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An Educational Digital Image Processing Facility

A central processing facility based on highly interactive time sharing, large core, and fast disk storage with direct hardwired access to programming CRT terminals in user offices, and hardwired access to remote digital refresh display devices for viewing of intermediate results prior to requests for hardcopy photographic prints, is described.

Abstract: *The design philosophy of a digital image processing facility should be predicated upon the role such equipment ultimately is to perform. A large percentage of such facilities are dedicated toward production image processing in which parameters and variables are seldom changed. However, this paper is devoted to describing an image processing facility whose main objective is the eduction and research development of graduate students in Electrical Engineering and Computer Science. Toward these goals, systems software, hardware architecture, and structural design philosophies tend to be radically different from production systems. One such digital image processing facility is described in which little, if any, production is experienced, but in which undergraduates, graduates, faculty, and staff users all have "hands on" access to rapidly processed digital imagery results.*

Introduction

The subject of digital image processing has grown over the past ten years from a few scattered research facilities to large-scale computational, display, and interactive exploitation facilities scattered throughout the world. However, underlying many such facilities lies the need for the education of competent individuals to utilize effectively the extremely sophisticated equipment and software that goes into the configuration of these facilities. Educational systems for digital image processing equipment are no less sophisticated but often require different design philosophies and hardware architecture for effective utilization of preciously few available resources. This paper, then, is directed toward the genesis and continued development of one such facility, the Image Processing Institute at the University of Southern California, dedicated solely to the educational and research goals of students pursuing graduate degrees.

The general design philosophy behind this digital image processing facility has been predicated upon the need to service many users simultaneously, to provide rapid visual access to processed pictorial results, and to handle large data arrays while simultaneously providing mass storage for easily accessible intermediate processed images. In addition, due to the hectic pace of faculty, staff, and student life, maximum efficiency of the user's personal time has been attempted while still providing timely, responsive, high-quality hardcopy picture input and output results.

These design constraints have led to a

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central processing facility based on highly interactive time sharing, large core, and fast disk storage with direct hardwired access to programming CRT terminals in user offices, and hardwired access to remote digital refresh display devices for viewing of intermediate results prior to requests for hardcopy photographic prints. The software system that makes the facility useful is designed around a TENEX operating system with a few optimized routines directly related to image processing tasks. A parallel design philosophy has been utilized to allow minor image processing tasks to be implemented in an off-line mode for highly interactive fast turnaround exploitation using local processing capabilities in order to offload the central facility from mundane but large bandwidth I/O tasks.

Hardware

Figure 1 presents the block diagram of the computing facility. The central processing unit centers around a PDP KI-10 with 512K words of core memory and fast disk storage of up to 128 million 36-bit words, or the equivalent of approximately 2000 images each with 512 by 512 pixels of 8 bits of brightness per pixel. The computing facility is switched through a network of PDP 11 series mini-computers for communication to other peripheral pieces of equipment as well as to the office terminals and real time digital display devices. The office terminals provide a unique convenience which, coupled with the interactive text editors, make keypunching and IBM cards obsolete. The real time digital display devices, two low resolution monochrome monitors (256 by 256 by 6) and two high resolution color monitors (512 by 512 by 8 by 3), provide viewable results of processing algorithms within seconds and, at most, minutes of program completion and output onto the large disk files. Consequently, job turnaround from image in to image out can be experienced in half-hour time frames rather than in the hours or even days experienced in earlier systems.

For off-line processing, the equipment connected to the 100K bps line can be switched to a "local exploitation facility" mode in which highly interactive but computationally simple processing algorithms can be exercised. In addition, the off-line processing mode provides for hardcopy output on the densitometer and flying spot display and hardcopy input on the densitometer and color facsimile scanner.

Software

The software system's design is based upon a TENEX time-sharing operation in which users are serviced simultaneously. Because of the experimental nature of research software, very few programs are run consecutively without modification. Consequently an efficient text editor and interactive CRT terminals allow for easy program modifcation with a minimum of effort. However, what one gives up in this software mode is the large batch number-crunching capability of sequential batch machines. Such jobs on this system are usually queued for third-shift runs when the user load is down, larger time slices are available in the CPU, and the dollar accounting is more favorable.

Very little special purpose software has been developed on the system other than image file transfers to the display device. However, one assembly language set of subroutines implemented on the PDP KI-10 has resulted in considerable improvement both in case of user programming and in efficiency of mass storage. A typical use of this set of software might be:

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CALL IPRESS (A, LENGTH, BITS)
CALL DSKIO (A, LENGTH, LINE, 0, FILE, BITS)
CALL DSKIO (A, LENGTH, LINE, 1, FILE, BITS)
CALL IXPAND (A, LENGTH, BITS)
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This sequence packs a line of imagery in the array A of length equal to LENGTH into contigous blocks of bits-per-pixel equal to BITS with subroutine IPRESS. DSKIO then writes out the packed array A into the line numbered LINE and onto an image file named FILE. The second DSKIO reads into the array A from image row named LINE. Finally, IXPAND expands the packed array into 36-bit PDP KI-10 computer words for conventional integer or floating point processing. This sequence of four subroutine instructions makes image processing software virtually available to even the most novice of users.

One additional aspect of the system's software that makes the configuration particularly useful for image processing is the user's ability to view his image files stored on the high-speed disks with real time digital TV technology with simple "file-to-monitor" transfer routines. For display on the monochrome 256 by 256 monitors the real time television (RTTV) is called, resulting in the transfer of the selected user images to the requested monitor in a matter of seconds. Similar instructions exist for transfer of 512 by 512 color digital images to either of the high-resolution COMTAL systems depicted in Figure 1. Once such a transfer is accomplished, users usually like to go into the local mode for off-line additional processing of their results in the exploitation facility scenarios.

Exploitation Facility

The items in the lower portion of Figure 1 (connected to the 100K bps line) can be operated independently of the large computers and as such provide the possibility for highly interactive scenarios to be developed for local processing results. Such processes as histogram gathering, grey scale and color remapping, small convolutions, pseudo-coloring, operator-defined object outlining, etc., are all easily implemented on the PDP 11/40 display stations. One particular sequence that allows for operator/user closed loop processing with the large computing facility is interactive file generation in the exploitation facility for retransmission back to the PDP KI-10 for incorporation in more powerful processing algorithms. One such application where this is particularly useful is in the situation where a user interactively segments an image (via manual trackball operations) for retransmission as "segmentation ground truth" for comparison with completely automatic algorithms being developed on the larger computing facili-

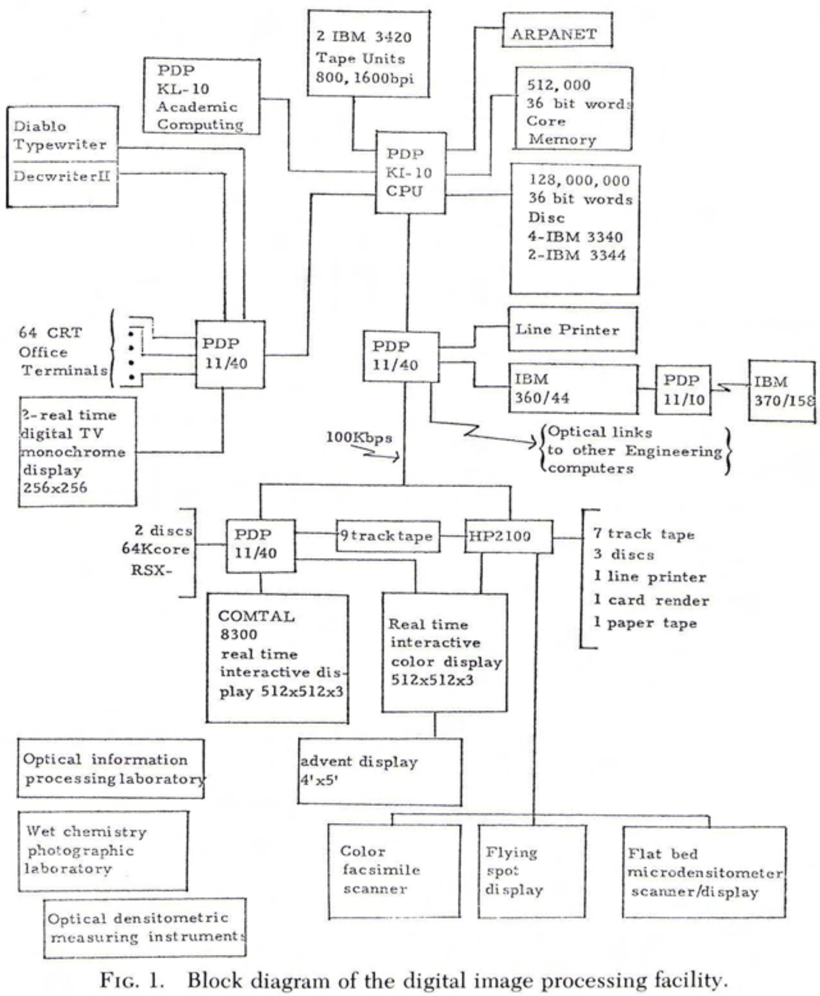

Fig. 1. Block diagram of the digital image processing facility.

ty. As mentioned previously, one of the major goals of the current systems configuration is the need for minimal training on the user's part ot make early effective use of the facility. With this goal in mind, a picture analysis (PICAN) operating system has been developed for one of the exploitation scenarios on the interactive display system, an example of which appears starting with Figure 2. This "menu" operating system has options which are presented on the monitor in a graphics overlay channel in a column on the right hand side of the screen. The user simply places the trackball in the appropriate box beside each option, and the computer implements the request. If quantitative data is desired as input, the computer makes the appropriate request on the terminal. For some variable inputs the grid at the bottom of the screen also can be used in a semi-quantitative fashion.

In Figure 2a an original image (an aerial reconnaissance scene of Los Angeles International Airport) is displayed with the trackball opposite the box selecting "Image #2." As this is the original image, its reference coordinate system is row = 1, column = 1, and magnification = 1. This reference coordinate system is maintained throughout the following interactive session at the console. Figure 2b has implemented the Roberts' edge operator on the original (last option in the menu) and has placed the results on "Image #1." In addition, because the edge energy is fairly dark, a pseudocolor chart has been selected (Chart #11) to emphasize the dark regions by coloring them yellowish brown. Proceeding to Figure 3a, we see a magnification of a factor of 2 implemented on "Image #3" and referenced to row 60, column 27 of the original image. Actually, Figure 3a is presented in the "storage mode—level slice" option (see the third and fourth options in the menu) and the number of grey levels colored red is determined by the trackball position in the grid at the bottom of the screen ($2^4/_5$ notches from the left). In Figure 3b the standard pseudocolor chart (option #7) is used to illuminate the fine detail of the magnified scene.

Figure 4 represents a magnification larger by a factor of four referenced to row and column 50 in the original. In Figure 4a the trackball is within the image display area, and as such, the system operates as a real time densitometer with the computer outputing the row, column, and brightness values of the trackball position. Again "Image #3" is used as a work plane area. Figures 4b,c,d, and e all represent different charts for pseudocoloring Figure 4a with chart selection depending upon trackball position in the grid at the bottom of the screen. Notice that Charts #4 and #16 color the brightness level "0", thereby changing the entire screen background.

Figures 5 and 6 serve to illustrate the difference between replication magnification and bilinear interpolation magnification. A factor of 8× has been implemented on the original at row 62 and column 110 by selecting the second option for Figure 5a and the next-to-last option for Figure 6a (see trackball positions in each of these scenes). The rest of Figures 5 and 6 indicate various pseudocolor charts on these two different magnification procedures. Replication is often useful for exact pixel brightness measurements (i.e., the operator has no problem placing the trackball in an 8 by 8 square) while interpolation is probably more useful for human interpretation.

In concluding this discussion on some of the interactive options discussed thus far, it should be emphasized that all options illustrated in Figures 2 through 6 take less wall clock time for implementation than it has taken the reader to scan these descriptive paragraphs. In addition, it is clear that many options still remain to be illustrated but in the interest of brevity and the lack of a real time effect of the written word, these other options will not be discussed. Clearly, however, additional options could be added depending on the development of localized software routines found useful for particular user needs.

The interactive exploitation scenario developed under PICAN has evolved over the years to become a very effective picture analysis tool for relatively inexperienced users. However, another aspect of digital image processing has similarly evolved during this time frame which capitalizes on such scenarios. Specifically, when mankind's mathematical and analytic tools reach a useful limit, but technological problems still remain to be solved, most often further breakthroughs are accomplished by placing a human as intimately in the signal processing loop as is possible and allowing his intuitive capabilities to take over. Such situations were extremely prevalent in one-dimensional signal processing applications in the past (e.g., sonar, radar, waveform analysis, and nonstationary signal detection in general). By analogy, some of the truly complex "image understanding" tasks of today will require similar "human-in-the-loop" procedures to learn effectively how

FIG. 2a. Original image to be interactively exploited.

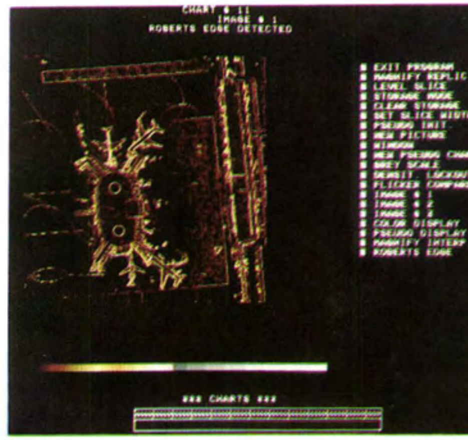

FIG. 2b. Roberts' edge of original.

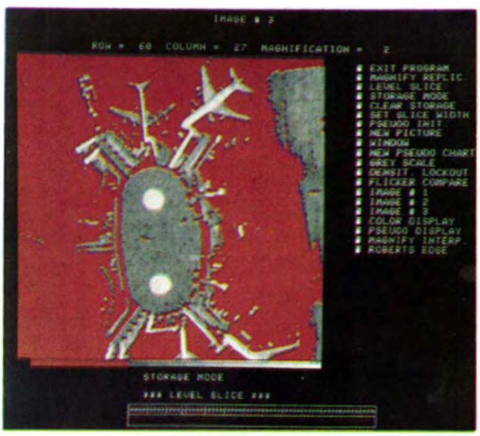

FIG. 3a. Factor of 2 magnification, storage mode.

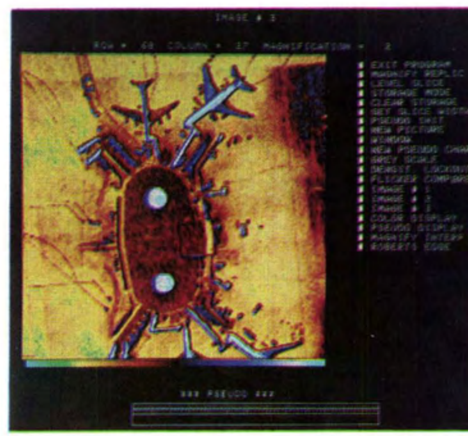

FIG. 3b. Factor of 2 magnification, pseudocolor mode.

and why a human is so expert at understanding images. However, until quite recently digital devices did not have the bandwidth and speed to keep up with human visual processes, and as such effective uses of his intuitive processes have not been made. However, with responsive highly interactive exploitation scenarios, and with proper computer monitoring, it is now becoming possible to configure such systems for this next stage of image understanding.

CONCLUSIONS

The design philosophy behind the system and software configuration of a digital image processing facility devoted to educational and research objectives has been presented. Time-sharing operating systems appear to present the most efficient and economical software solution while large disk storage and direct image I/O become useful hardware devices. An off-line exploitation station for interactive image processing also was described for non-number-crunching objectives. The configuration has been in existence for three years with the result of minor modifcations in evolving hardware and software improvements and currently represents an efficient economical facility for image processing, teaching, and research.

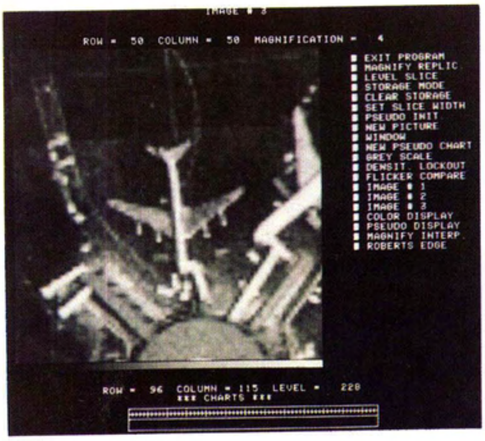

FIG. 4a. Factor of 4 magnification, densitometer mode.

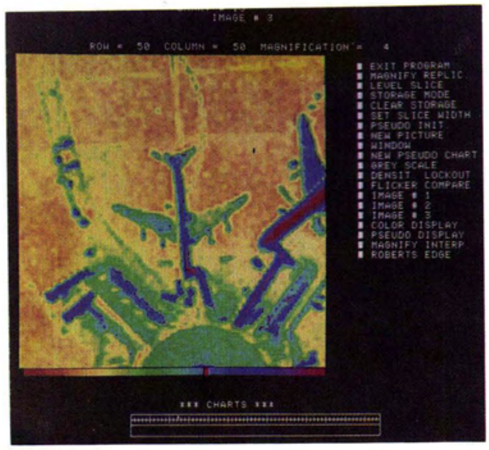

FIG. 4b. Factor of 4 magnification, pseudocolor Chart #15.

FIG. 4c. Factor of 4 magnification, pseudocolor Chart #4.

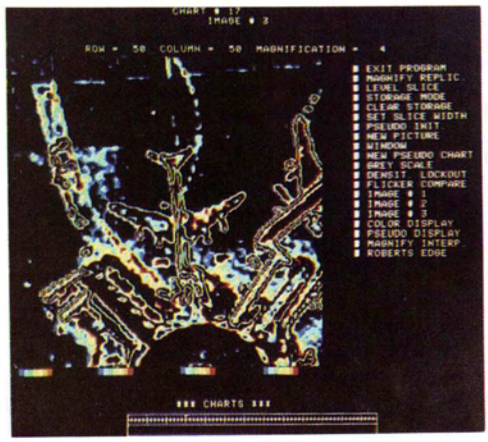

FIG. 4d. Factor of 4 magnification, pseudocolor Chart #17.

FIG. 4e. Factor of 4 magnification, pseudocolor Chart #16.

FIG. 5a. Factor of 8 replication, monochrome.

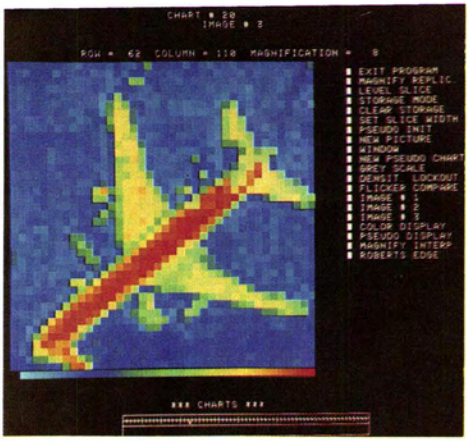

FIG. 5b. Factor of 8 replication, pseudocolor Chart #20.

FIG. 5c. Factor of 8 replication, pseudocolor Chart #3.

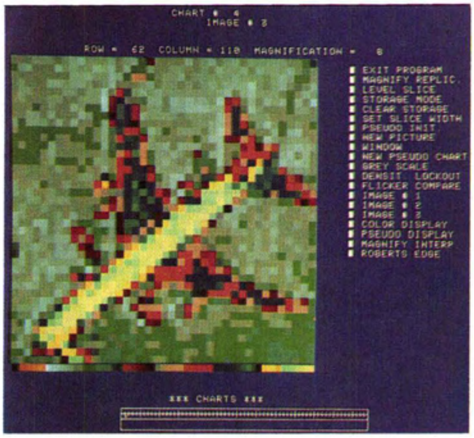

FIG. 5d. Factor of 8 replication, pseudocolor Chart #4.

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FIG. 6a. Factor of 8 interpolation, monochrome.

FIG. 6b. Factor of 8 interpolation, pseudocolor Chart #4.

FIG. 6c. Factor of 8 interpolation, pseudocolor Chart #33.

FIG. 6d. Factor of 8 interpolation, pseudocolor Chart #6.