FOURIER TRANSFORM IN USASI BASIC FORTRAN
C
C
C     TRANSFORM(K1,K2,...) = SUM(DATA(J1,J2,...)*EXP(ISIGN*2*PI*SQRT(-1)
C     *((J1-1)*(K1-1)/NN(1)+(J2-1)*(K2-1)/NN(2)+...))), SUMMED FOR ALL
C     J1, K1 BETWEEN 1 AND NN(1), J2, K2 BETWEEN 1 AND NN(2), ETC.
C     THERE IS NO LIMIT TO THE NUMBER OF SUBSCRIPTS.  DATA IS A
C     MULTIDIMENSIONAL COMPLEX ARRAY WHOSE REAL AND IMAGINARY
C     PARTS ARE ADJACENT IN STORAGE, SUCH AS FORTRAN IV PLACES THEM.
C     IF ALL IMAGINARY PARTS ARE ZERO (DATA ARE DISGUISED REAL), SET
C     IFORM TO ZERO TO CUT THE RUNNING TIME BY UP TO FORTY PERCENT.
C     OTHERWISE, IFORM = +1.  THE LENGTHS OF ALL DIMENSIONS ARE
C     STORED IN ARRAY NN, OF LENGTH NDIM.  THEY MAY BE ANY POSITIVE
C     INTEGERS, THO THE PROGRAM RUNS FASTER ON COMPOSITE INTEGERS, AND
C     ESPECIALLY FAST ON NUMBERS RICH IN FACTORS OF TWO.  ISIGN IS +1
C     OR -1.  IF A -1 TRANSFORM IS FOLLOWED BY A +1 ONE (OR A +1
C     BY A -1) THE ORIGINAL DATA REAPPEAR, MULTIPLIED BY NTOT (=NN(1)*
C     NN(2)*...).  TRANSFORM VALUES ARE ALWAYS COMPLEX, AND ARE RETURNED
C     IN ARRAY DATA, REPLACING THE INPUT.  IN ADDITION, IF ALL
C     DIMENSIONS ARE NOT POWERS OF TWO, ARRAY WORK MUST BE SUPPLIED,
C     COMPLEX OF LENGTH EQUAL TO THE LARGEST NON 2**K DIMENSION.
C     OTHERWISE, REPLACE WORK BY ZERO IN THE CALLING SEQUENCE.
C     NORMAL FORTRAN DATA ORDERING IS EXPECTED, FIRST SUBSCRIPT VARYING
C     FASTEST.  ALL SUBSCRIPTS BEGIN AT ONE.
C
C     RUNNING TIME IS MUCH SHORTER THAN THE NAIVE NTOT**2, BEING
C     GIVEN BY THE FOLLOWING FORMULA.  DECOMPOSE NTOT INTO
C     2**K2 * 3**K3 * 5**K5 * ....  LET SUM2 = 2*K2, SUMF = 3*K3 + 5*K5
C     + ... AND NF = K3 + K5 + ....  THE TIME TAKEN BY A MULTI-
C     DIMENSIONAL TRANSFORM ON THESE NTOT DATA IS T = T0 + NTOT*(T1+

C     T2*SUM2+T3*SUMF+T4*NF).  ON THE CDC 3300 (FLOATING POINT ADD TIME
C     OF SIX MICROSECONDS), T = 3000 + NTOT*(500+43*SUM2+68*SUMF+
C     320*NF) MICROSECONDS ON COMPLEX DATA.  IN ADDITION, THE
C     ACCURACY IS GREATLY IMPROVED, AS THE RMS RELATIVE ERROR IS
C     BOUNDED BY 3*2**(-B)*SUM(FACTOR(J)**1.5), WHERE B IS THE NUMBER
C     OF BITS IN THE FLOATING POINT FRACTION AND FACTOR(J) ARE THE
C     PRIME FACTORS OF NTOT.
C
C     PROGRAM BY NORMAN BRENNER FROM THE BASIC PROGRAM BY CHARLES
C     RADER.  RALPH ALTER SUGGESTED THE IDEA FOR THE DIGIT REVERSAL.
C     MIT LINCOLN LABORATORY, AUGUST 1967.  THIS IS THE FASTEST AND MOST
C     VERSATILE VERSION OF THE FFT KNOWN TO THE AUTHOR.  SHORTER PRO-
C     GRAMS FOUR1 AND FOUR2 RESTRICT DIMENSION LENGTHS TO POWERS OF TWO.
C     SEE-- IEEE AUDIO TRANSACTIONS (JUNE 1967), SPECIAL ISSUE ON FFT.
C
C     THE DISCRETE FOURIER TRANSFORM PLACES THREE RESTRICTIONS UPON THE
C     DATA.
C     1.  THE NUMBER OF INPUT DATA AND THE NUMBER OF TRANSFORM VALUES
C     MUST BE THE SAME.
C     2.  BOTH THE INPUT DATA AND THE TRANSFORM VALUES MUST REPRESENT
C     EQUISPACED POINTS IN THEIR RESPECTIVE DOMAINS OF TIME AND
C     FREQUENCY.  CALLING THESE SPACINGS DELTAT AND DELTAF, IT MUST BE
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```
C     TRUE THAT DELTAF=2*PI/(NN(I)*DELTAT).  OF COURSE, DELTAT NEED NOT
C     BE THE SAME FOR EVERY DIMENSION.
C     3.  CONCEPTUALLY AT LEAST, THE INPUT DATA AND THE TRANSFORM OUTPUT
C     REPRESENT SINGLE CYCLES OF PERIODIC FUNCTIONS.
C
C     EXAMPLE 1.  THREE-DIMENSIONAL FORWARD FOURIER TRANSFORM OF A
C     COMPLEX ARRAY DIMENSIONED 32 BY 25 BY 13 IN FORTRAN IV.
C     DIMENSION DATA(32,25,13),WORK(50),NN(3)
C     COMPLEX DATA

C     DATA NN/32,25,13/
C     DO 1 I=1,32
C     DO 1 J=1,25
C     DO 1 K=1,13
C  1  DATA(I,J,K)=COMPLEX VALUE
C     CALL FOURT(DATA,NN,3,-1,1,WORK)
C
C     EXAMPLE 2.  ONE-DIMENSIONAL FORWARD TRANSFORM OF A REAL ARRAY OF
C     LENGTH 64 IN FORTRAN II.
C     DIMENSION DATA(2,64)
C     DO 2 I=1,64
C     DATA(1,I)=REAL PART
C  2  DATA(2,I)=0.
C     CALL FOURT(DATA,64,1,-1,0,0)
C
      DIMENSION DATA(1),NN(1),IFACT(32),WORK(1)
C     CDC 6600 INITIALIZATION
      WR=0.
      WI=0.
      WSTPR=0.
      WSTPI=0.
      TWOPI=6.283185307
      IF(NDIM-1)920,1,1
1     NTOT=2
      DO 2 IDIM=1,NDIM
      IF(NN(IDIM))920,920,2
2     NTOT=NTOT*NN(IDIM)
C
C     MAIN LOOP FOR EACH DIMENSION
C
      NP1=2
      DO 910 IDIM=1,NDIM
      N=NN(IDIM)
      NP2=NP1*N
      IF(N-1)920,900,5
C
C     FACTOR N
C
5     M=N
      NTWO=NP1
      IF=1
      IDIV=2
10    IQUOT=M/IDIV
      IREM=M-IDIV*IQUOT
      IF(IQUOT-IDIV)50,11,11
```

```
   11    IF(IREM)20,12,20
   12    NTWO=NTWO+NTWO
         M=IQUOT
         GO TO 10
   20    IDIV=3
   30    IQUOT=M/IDIV
         IREM=M-IDIV*IQUOT
         IF(IQUOT-IDIV)60,31,31
   31    IF(IREM)40,32,40
   32    IFACT(IF)=IDIV
         IF=IF+1
         M=IQUOT
         GO TO 30
   40    IDIV=IDIV+2
         GO TO 30
   50    IF(IREM)60,51,60
   51    NTWO=NTWO+NTWO
         GO TO 70
   60    IFACT(IF)=M
         C
         C     SEPARATE FOUR CASES--
         C        1, COMPLEX TRANSFORM OR REAL TRANSFORM FOR THE 4TH, 5TH,ETC,
         C           DIMENSIONS,
         C        2, REAL TRANSFORM FOR THE 2ND OR 3RD DIMENSION,  METHOD--
         C           TRANSFORM HALF THE DATA, SUPPLYING THE OTHER HALF BY CON-
         C           JUGATE SYMMETRY,
         C        3, REAL TRANSFORM FOR THE 1ST DIMENSION, N ODD,  METHOD--
         C           TRANSFORM HALF THE DATA AT EACH STAGE, SUPPLYING THE OTHER
         C           HALF BY CONJUGATE SYMMETRY,
         C        4, REAL TRANSFORM FOR THE 1ST DIMENSION, N EVEN,  METHOD--
         C           TRANSFORM A COMPLEX ARRAY OF LENGTH N/2 WHOSE REAL PARTS

         C           ARE THE EVEN NUMBERED REAL VALUES AND WHOSE IMAGINARY PARTS
         C           ARE THE ODD NUMBERED REAL VALUES,  SEPARATE AND SUPPLY
         C           THE SECOND HALF BY CONJUGATE SYMMETRY,
         C
   70    NON2=NP1*(NP2/NTWO)
         ICASE=1
         IF(IDIM-4)71,90,90
   71    IF(IFORM)72,72,90
   72    ICASE=2
         IF(IDIM-1)73,73,90
   73    ICASE=3
         IF(NTWO-NP1)90,90,74
   74    ICASE=4
         NTWO=NTWO/2
         N=N/2
         NP2=NP2/2
         NTOT=NTOT/2
         I=3
         DO 80 J=2,NTOT
         DATA(J)=DATA(I)
   80    I=I+2
   90    I1RNG=NP1
         IF(ICASE-2)100,95,100
   95    I1RNG=NP0*(1+NPREV/2)
```

```
      C
      C     SHUFFLE ON THE FACTORS OF TWO IN N.  AS THE SHUFFLING
      C     CAN BE DONE BY SIMPLE INTERCHANGE, NO WORKING ARRAY IS NEEDED
      C
  100 IF(NTWO-NP1)600,600,110
  110 NP2HF=NP2/2
      J=1

      DO 150 I2=1,NP2,NON2
      IF(J-I2)120,130,130
  120 I1MAX=I2+NON2-2
      DO 125 I1=I2,I1MAX,2
      DO 125 I3=I1,NTOT,NP2
      J3=J+I3-I2
      TEMPR=DATA(I3)
      TEMPI=DATA(I3+1)
      DATA(I3)=DATA(J3)
      DATA(I3+1)=DATA(J3+1)
      DATA(J3)=TEMPR
  125 DATA(J3+1)=TEMPI
  130 M=NP2HF
  140 IF(J-M)150,150,145
  145 J=J-M
      M=M/2
      IF(M-NON2)150,140,140
  150 J=J+M
      C
      C     MAIN LOOP FOR FACTORS OF TWO.  PERFORM FOURIER TRANSFORMS OF
      C     LENGTH FOUR, WITH ONE OF LENGTH TWO IF NEEDED.  THE TWIDDLE FACTOR
      C     W=EXP(ISIGN*2*PI*SQRT(-1)*M/(4*MMAX)).  CHECK FOR W=ISIGN*SQRT(-1)
      C     AND REPEAT FOR W=ISIGN*SQRT(-1)*CONJUGATE(W).
      C
      NON2T=NON2+NON2
      IPAR=NTWO/NP1
  310 IF(IPAR-2)350,330,320
  320 IPAR=IPAR/4
      GO TO 310
  330 DO 340 I1=1,I1RNG,2
      DO 340 J3=I1,NON2,NP1

      DO 340 K1=J3,NTOT,NON2T
      K2=K1+NON2
      TEMPR=DATA(K2)
      TEMPI=DATA(K2+1)
      DATA(K2)=DATA(K1)-TEMPR
      DATA(K2+1)=DATA(K1+1)-TEMPI
      DATA(K1)=DATA(K1)+TEMPR
  340 DATA(K1+1)=DATA(K1+1)+TEMPI
  350 MMAX=NON2
  360 IF(MMAX-NP2HF)370,600,600
  370 LMAX=MAX0(NON2T,MMAX/2)
      IF(MMAX-NON2)405,405,380
  380 THETA=-TWOPI*FLOAT(NON2)/FLOAT(4*MMAX)
      IF(ISIGN)400,390,390
  390 THETA=-THETA
  400 WR=COS(THETA)
```

```
            WI=SIN(THETA)
            WSTPR=-2.*WI*WI
            WSTPI=2.*WR*WI
      405   DO 570 L=NON2,LMAX,NON2T
            M=L
            IF(MMAX-NON2)420,420,410
      410   W2R=WR*WR-WI*WI
            W2I=2.*WR*WI
            W3R=W2R*WR-W2I*WI
            W3I=W2R*WI+W2I*WR
      420   DO 530 I1=1,I1RNG,2
            DO 530 J3=I1,NON2,NP1
            KMIN=J3+IPAR*M
            IF(MMAX-NON2)430,430,440
      430   KMIN=J3

      440   KDIF=IPAR*MMAX
      450   KSTEP=4*KDIF
            DO 520 K1=KMIN,NTOT,KSTEP
            K2=K1+KDIF
            K3=K2+KDIF
            K4=K3+KDIF
            IF(MMAX-NON2)460,460,480
      460   U1R=DATA(K1)+DATA(K2)
            U1I=DATA(K1+1)+DATA(K2+1)
            U2R=DATA(K3)+DATA(K4)
            U2I=DATA(K3+1)+DATA(K4+1)
            U3R=DATA(K1)-DATA(K2)
            U3I=DATA(K1+1)-DATA(K2+1)
            IF(ISIGN)470,475,475
      470   U4R=DATA(K3+1)-DATA(K4+1)
            U4I=DATA(K4)-DATA(K3)
            GO TO 510
      475   U4R=DATA(K4+1)-DATA(K3+1)
            U4I=DATA(K3)-DATA(K4)
            GO TO 510
      480   T2R=W2R*DATA(K2)-W2I*DATA(K2+1)
            T2I=W2R*DATA(K2+1)+W2I*DATA(K2)
            T3R=WR*DATA(K3)-WI*DATA(K3+1)
            T3I=WR*DATA(K3+1)+WI*DATA(K3)
            T4R=W3R*DATA(K4)-W3I*DATA(K4+1)
            T4I=W3R*DATA(K4+1)+W3I*DATA(K4)
            U1R=DATA(K1)+T2R
            U1I=DATA(K1+1)+T2I
            U2R=T3R+T4R
            U2I=T3I+T4I
            U3R=DATA(K1)-T2R

            U3I=DATA(K1+1)-T2I
            IF(ISIGN)490,500,500
      490   U4R=T3I-T4I
            U4I=T4R-T3R
            GO TO 510
      500   U4R=T4I-T3I
            U4I=T3R-T4R
      510   DATA(K1)=U1R+U2R
```

```
      DATA(K1+1)=U1I+U2I
      DATA(K2)=U3R+U4R
      DATA(K2+1)=U3I+U4I
      DATA(K3)=U1R-U2R
      DATA(K3+1)=U1I-U2I
      DATA(K4)=U3R-U4R
  520 DATA(K4+1)=U3I-U4I
      KMIN=4*(KMIN-J3)+J3
      KDIF=KSTEP
      IF(KDIF-NP2)450,530,530
  530 CONTINUE
      M=MMAX-M
      IF(ISIGN)540,550,550
  540 TEMPR=WR
      WR=-WI
      WI=-TEMPR
      GO TO 560
  550 TEMPR=WR
      WR=WI
      WI=TEMPR
  560 IF(M-LMAX)565,565,410
  565 TEMPR=WR
      WR=WR*WSTPR-WI*WSTPI+WR

  570 WI=WI*WSTPR+TEMPR*WSTPI+WI
      IPAR=3-IPAR
      MMAX=MMAX+MMAX
      GO TO 360
C
C     MAIN LOOP FOR FACTORS NOT EQUAL TO TWO.  APPLY THE TWIDDLE FACTOR
C     W=EXP(ISIGN*2*PI*SQRT(-1)*(J2-1)*(J1-J2)/(NP2*IFP1)), THEN
C     PERFORM A FOURIER TRANSFORM OF LENGTH IFACT(IF), MAKING USE OF
C     CONJUGATE SYMMETRIES.
C
  600 IF(NTWO-NP2)605,700,700
  605 IFP1=NON2
      IF=1
      NP1HF=NP1/2
  610 IFP2=IFP1/IFACT(IF)
      J1RNG=NP2
      IF(ICASE-3)612,611,612
  611 J1RNG=(NP2+IFP1)/2
      J2STP=NP2/IFACT(IF)
      J1RG2=(J2STP+IFP2)/2
  612 J2MIN=1+IFP2
      IF(IFP1-NP2)615,640,640
  615 DO 635 J2=J2MIN,IFP1,IFP2
      THETA=-TWOPI*FLOAT(J2-1)/FLOAT(NP2)
      IF(ISIGN)625,620,620
  620 THETA=-THETA
  625 SINTH=SIN(THETA/2.)
      WSTPR=-2.*SINTH*SINTH
      WSTPI=SIN(THETA)
      WR=WSTPR+1.
      WI=WSTPI
```

```
            J1MIN=J2+IFP1
            DO 635 J1=J1MIN,J1RNG,IFP1
            I1MAX=J1+I1RNG-2
            DO 630 I1=J1,I1MAX,2
            DO 630 I3=I1,NTOT,NP2
            J3MAX=I3+IFP2-NP1
            DO 630 J3=I3,J3MAX,NP1
            TEMPR=DATA(J3)
            DATA(J3)=DATA(J3)*WR-DATA(J3+1)*WI
    630     DATA(J3+1)=TEMPR*WI+DATA(J3+1)*WR
            TEMPR=WR
            WR=WR*WSTPR-WI*WSTPI+WR
    635     WI=TEMPR*WSTPI+WI*WSTPR+WI
    640     THETA=-TWOPI/FLOAT(IFACT(IF))
            IF(ISIGN)650,645,645
    645     THETA=-THETA
    650     SINTH=SIN(THETA/2.)
            WSTPR=-2.*SINTH*SINTH
            WSTPI=SIN(THETA)
            KSTEP=2*N/IFACT(IF)
            KRANG=KSTEP*(IFACT(IF)/2)+1
            DO 698 I1=1,I1RNG,2
            DO 698 I3=I1,NTOT,NP2
            DO 690 KMIN=1,KRANG,KSTEP
            J1MAX=I3+J1RNG-IFP1
            DO 680 J1=I3,J1MAX,IFP1
            J3MAX=J1+IFP2-NP1
            DO 680 J3=J1,J3MAX,NP1
            J2MAX=J3+IFP1-IFP2
            K=KMIN+(J3-J1+(J1-I3)/IFACT(IF))/NP1HF
            IF(KMIN-1)655,655,665

    655     SUMR=0.
            SUMI=0.
            DO 660 J2=J3,J2MAX,IFP2
            SUMR=SUMR+DATA(J2)
    660     SUMI=SUMI+DATA(J2+1)
            WORK(K)=SUMR
            WORK(K+1)=SUMI
            GO TO 680
    665     KCONJ=K+2*(N-KMIN+1)
            J2=J2MAX
            SUMR=DATA(J2)
            SUMI=DATA(J2+1)
            OLDSR=0.
            OLDSI=0.
            J2=J2-IFP2
    670     TEMPR=SUMR
            TEMPI=SUMI
            SUMR=TWOWR*SUMR-OLDSR+DATA(J2)
            SUMI=TWOWR*SUMI-OLDSI+DATA(J2+1)
            OLDSR=TEMPR
            OLDSI=TEMPI
            J2=J2-IFP2
            IF(J2-J3)675,675,670
    675     TEMPR=WR*SUMR-OLDSR+DATA(J2)
```

```
            TEMPI=WI*SUM1
            WORK(K)=TEMPR-TEMPI
            WORK(KCONJ)=TEMPR+TEMPI
            TEMPR=WR*SUMI-OLDSI+DATA(J2+1)
            TEMPI=WI*SUMR
            WORK(K+1)=TEMPR+TEMPI
            WORK(KCONJ+1)=TEMPR-TEMPI

      680   CONTINUE
            IF(KMIN-1)685,685,686
      685   WR=WSTPR+1.
            WI=WSTPI
            GO TO 690
      686   TEMPR=WR
            WR=WR*WSTPR-WI*WSTPI+WR
            WI=TEMPR*WSTPI+WI*WSTPR+WI
      690   TWOWR=WR+WR
            IF(ICASE-3)692,691,692
      691   IF(IFP1-NP2)695,692,692
      692   K=1
            I2MAX=I3+NP2-NP1
            DO 693 I2=I3,I2MAX,NP1
            DATA(I2)=WORK(K)
            DATA(I2+1)=WORK(K+1)
      693   K=K+2
            GO TO 698
      C
      C     COMPLETE A REAL TRANSFORM IN THE 1ST DIMENSION, N ODD, BY CON-
      C     JUGATE SYMMETRIES AT EACH STAGE.
      C
      695   J3MAX=I3+IFP2-NP1
            DO 697 J3=I3,J3MAX,NP1
            J2MAX=J3+NP2-J2STP
            DO 697 J2=J3,J2MAX,J2STP
            J1MAX=J2+J1RG2-IFP2
            J1CNJ=J3+J2MAX+J2STP-J2
            DO 697 J1=J2,J1MAX,IFP2
            K=1+J1-I3
            DATA(J1)=WORK(K)

            DATA(J1+1)=WORK(K+1)
            IF(J1-J2)697,697,696
      696   DATA(J1CNJ)=WORK(K)
            DATA(J1CNJ+1)=-WORK(K+1)
      697   J1CNJ=J1CNJ-IFP2
      698   CONTINUE
            IF=IF+1
            IFP1=IFP2
            IF(IFP1-NP1)700,700,610
      C
      C     COMPLETE A REAL TRANSFORM IN THE 1ST DIMENSION, N EVEN, BY CON-
      C     JUGATE SYMMETRIES.
      C
      700   GO TO (900,800,900,701),ICASE
      701   NHALF=N
            N=N+N
```

```
      THETA=-TWOPI/FLOAT(N)
      IF(ISIGN)703,702,702
  702 THETA=-THETA
  703 SINTH=SIN(THETA/2.)
      WSTPR=-2.*SINTH*SINTH
      WSTPI=SIN(THETA)
      WR=WSTPR+1.
      WI=WSTPI
      IMIN=3
      JMIN=2*NHALF-1
      GO TO 725
  710 J=JMIN
      DO 720 I=IMIN,NTOT,NP2
      SUMR=(DATA(I)+DATA(J))/2.
      SUMI=(DATA(I+1)+DATA(J+1))/2.

      DIFR=(DATA(I)-DATA(J))/2.
      DIFI=(DATA(I+1)-DATA(J+1))/2.
      TEMPR=WR*SUMI+WI*DIFR
      TEMPI=WI*SUMI-WR*DIFR
      DATA(I)=SUMR+TEMPR
      DATA(I+1)=DIFI+TEMPI
      DATA(J)=SUMR-TEMPR
      DATA(J+1)=-DIFI+TEMPI
  720 J=J+NP2
      IMIN=IMIN+2
      JMIN=JMIN-2
      TEMPR=WR
      WR=WR*WSTPR-WI*WSTPI+WR
      WI=TEMPR*WSTPI+WI*WSTPR+WI
  725 IF(IMIN-JMIN)710,730,740
  730 IF(ISIGN)731,740,740
  731 DO 735 I=IMIN,NTOT,NP2
  735 DATA(I+1)=-DATA(I+1)
  740 NP2=NP2+NP2
      NTOT=NTOT+NTOT
      J=NTOT+1
      IMAX=NTOT/2+1
  745 IMIN=IMAX-2*NHALF
      I=IMIN
      GO TO 755
  750 DATA(J)=DATA(I)
      DATA(J+1)=-DATA(I+1)
  755 I=I+2
      J=J-2
      IF(I-IMAX)750,760,760
  760 DATA(J)=DATA(IMIN)-DATA(IMIN+1)

      DATA(J+1)=0.
      IF(I-J)770,780,780
  765 DATA(J)=DATA(I)
      DATA(J+1)=DATA(I+1)
  770 I=I-2
      J=J-2
      IF(I-IMIN)775,775,765
  775 DATA(J)=DATA(IMIN)+DATA(IMIN+1)
```

```
            DATA(J+1)=0.
            IMAX=IMIN
            GO TO 745
      780   DATA(1)=DATA(1)+DATA(2)
            DATA(2)=0.
            GO TO 900
      C
      C     COMPLETE A REAL TRANSFORM FOR THE 2ND OR 3RD DIMENSION BY
      C     CONJUGATE SYMMETRIES.
      C
      800   IF(I1RNG-NP1)805,900,900
      805   DO 860 I3=1,NTOT,NP2
            I2MAX=I3+NP2-NP1
            DO 860 I2=I3,I2MAX,NP1
            IMIN=I2+I1RNG
            IMAX=I2+NP1-2
            JMAX=2*I3+NP1-IMIN
            IF(I2-I3)820,820,810
      810   JMAX=JMAX+NP2
      820   IF(IDIM-2)850,850,830
      830   J=JMAX+NP0
            DO 840 I=IMIN,IMAX,2
            DATA(I)=DATA(J)

            DATA(I+1)=-DATA(J+1)
      840   J=J-2
      850   J=JMAX
            DO 860 I=IMIN,IMAX,NP0
            DATA(I)=DATA(J)
            DATA(I+1)=-DATA(J+1)
      860   J=J-NP0
      C
      C     END OF LOOP ON EACH DIMENSION
      C
      900   NP0=NP1
            NP1=NP2
      910   NPREV=N
      920   RETURN
            END

      ROUTINES CALLED:
      MAX0  , FLOAT , COS   , SIN

      OPTIONS =/ON,/OP:3

      BLOCK        LENGTH
      FOURT   3472   (015440)*

      **COMPILER ----- CORE**
         PHASE       USED  FREE
      DECLARATIVES 00622 14690
      EXECUTABLES  01583 13729
      ASSEMBLY     02435 17517
```

User's Guide

File Structures

```
$FU FILDMP

FILDMP  V007B

$KB±/B±<DP0±PROCSD.IMG


  PROCSD.IMG  (B±TES)

0000000 000 000 117 072 100 000 100 000 000 000 000 000 000 000 000 000
0000020 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000040 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000060 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000100 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000120 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000140 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000160 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000200 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000220 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000240 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000260 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000300 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000320 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000340 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000360 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000400 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000420 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000440 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000460 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000500 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000520 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000540 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000560 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000600 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000620 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000640 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000660 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000700 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000720 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000740 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0000760 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0001000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0001020 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0001040 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0001060 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0001100 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0001120 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0001140 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0001160 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0001200 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0001220 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0001240 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
0001260 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000 000
```

0001300	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
0001320	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
0001340	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
0001360	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
0001400	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
0001420	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
0001440	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000
0001460	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000

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Vita

Dennis A. McGaugh was born on November 9, 1947 in Eugene, Oregon. He graduated from South Eugene High School in 1966. After spending three years at Oregon State University, he was drafted into the Army in 1969. He received basic and advanced infantry training at Ft. Ord, California and then entered Infantry Officer's Candidate School at Ft. Benning, Georgia where he graduated in November 1970, and was commissioned a Second Lieutenant in Military Intelligence. During his first assignment at NSA, Ft. Meade, Maryland, he attended the John Hopkins University, Baltimore and graduated in September 1973 with a Bachelor of Science in Mechanical Engineering. His next assignment was to USASA Field Station, Korea, were he served a the operations officer of the 146th ASA Aviation Company from October 1974 until November 1975. He then attended the US Army Military Intelligence Officer's Advanced Course at Ft. Huadruca, Arizonia before entering the Air Force Institute of Technology in September 1976.

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19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Image Processing System	DICOMED
Fourier Transformation(s)	IPS
Fast Fourier Transformation(s)	FFT
Linear Image Filtering	DFT
Power Spectrum	IFFT

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A FORTRAN program is presented that will interactively prepare digitized images (pictures) for experimental analysis. The digital preparation includes the ability to Discrete Fourier Transform (DFT), Inverse Fourier Transform (IDFT), threshold image power spectral density, and to perform two-dimensional image filtering. Further, a brief discussion of image distortion measurements, optimal image size for experimental

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20. presentation, and image aliasing is provided. A sample of typical processed image results is also supplied.