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Image Discrimination Enhancement Combination System (IDECS)

ROBERT M. HARALICK AND PHIL CURRIER

Remote Sensing Laboratory, University of Kansas, Space Technology Center, Lawrence, Kansas 66045

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This paper describes the structure of the IDECS system developed at the University of Kansas Remote Sensing Laboratory beginning in 1964. The IDECS is a computer controllable hybrid analog–digital machine that can display black and white or color images and can do its own image acquisition, enhancement, and combinations. IDECS processing operations require no memory and include level slicing, isometric 3-D display, linear combinations, tone-to-hue conversions, area selection, and differentiation.

1. INTRODUCTION

In this paper we describe the structure of the Image Discrimination Enhancement Combination System (IDECS) which was developed at the University of Kansas beginning in 1964 under the leadership of R. K. Moore, Director of the Remote Sensing Laboratory, with the sponsorship of NASA and DOD.[1]

All investigators who have done image processing know of the need for interactive image processing machinery. The IDECS is a computer-controllable hybrid analog–digital machine that can display black and white or color images and can do its own image enhancement and combinations. It can also serve as a device to perform the frequent format conversions which image-processing investigators so often need.[2] IDECS handles image data in video signal format, the same format used in commercial television. Each IDECS operation takes 1/30 sec, its frame rate. The processing operations currently implemented in IDECS require no memory; they include various kinds of level slicing, linear combinations, and nonlinear operations which can be done manually or under computer control. The format conversions that can be performed by IDECS include all those possible between any two of the following three formats: photographic

[1] In 1967 G. Kelly and in 1969 R. Haralick joined with Moore in guiding its development. G. Dalke and P. Anderson, who were then Ph.D. and D.E. candidates, supervised M.S. candidates who designed and built the system's circuitry.

[2] Almost all image producing sensors (cameras, scanners, radars, vidicons, etc.) produce images in photographic or video signal image format. These analog data must usually be put in video signal or digital image format for processing. The latter conversion requires an expensive A/D operation. After the processing step, the resulting images must be displayed and this entails conversion of a video image format or digital image format to a photographic image format. The latter conversion requires a D/A operation.

image format (this includes paper print, transparency, and instantaneous radiance image format), digital image format, and video signal format.

It is our hope that the approach to the design of a versatile image display, format conversion, and near-real-time image discrimination, enhancement, and combination processing system described here will aid other investigators in planning their own systems.

2. IDECS SYSTEM DESCRIPTION

The IDECS is a hybrid analog–digital facility for performing image format conversions and for displaying a wide variety of enhancements, measurements, and category discriminations on single and multiple images. Input or output images can be in photographic image format or digital image format and may be input to IDECS from a digital computer, from flying spot scanners, or from a vidicon. Near-real-time (TV scan rates) enhancing or processing operations include image comparison by flickering or by coloring, image framing, image congruencing, level slicing, density to hue conversion, digital-to-analog conversion, analog-to-digital conversion, linear combining, quantizing (a not necessarily linear A/D conversion), and Boolean operations on binary images. The primary IDECS image output is on a color TV monitor and a black-and-white TV monitor.[3]

The wide variety in the sequential way one could use these operations necessitates that the IDECS be configured in a particularly flexible manner. For this purpose the IDECS has a 20×20 configuration matrix whose columns are indexed by system component outputs and whose rows are indexed by system component inputs. By pressing a row and column button, the output from any system component can be connected to any other system component and the corresponding lamp on the configuration matrix will light up.

To enable image data to come to IDECS in digital image format from a computer, the IDECS is interfaced to a PDP-15 minicomputer. In addition to allowing image data to be transferred, the interface allows almost all IDECS operations to be computer controlled. This control is established through the IDECS central processor unit (CPU) which has an instruction set of 64 instructions, 16 general 8-bit index registers, and essentially no memory. A block diagram of the video signal flow through IDECS is shown in Fig. 1, and a block diagram of the flow of control is shown in Fig. 2. To aid in establishing the operating condition of IDECS at any time, the IDECS CPU has a slow-speed

[3] Some companies manufacturing image processing and display equipment: Aydin Controls, 414 Commerce Drive, Fort Washington, Pa. 19034; Bendix Aerospace Systems Division, 3300 Plymouth Road, Ann Arbor, Mich. 48107; Comtal Corporation, 169 North Halstead, Pasadena, Calif. 91107; Evans and Sutherland Computer Corporation, 3 Research Road, Salt Lake City, Utah 84112; General Electric Company, Space Division, Apollo and Ground Systems, P.O. Box 2500, Daytona Beach, Fla. 32015; Genisco Computers, 17805-D Sky Park Circle Drive, Irvine, Calif. 92707; International Imaging Systems, 510 Logue Avenue, Mountain View, Calif. 94043; Interpretation Systems, Inc., P.O. Box 1007, Lawrence, Kans. 66044; Ramtek Corporation, 292 Commercial Street, Sunnyvale, Calif.; Rank Precision Industries, Inc., 411 Jarvis Avenue, Des Plaines, Ill. 60018; Spatial Data Systems, Inc., Box 249–500 South Fairview, Goleta, Calif. 93017.

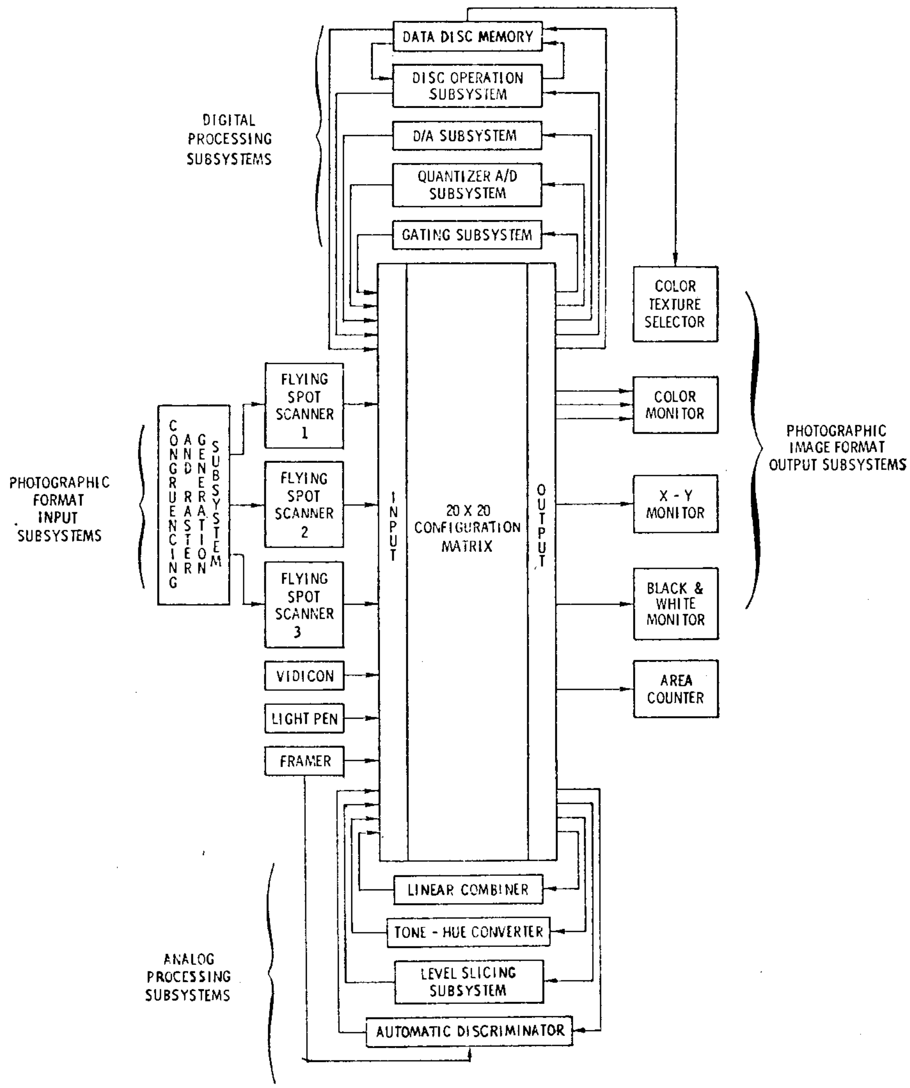

FIG. 1. Illustrates IDECS signal flow possibilities.

A/D converter to sample and transfer to the computer any of the signals in IDECS.

2.1. Photographic-Image-Format Input Subsystem

Images in photographic format can be input to IDECS by a vidicon or any one of three flying spot scanners. The input subsystem uses a standard TV raster of 525 lines at a bandwidth of 5 MHz. Because of the requirement for a close correspondence between the video signal produced by the vidicon and the light radiance seen by the vidicon, all the contrast normalizing circuitry which the

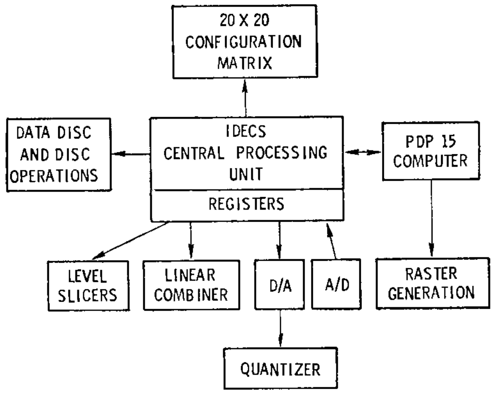

FIG. 2. Illustrates the flow of control in IDECS.

usual vidicon camera contains has been bypassed. The lens which originally came with the camera has been replaced with a good F1.4 lens from a 35-mm camera. This type of change in lens can considerably reduce the vignetting due to low grade optics. The new lens is attached to the camera with a bellows arrangement which allows the camera to zoom in on a small area if necessary. The camera is mounted on a mast to allow for easy vertical positioning and arranged with both a light table and flood lamps to accommodate transparencies and paper prints, respectively.

The three flying-spot scanners have zoom capability and allow three image transparencies between 35 mm and 3 × 4 in. in size to be input to IDECS simultaneously, which is useful for processing multiband or time-sequential remotely sensed multiimages. Transparencies to be scanned are positioned above the scanner's CRT with an enlarging lens placed between. A condenser lens focused the light transmitted through the image onto the cathode of a video photomultiplier tube. A reference photomultiplier tube and an automatic gain control (AGC) loop to modulate the cathode of the CRT are used to assure uniformity of light level over the entire area of the image being scanned. The reference photomultiplier tube is positioned beside the enlarging lens and senses the raw light output from the CRT raster. The error between the actual light sensed and the desired light brightness is amplified by the AGC amplifier and used as a signal to modulate the cathode of the CRT.

The scanner rasters are controlled by a congruencing subsystem which can electronically rotate, translate, and scale the raster for each scanner individually. The operator can register multiple images by adjusting the horizontal and vertical position and size controls and by rotating one raster with respect to another while the two images are electronically flickered on the black-and-white monitor. When the images are aligned, the displeasing motion and interference pattern which occur for misaligned images disappear. Alternatively, the operator may make the raster adjustments while watching the color monitor where one image is displayed in one color and the other image is displayed in another color.

The scanners have three modes of operation:

(1) A continuous scan where the horizontal and vertical deflection signals for the scanner CRT are driven by ramps which are synchronized with the display units;

(2) A staircase or dot scan where the horizontal and vertical deflection signals for the scanuer CRT are driven by the output of two digital-to-analog converters controlled by two binary counters which are synchronized with the display units;

(3) A PDP-15 computer-controlled slow scan where the scanning dot is moved horizontally and vertically to locations specified by the computer.

Modes (1) and (2) are used when real time processing is desired and mode (3), the program-controlled scan mode, is used to gather information from specific areas of the image and to obtain a more accurate 8 bit analog-to-digital conversion when necessary.

The final component of the photographic format input subsystem is a light pen to allow the investigator to specify arbitrary regions on any image.

2.2. Photographic-Image-Format Output Display Subsystems

IDECS has three separate displays: a black-and-white image monitor, a color image monitor, and an X–Y monitor. The black-and-white monitor is driven by two video signal channels. The operator can select to display the video signal on either channel or select to automatically flicker between the video signals on the channels. The flicker rate can be varied in four steps from 0.5 to 30 Hz.

The color monitor is driven by three channels wired directly to the red, green, and blue guns of the color CRT. The black-and-white and color monitors have the standard 525-line raster of commercial television sets.

The X–Y monitor can be used as video signal monitor which allows the investigator to look at any of the video signals in IDECS. One function in this mode would be to permit examination of the video signal for any image line or group of contiguous image lines. This function is important because it can give the investigator an immediate look at his raw or processed data and thereby increase his faith in the proper functioning of the hardware and his processing algorithms. Another function in this mode is to make gain and bias settings for the vidicon and scanner amplifiers easy to do: adjustments are made while watching the monitor.

The other mode in which to operate the X–Y monitor is to display the video signal for the image as an isometric projection. This is done by displaying the video signal for the first line of the image at the top of the screen and then displaying each successive line below the preceding line and slightly displaced to the left. The resulting image makes the white parts of the image stand up as mountains and the black parts of the image appear as valleys.

2.3. Image-Framer and Gating Subsystem

Once images are in the IDECS system, the first operation usually is to select the portion of the image to be processed. To do this the IDECS has a framer which generates a white rectangle of any size, capable of being superimposed in any position on the TV monitor. Position and size adjustments are easily made while automatically flickering between the image and the white framer output.

One of the uses of the framer is in the gating subsystem, where the framer can define a portion of the image video signal for processing. This selected portion, for example, could be used to constrain level slicing to a specific area in the image or be used to define the image density cross section of some field, as displayed on the X–Y monitor.

The actual gating subsystem is not restricted to the framer, but can be driven by any binary signal.

The framer is additionally used in the automatic discriminator subsystem described in Section 2.5.

2.4. Level-Slicer Subsystem

One of the simplest enhancing operations easily done on images in video signal formats is level slicing. A level slicer produces a binary 1 output only if the input video signal is between two adjustable thresholds. Thus a level slicer converts a continuous tone image to a binary image. IDECS has four independently controllable level slicers. The thresholds on each can be specified in two ways: (1) top level and bottom level, (2) bottom level and aperture window. In addition, the outputs of the level slicers may be automatically ANDED together implementing a simple MIN–MAX decision rule for multiimage data. The thresholds on the level slicers can be specified manually or specified under computer control. Manual adjustment of the level-slicer thresholds is usually done either by automatic flickering between the image and the output of the level slicers, producing a white level selection on the input images, or by causing the output to be presented in a different color than the image. The level-slicer subsystem has one output which is the AND of the output of all level slicers currently turned on.

The automatic adjustment mode of the thresholds by the PDP-15 computer allows program control of the level slicers. In effect the PDP-15 generates a decision rule from data gathered by IDECS and the IDECS implements the resulting rule in near-real-time on data obtained by scanning the input images. In general, five steps are required in performing such decision rule category assignments:

(1) The images must be registered;

(2) training data must be obtained by the computer from the images by directing the IDECS to scan appropriate areas;

(3) from the training data, the PDP-15 determines the parameters for the decision rule;

(4) the calculated parameters are used to set thresholds in the level slicers; and

(5) the IDECS displays the resulting category assignments.

2.5. Automatic Discriminator

The automatic discriminator is basically a level slicer whose thresholds are automatically adjusted in a dynamic way. It is used to select all points on an image whose grey tones fall within the contiguous range of grey tones detected in a small rectangular training area on the image. To accomplish this operation, a rectangular training area is first defined on the image typically using the framer controls and flickering between the framer output and the image. The peak detectors in the automatic discriminator then sample and hold the maximum and minimum video signal in the framed area and set the thresholds of the discriminator's internal level slicer to those levels. The output would typically be displayed as single color superimposed over the image.

2.6. Tone-to-Hue Converters

Level selectors, while solving the desired task of delineating areas within a specified density range, often create a new problem for the image interpreter. The unexpected problem comes from the binary nature of level selector output; i.e., the entire range between two density values is displayed in a fixed intensity of some arbitrary color. Subtle changes and detail within the selected range, the stuff of which many decisions are made, is lost to the interpreter. The example of Fig. 3 illustrates the nature of the problem. A density cross section is shown for one line of two different images. The abscissa is the line and the ordinate is the image grey tone. An upper and a lower threshold level for the level selector are indicated as dotted lines.

The outputs of (a) and (b) are identical, and they would appear the same to the interpreter, despite the fact that in (a) the densities between 1 and 2, and between 3 and 4, are decreasing and increasing, respectively, and the density from 2 to 3 has almost the same value as the upper threshold value. In (b) from 1 to 2 the density was barely selected, while from 3 to 4 the selected portion is part of a greater gradient.

The (advantage of and) problem with level slicing is that it hides context and makes a discrete quantification. Two techniques have been tried with the IDECS to circumvent this problem. One was to use the output of the level selector to superimpose a light different color on the original image. In this way, the original image is highlighted by the level selector output and the changes within the level are not entirely lost. Similarly, the output of the level selector could be used as a gating signal for the original image, so only the selected portion would be displayed. Neither of these techniques has proved satisfactory for all cases.

An entirely different approach to the problem, suggested by E. Sarazan, yields a more effective technique. To simplify density identifications, shades of grey

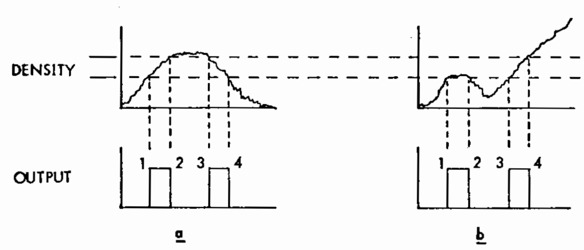

FIG. 3. Illustrates two radically different situations where the level slicers would provide identical outputs.

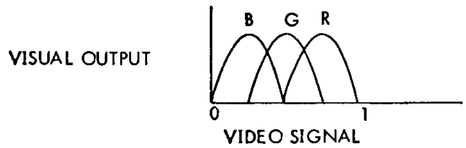

Fig. 4. The output characteristics of a simple tone–hue conversion process.

which are hard for humans to discriminate are converted to different colors which are easy to identify. Sarazan designed an electronic circuit to continuously map grey tones into color. The function is called a tone-to-hue converter.

Let us consider a simple way of performing this mapping. Let the input to the tone–hue converter be the video signal of the image to be converted. Let the output of the converter be three video signals, for the blue, green, and red guns, respectively, of a color CRT. In Fig. 4, the three output responses of the simple mapping are shown. As the input signal increases from 0 V, the blue color gun is increasingly driven until full intensity is reached at about $\frac{1}{3}$ V. Then as the blue signal is decreased the green is increased, and so on with the red. The intensity values are adjusted so the peak outputs appear visually equal and the placement of the breakpoints is controlled to allow the transition between primary colors to be viewed as a continuous change.

The IDECS tone–hue converter designed by E. Sarazan differs from the simple converter in two ways: (1) Instead of the restriction of using red, blue and green, any three colors may be used; (2) instead of the colors cycling once over the range of the input video signal, the colors cycle twice. The additional cycling is achieved by appropriately cascading two simple tone–hue converter circuits together. The additional cycling gives an even better presentation of most continuous tone images. The repetition of the colors is not a problem since identification is apparent from context. The input/output characteristics of the IDECS tone–hue converter are shown in Fig. 5.

2.7. Linear Combiner

Optical or electronic linear combination is probably the most frequently used method of enhancing multiimages. A combiner can take multiple images for its input and produce a false color image for its output. The IDECS electronic linear combiner accepts up to three video signals for its input and produces three video

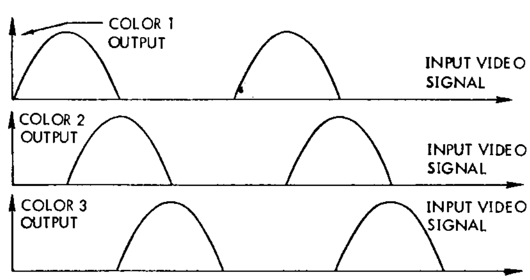

Fig. 5. The input/output characteristics of the IDECS tone–hue converter.

signals for its output. Each video signal output is a manually- or computer-controlled linear combination of the three input video signals. The output of the linear combiner can drive the three color guns of the TV monitor directly, or the circuit can be used as a preprocessing technique on the video data by performing a linear transformation on the space defined by the three input signals.

2.8. Quantizer

The quantizer subsystem allows a 4-bit analog-to-digital conversion of any image in the 1/30-sec frame rates of IDECS. The A/D conversion can be linear or nonlinear, the kind of conversion being controlled by the IDECS CPU. Each of the 16 8-bit general registers in the IDECS CPU drives a digital-to-analog converter and the output of each digital-to-analog converter derives a comparator in the quantizer. Each quantizer comparator produces an output when the video signal is less than the voltage of its corresponding D/A converter. The comparator outputs are coded to binary numbers to effect the conversion.

When the IDECS 8-bit general registers are set so that the D/A converter outputs linearly increase for successive D/A's, the quantization is linear or equal interval quantization. The quantization can, however, just as easily be an equal-probability or a general-probability quantization. The PDP-15 obtains from the IDECS counter the area of the image being worked with. The PDP-15 then sends to the IDECS CPU an 8-bit binary number and tells the IDECS CPU to load its first index register with it. The computer requests an area count for output of the first comparator. If the area is greater than what the computer wants, it will send to the IDECS CPU a smaller binary number. If the area is less than what the computer wants it will send to the IDECS CPU a greater binary number. In this iterative manner the computer sets each successive IDECS index register. Since the index registers have 8 bits, the resulting probability quantization is equivalent to doing an 8-bit A/D conversion and then a 4-bit quantizing. The advantage of doing the simple A/D and of never transmitting unnecessary data to the computer should be obvious.

2.9. Data Disk, D/A, Color Selector

IDECS has a 24-channel 2.4-million-bit data disk capable of dumping its entire contents of the 1/30-sec frame rate of IDECS. Outputs from the computer, light pen, level slicers, automatic discriminator, and quantizer can be stored on the data disk. Each channel can store one binary image. Thus 24 binary images, 6 4-bit images, or 3 8-bit images can be stored on the disk.

The output of each disk channel is connected to a color/texture panel where the operator can choose to display the binary image in any one of 10 colors and any one of 10 texture patterns. The channels are also grouped into three groups of eight channels each. Each group of eight channels can drive a D/A converter enabling the black and white display of any digital image on the disk.

The data disk has its own operation panel which allows manual control of Boolean operations between disk channels. AND, OR, NOT, and EXCLUSIVE OR are some of the implemented Boolean operations. Each Boolean operation takes 1/30 sec, the frame rate of IDECS. Any Boolean operation capable of being done manually is also capable of being done under computer through the IDECS CPU.

The disk also provides a separate function for the system, namely, synchronization. In order to avoid the problem of the IDECS frame rate drifting out of phase with the disk rotation speed, the entire system needs to be synchronized. The easiest way to achieve this is by slaving the system to the disk timing track. Separately available from the disk are clock pulses coincident with bit positions on the disk, and an end of revolution pulse (EOR). The EOR pulse is used to generate vertical synch pulses, and a MODULO 192 counter driven by the clock pulses generates the horizontal synch pulses. The number 192 comes from the fact that the disk has a maximum capacity per track of 525 lines of 192 bits. By choosing a 525-line system, conventional television sets are easily adapted to the IDECS.

3. COMMERCIALLY AVAILABLE PROCESSING SYSTEMS[3]

In order to place the University of Kansas Image Processing equipment into proper perspective, it would be desirable to compare it to existing equipment at other facilities. Unfortunately, most research groups who have developed their own in-house hardware have not published descriptions per se, but rather refer to the context of specific processing tasks. Quite naturally, most groups with whom we are familiar have expressed a common sentiment that they do not consider their hardware complete; that there are still several items to be refined or developed before they would want to describe it as a finished system. Commercially available equipment, on the other hand, is well described, along with open invitations to let the manufacturer design special packages to fit the user's needs.

By examining the available block diagrams of private equipment and looking at the commercial market it is possible, however, to discern the underlying philosophy which has guided the hardware development.

Four types of equipment are apparent. By far the most dominant are the strictly digital systems. In these systems imagery is first digitized and then all processing is performed in the computer and the end product is redisplayed. Within the range of these systems various specializations occur. For example, some are designed for ERTS imagery; some emphasize the flexibility of their digitizer; others have concentrated on an interactive output; still others have specialized in extracting or replacing specific parts of an image. The list is about as long as the number of hardware installations.

A second group of image processors is the group that has concentrated on optical operations. The simplest are multiple-image projection systems where various color filters are inserted to create false color or pseudocolor scenes on a viewing screen. These systems are generally limited to a small set of operations but present to the viewer a high resolution large scale display. A more sophisticated group of optical processors utilizes the Fourier properties of lenses. Both projection and reflection systems are used and both generally work with a single image at a time. Again, a very high resolution output is possible and virtually any operation requiring Fourier filtering and image reconstruction is possible in real time.

A third group of purely analog processors tends to offer level selection, pseudo-three-dimensional display, and an electronic version of optical combination as the basic operations. These systems are very interactive processors with the operator viewing his results in near-real-time (video scan rates).

The fourth group is a small number of hybrid systems comprised of any of the above features. Most common is an interactive analog display capability where some analog features are possible either as preprocessing or in lieu of some digital operation. With few exceptions, however, equal emphasis has not been placed on both the digital and the analog portions. It is not uncommon, for example, to find a well-engineered commercial analog input part and display tied to a mini-computer or a general interface, with no processing software support provided.

Very few private or commercial equipments are designed to be fully hybrid, with analog, digital, and optical activities simultaneously existing to optimize current technologies. Certainly the trend of more digital hardware for less money coupled with the flexibility, repeatability, and accuracy of digital systems will be influential factors in future hardware development. However, the more recent generation of analog processing modules with greater bandwidth and stability than their earlier counterparts makes an image-dedicated analog computer a feasible product. Analog image processing has suffered from a lack of primary building blocks with which useful, complex operations can be synthesized. It is quite possible that some future image processing systems may very well have a cost effective, digitally controlled, video analog computer as a pre- or post-processing element. Such a hybrid system would certainly warrant serious consideration.

4. CONCLUSION

We have described the IDECS in terms of what the subsystems are and what they do, rather than in terms of how specific image processing tasks may be performed with them. Our purpose has been to outline the IDECS as a working example for those who are considering building a similar system. The virtually unlimited options for electronic image processing prevent the development of anything like a "complete" package; and in the history of IDECS, new processing ideas have appeared at a rate of three or four per year.

One should therefore try to anticipate system expansion and design the basic architecture to be as flexible as possible. Three techniques have been used which simplify system modification. Industry standards for line terminations, video voltage levels, and synchronization pulses should be followed. Each separate subsystem should be selfcontained with all input–output connections standized. And in the case of the IDECS, all subsystem inputs and outputs are routed through a switching matrix for configuration flexibility.

The IDECS has also proved to be a clustering point for relating other ideas and studies within the context of a very flexible image format data processing scheme.