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Hybrid Image Processing System

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A hybrid optical/digital image processing system has been developed for an ongoing research program in hybrid image processing. This system is described and its capabilities and limitations are discussed. Major system components include a coherent optical processor, digital processor (minicomputer), and optical/digital input/output (I/O) devices. The I/O devices include an image dissector camera, microdensitometer, video camera, and film writer. An extensive menu-oriented software package is installed in this system.

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HYBRID IMAGE PROCESSING SYSTEM

INTRODUCTION

This report describes a hybrid optical/digital image processing system which was developed for an ongoing research program in the area of hybrid image processing. The advantages of optical image processing have been most successfully exploited in hybrid systems. Optical operations promise fast processing times although at reduced flexibility and accuracy. Digital operations, however, offer high flexibility and accuracy at the expense of speed [1,2]. In the design of the present system, emphasis was placed on system flexibility for the investigation of varied problems in a research environment. Discussion is included in this report of the capabilities and limitations of the hybrid image processor. This information should assist potential users in an assessment of its applicability to research problems of interest.

Major components of the processing system are shown in Fig. 1. It consists of three subsystems: (a) a coherent optical processor; (b) the digital processor and associated peripherals; and (c) optical/digital, input/output (I/O) devices. The coherent optical processor includes laser sources and various optical components on a vibration isolation table. Components within the digital portion of the system include a minicomputer, interactive terminal, digital image display, and standard computer peripherals. Optical/digital I/O devices include a microdensitometer, image dissector camera, video camera system, and film writer.

The next section of this report describes the coherent optical portion of the system. Succeeding sections describe the digital and optical/digital I/O devices. A discussion of the image processing software is given in the final section. The software determines the actual digital image processing operations that are to be performed, and integrates the coherent optical subsystem and various I/O devices into the system.

COHERENT OPTICAL PROCESSOR

The optical portion of the hybrid image processing system is conceived of as a general purpose coherent optical processor. Its design emphasizes flexibility such that it is able to perform a number of varied operations that are of interest. A more rigid design would be more efficient in the implementation of a particular processing scheme, but would not be as readily adaptable to other techniques. Optical operations of interest include analysis of Fourier power spectra, matched spatial filtering, and composite transform generation [3]. Processing in some cases may require intermediate steps to be performed digitally. A good introduction to coherent optical processing techniques can be found in the text by Goodman [4] and will not be discussed here.

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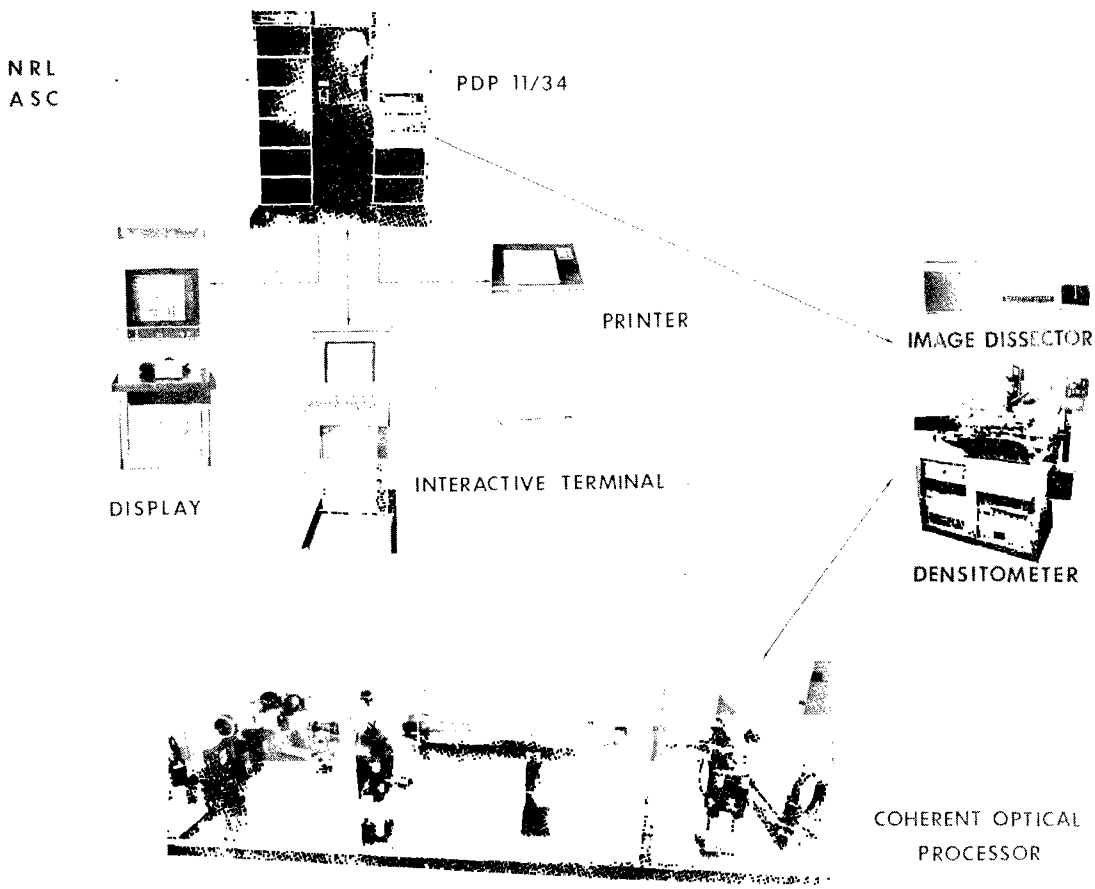

Fig. 1 — Hybrid optical/digital processing system

The optical processor is shown schematically in Fig. 2. A standard configuration is shown here for illustrative purposes. Collimated coherent laser light is incident upon plane P_0. Lens L_1 forms at plane P_1 the two-dimensional Fourier transform of the input light distribution at plane P_0. A complex spatial or matched filter is placed in plane P_1. The filtered output is then transformed again by lens L_2 and the resulting intensity distribution is examined in plane P_2. Depending on the type of filtering employed, the output distribution may range in character from an image similar to the input image at P_0, but with a modified spatial frequency distribution, to a correlation of the input image with a matched filter.

Figure 3 is a photograph of the optical processor. The laser source is a krypton ion laser operating at 647 nanometers. The beam is spatially filtered, expanded to 50 mm diameter, and directed through apertures to the processor input plane. Liquid gates are available for use with photographic film both in the input plane P_0 and the filtering plane P_1 in Fig. 2.

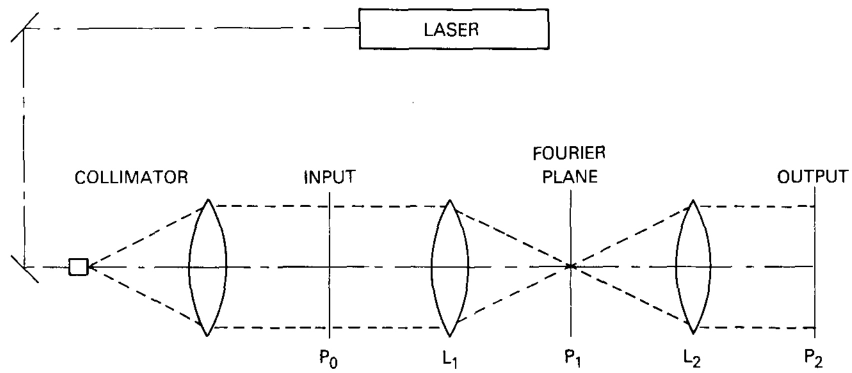

Fig. 2 — Schematic of coherent optical processor

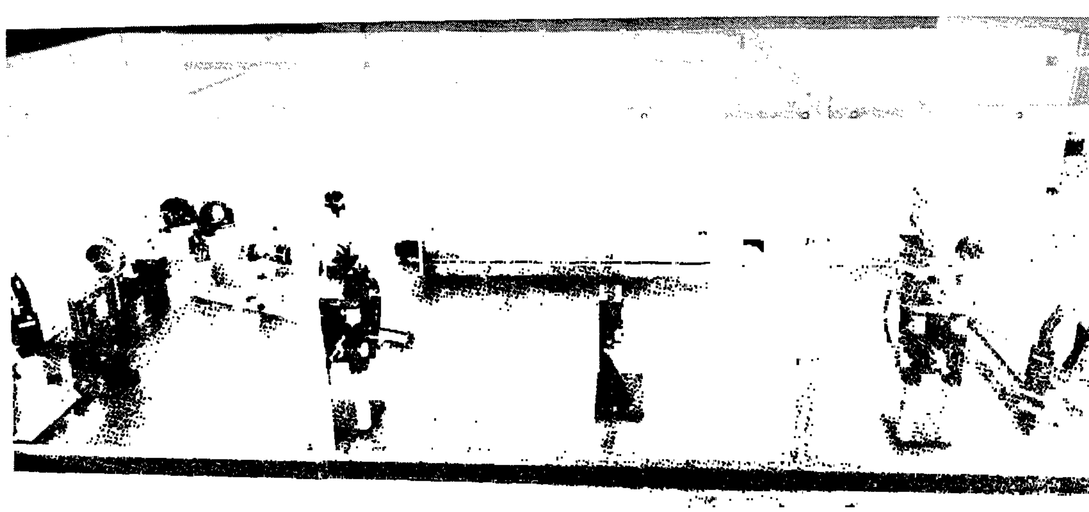

Fig. 3 — Coherent optical processor

The use of liquid gates has been found to be important because of observed variations in film emulsion and base thicknesses [4, p.155]. For most experiments p-xylene is being used as the index matching fluid. If no liquid gate is used in the input plane, Fourier power spectra in plane P_1 are observed to be asymmetric and to show significant shifts in the central peaks.

The Fourier transform lenses are 150-mm diameter, 760-mm focal length, air-spaced doublets. A number of factors determine the range of spatial frequencies that may be examined in the filter plane P_1 (Fig. 2). In particular, system apertures limit spatial frequency output at P_1 to $\leqslant 100$ line pairs/mm at 647 nm. In the Fourier transform plane P_1, the distance from the optical axis is related to the spatial frequency by the relation $f = x/F\lambda$ where f is the spatial frequency, x is the distance from the optical axis, λ is the wavelength of the coherent source, and F is the focal length of the lens. If examination by a sensor of the Fourier plane is limited to a radius of 25 mm, for example, the preceding relation limits spatial frequencies to $\leqslant 50$ line pairs/mm.

Various systems are available for the detection and recording of the optically processed data. These include photographic film, a wedge/ring detector, an image dissector camera, a video camera, and a film writer. The image dissector camera and video camera convert optical data directly into digital form for use in the digital processor while photographic film must first be digitized either by a microdensitometer or one of the camera systems. The film writer writes a digitized image onto a piece of photographic film. It is possible with this device to write onto film a processed image or other optical data and subsequently reenter this information into the optical processor. A feedback loop in the processing is thereby provided. These devices will be described later in more detail. The wedge/ring detector is not directly interfaced to the processor and is used at present both for alignment purposes and for analysis of Fourier power spectra.

A schematic diagram of the wedge/ring detector, which was purchased from Recognition Systems, Inc., is shown in Fig. 4. It is seen to consist of 32 wedge and 32 ring elements which can be read out separately or in combination from a control box. It is normally used in the Fourier transform plane of an optical processor to characterize the input data [5]. This device attempts to make use of the fact that the diffraction patterns for many input scenes have a structure with circular symmetry or are characterized by radial spikes. This character results from the presence of a regular array structure in many man-made and natural inputs as well as the presence of sharp edges which generate radial intensity spikes in the Fourier transform plane. Use of this device to characterize the input then reduces the description of that input to 64 numbers as opposed to something of the order of 10^6 for the input itself. The wedges and rings are each limited to only a half plane because of the known radial symmetry of the Fourier power spectrum for an input with no phase variations across the input plane.

While the wedge/ring detector is used primarily in the Fourier transform plane (plane P_1 in Fig. 2), the image dissector and video cameras may be used either there or in the correlation plane (plane P_2 in Fig. 2). The image dissector camera is generally the preferred device because it has a somewhat larger dynamic range, better resolution, and a variable input scanning format. However, because there is no sensor integration in the dissector tube, readout time is longer and there is no continuous image output, which is particularly useful for experimental adjustment and calibration purposes.

The I/O devices used in the coherent processor are not real time, and therefore the inherent speed of the optical processor is not being utilized. However, the system does permit modelling of real time operations and provides insight into the problems of a given application. Development of a specific technique for a given application requires consideration of the limitations and specifications of possible candidate I/O devices.

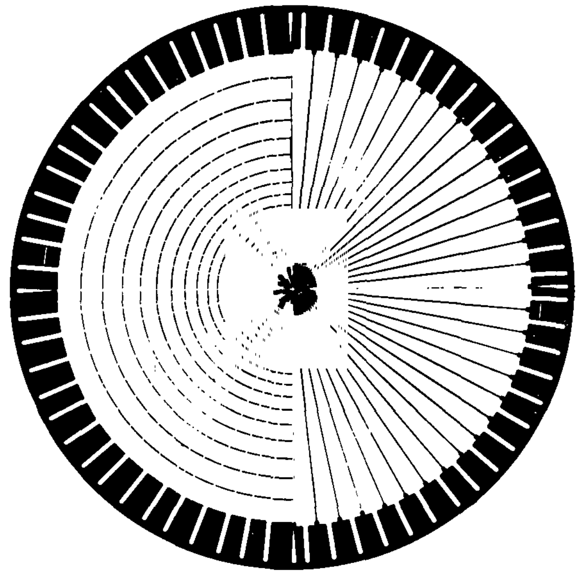

Fig. 4 — Schematic of wedge/ring detector

DIGITAL PROCESSOR AND PERIPHERALS

The digital processor is a Digital Equipment Corp. (DEC) PDP-11/34 minicomputer. This processor includes 124K 16-bit words and a hardware floating point unit. A total of 8 million words of storage on magnetic disk systems are also included. The disk systems, which have removable disk cartridges, serve as mass on-line storage for imagery and for the operating software. A 9-track, industry compatible, magnetic tape system and a Versatec printer/plotter unit are standard peripherals. The tape drive is utilized for archival storage of imagery and for shorter term storage when disk overflow is encountered. It also serves as an interface between the hybrid system and the NRL Advanced Scientific Computer (ASC) facility. Printer/plotter output is very useful for program development and is used for certain options in the image processing software. This same device can produce hard copy for an interactive Tektronix CRT terminal.

Tektronix 4010 and 4025 terminals serve as console terminals to the operating software. Extensive use is made of the graphics capabilities of these terminals within the image processing software.

A digital display system, the Model 70/CS manufactured by Stanford Technology Inc., is utilized as an interactive display with which to view the processed imagery. This device contains sufficient refresh memory for one 512 by 512 digital picture and can display 256 levels (8 bits) of grey level intensity per picture element. The refresh memory contents are continuously read out through digital-to-analog converters. Combination of these signals with timing signals results in a composite video signal which is then fed to a standard video monitor. The system also contains digital look-up tables which can provide quasi real time processing for some simpler types of digital processing. These tables, in conjunction with the color video monitor, also permit the use of pseudo color. In this process, grey level intensities are encoded as various colors.

OPTICAL/DIGITAL I/O DEVICES

This section of this report describes in more detail four subsystems which were previously mentioned: (1) an image dissector camera; (2) a high speed microdensitometer; (3) a video (television) system; and (4) a film writer. All four systems are to be interfaced to the digital portion of the hybrid optical/digital processor. Although these devices are utilized with the coherent optical processor, they can also be used to digitize photographic transparencies or video imagery and to write on film directly without any interaction with the optical processor. Consequently, this flexibility permits processing that is completely digital. These devices are summarized in Table 1.

Table 1 — Summary of Optical/Digital I/O Devices

Device	Resolution	Number of lines	Digitizing time for 512 by 512 image (min)	Signal-to-noise ratio (dB)
Image dissector	60% modulation @ 20 lp/mm	1000	2-6	40
Video camera	4% modulation @ 1000 lines	480	2	40
Microdensitometer	2-400 lp/mm	500 (fixed scan raster)	3	60
Film writer	2.5-20 lp/mm	8000 max (depends upon film size)	2-3	60

Image Dissector Camera

The ITT dissector camera system features an image dissector tube, amplifying and control electronics, and an analog-to-digital converter. It is uniquely suited for random access scanning under computer control. The image dissector tube, a non-storage device, samples the image brightness of a single point at any one time. The output signal is directly proportional to the brightness and is independent of the scan velocity or scan history. This signal is then integrated for times of from 50 to 1000 μs and the resulting sum is converted into digital form. A maximum signal to noise ratio of about 40 db is realized. The output is linear over a dynamic range of 100 (7 grey levels). Both linear and logarithmic outputs are provided. The resolution of the camera is such that one obtains typically a 60% modulation at 20 line pairs/mm. This provides about 500 line pairs (1000 TV lines) across a square which fits into the quality photocathode area of 36 mm. Digitization of a 512 by 512 image takes from 2 to 6 min. depending upon the integration time.

Microdensitometer

The Tech/Ops high speed microdensitometer consists of a scanning film table and stationary optical system. A photographic transparency is scanned in a fixed rectangular raster of 400 by 500 points. However, the raster dimensions may be varied incrementally in both axes by mechanical adjustments. Nine settings are available which range from 1 μm to 256 μm per point. The resolution of the optical system may be adjusted to be consistent with the raster size. Resolutions of from 2 to 400 line pairs/mm are obtainable. Intensity values are converted to a logarithmic scale (optical density) and then are converted to digital form. The dynamic range of the instrument is 3.0 optical density units (ratio of 1000:1). A 10-bit analog-to-digital converter is used. The time required to digitize a single transparency is 200 s.

Video Camera System

In addition to its use with the coherent optical processor, the video camera system permits both direct digitization from a video camera and digitization from a video tape recording. This latter capability is particularly important with respect to field experimentation. Video imagery that was obtained in the field and that was recorded on video tape can be digitized subsequently in the laboratory for image processing.

The equipment consists of a Colorado Video Model 270A Video Digitizer, a Sierra Scientific Model LSP-1 video camera, an Ampex DR-10A video disk recorder, and associated magnetic tape recorders. The digitizer accepts standard composite video with a 2:1 interlace and encodes the analog intensity into a 8-bit digital output. A single horizontal scan line is digitized into 512 picture elements and up to 480 raster lines per frame may be digitized. Digitization of a single video frame (two fields) requires at least 35 s since the digitizer is not a real time device. (In practice, 2 or 3 min are required because of software considerations). Consequently, the frame to be digitized must be repeated during the digitizing time. The Ampex video disk recorder is utilized when object motion precludes recording or viewing many stationary frames. A single frame can be recorded on the disk recorder and played back continuously for the required time to the digitizer.

The television camera is equipped with a plumbicon pickup tube. Standard and variable scan rates are available with 2:1 interlace. A signal to noise ratio of greater than 40 db is specified. Horizontal resolution is 1000 TV lines (4% modulation) at the center and 600 TV lines at the corners.

Film Writer

The film writer, Model P-1500 which is manufactured by Optronics International, Inc., consists of a rotating drum and stationary light emitting diode (LED) source. A piece of photographic film is placed upon the drum for exposure to the modulated LED source. A digital input, which represents the grey level intensity of a picture element, is converted to an analog voltage which in turn drives the LED source. The film is exposed to the modulated LED as the drum rotates. Stepping of the drum in a direction parallel to the rotational axis is also under computer control.

The maximum permitted film size is 25 by 25 cm. Resolutions of from 2.5 to 20 line pairs/mm are available. Intensity values (8 bits) are converted to photographic densities over a 0 to 2.5 O.D. range. At least 64 grey levels are obtainable on a repeatable basis. The time required to write a 512 by 512 image is 2 to 3 min.

SOFTWARE

The software for image processing that is presently installed in the hybrid optical/digital system consists for the most part of a comprehensive software package developed by the Pattern Analysis and Recognition Corp. (PAR) for the USAF Rome Air Development Center (RADC) [6,7]. This package provides full capability for handling and processing of imagery with additional capability for feature extraction and analysis. Design of this software emphasizes the research environment and a high degree of interaction between the researcher and the results of the many processing options.

Various routines are called by an executive routine according to user options displayed on a Tektronix CRT display. Figure 5 shows a functional overview of the software. A master menu lists various option menus which are organized according to the type of processing. Menu "INPUT" provides for the input of imagery through the I/O devices previously described. Most menus contain options for the processing phase. In this phase, imagery is processed to enhance certain characteristics and to deemphasize others. Except for one case, the output is another image. Menu "IMAGE STATISTICS, HISTOGRAMS" provides statistical information, e.g., a grey value histogram, with respect to a particular image. Since the output images are formatted in the same manner as the input images, many different operations may be applied sequentially until the desired enhancement is achieved. Menu "TRANSFORMS, FILTERS" differs from the other processing in that it contains the global Hadamard transform [8]. The other processing options are local in nature, i.e., the grey level at a point in the processed image depends only upon grey levels in the neighborhood of the original image point.

The options "FEATURE EXTRACTION" provide a capability for the extraction of feature vectors and their distribution in multidimensional feature space [9]. Menus "FILE MANIPULATIONS", "DISPLAY OPTIONS", and "UTILITY FUNCTIONS, EXIT" facilitate handling of the large data base associated with imagery and optimize interaction of the user with the system. In particular, the display options allow final and intermediate results of processing to be displayed on the digital display. File manipulations permit file maintenance functions including file directories. Magnetic tape I/O routines are also included.

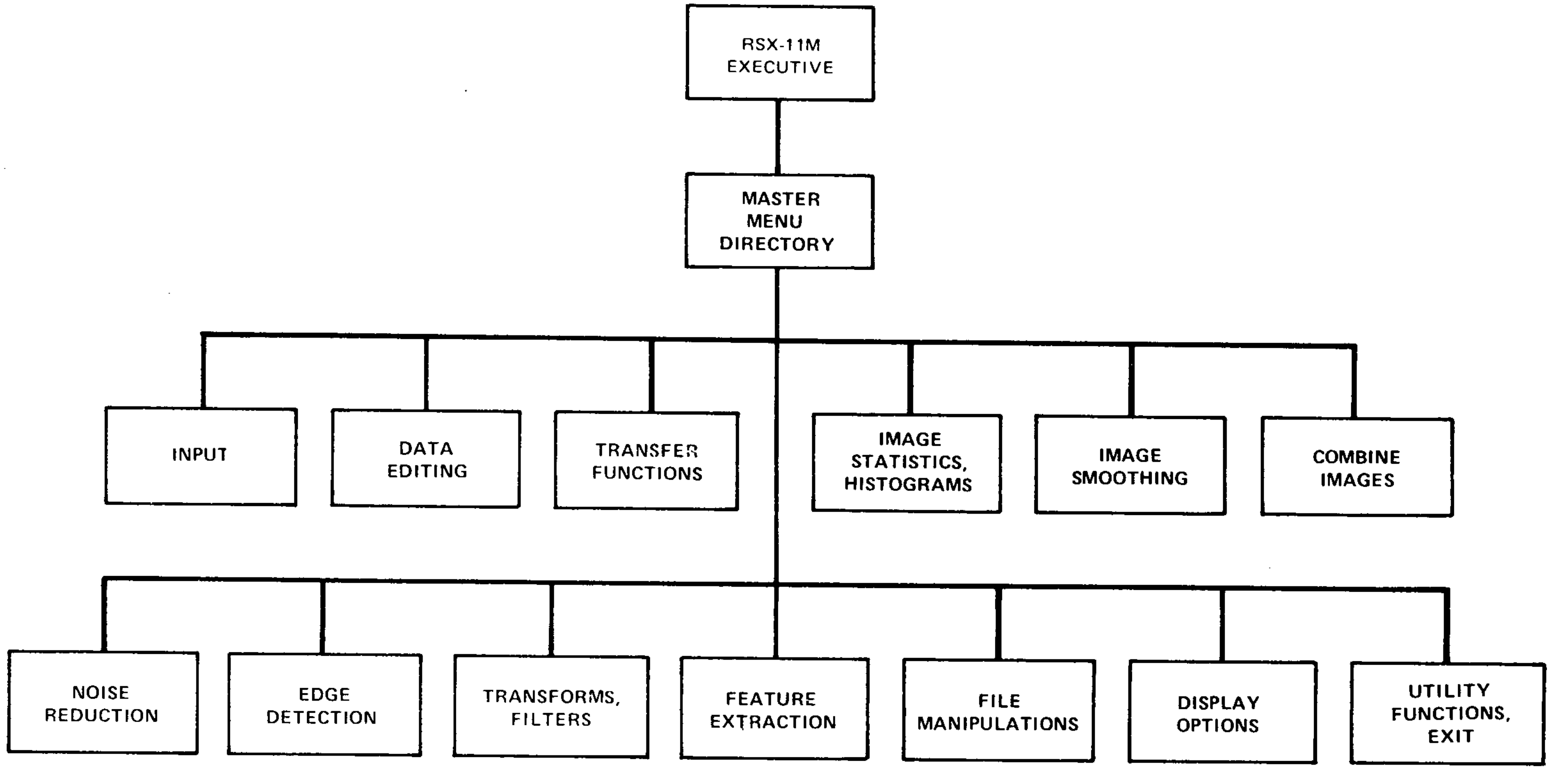

Fig. 5 — Software organization

Examples of the processing capability of this software can be seen from an examination of the individual menus. Menu "TRANSFER FUNCTIONS" contains a series of options that allow transfer functions of various types to be applied to the grey values of an image. For each input picture element (pixel) grey value, the function defines an output grey value. Hence, the output value at a pixel depends only upon the input value at that one pixel and upon no other pixels in the image. One option allows the user to define an arbitrary piecewise linear transfer function and then to apply this function to an image.

Menu "IMAGE STATISTICS, HISTOGRAMS" contains options that provide grey value histograms and statistical information on a given image, a row within an image, or a region within an image. Statistical data include parameters such as the mean, standard deviation, and median. One option allows the user to display an intensity profile of any given row of an image. All output information is displayed graphically on the Tektronix CRT terminal.

Menu "IMAGE SMOOTHING" consists of options that perform smoothing operations on an image. The output grey value for an input pixel depends upon an array of pixels in the neighborhood of the transformed pixel. One of these options is a weighted smooth with adjustable dimensions. Menu "EDGE DETECTION" contains options that detect edges within an image by looking for grey level gradients. The output image of these routines is a binary image, i.e., grey values of zero and maximum only. Other options are available that attempt to remove extraneous edges and fill in missing edges.

The RADC software package originally contained no software interfaces for the optical portion of the hybrid optical/digital processor and for the digital display. Such interfaces exist or are being written for the digital display, image dissector camera, video camera, microdensitometer, and film writer. The task of adding routines to the RADC package is simplified by its modular nature.

Additional routines have been added to perform image processing for specific experiments. For example, a routine was written that registers and adds successive images. The summed image can then be normalized and displayed on the digital display. Near term programs involving the processing of infrared imagery and optical Fourier transforms require additional software. FORTRAN callable interface routines have been written to facilitate software development. Systems additions may be written in FORTRAN, if desired.

Initially the software ran under the DEC DOS/BATCH operating system. However, the RADC package was converted recently to the DEC RSX-11M operating system by Amherst Systems, Inc. under RADC sponsorship. This converted package is currently installed in the NRL system. Its use allows the support of up to 124K words of memory in the PDP-11/34 whereas support by DOS/BATCH is limited to 28K. A larger memory permits larger data buffers and increased system throughput. Also, RSX-11M supports multiple users on a single system.

Software documentation consists of a users and programmers manual for the RSX-11M RADC package [7]. Addenda that describe NRL additions to this software are being prepared.

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