A RADIOLOGICAL IMAGE PROCESSING FACILITY
AND SOME OF ITS THREE-DIMENSIONAL DATA MANIPULATION CAPABILITIES

H.K. Huang, Nicholas J. Mankovich, K.S. Chuang, Patrick Papin, S.B. Lo
Department of Radiological Sciences, University of California at Los Angeles,
Los Angeles, CA 90024
and
C.K. Wong, Department of Mathematics, University of Iowa, Iowa City
Jose Hernandez-Armas, University of La Laguna, Tenerife, Spain

ABSTRACT
In anticipation of the arrival of a digital radiology department, a dedicated image processing laboratory has been established within the Department of Radiological Sciences, UCLA. This laboratory consists of a multiple user computer, an image processor, a communication system, and an image mass storage device. Three major areas of activities in the laboratory are the development of a radiological image archiving and communication system, installation of a multiple digital viewing station, and research on picture processing techniques to enhance the image diagnostic value.

This paper describes the system configuration of the laboratory and some of its capabilities in manipulating three-dimensional medical images.

INTRODUCTION
The appearance of high speed digital electronics and communication technology in radiological sciences is gradually changing the method of acquiring, viewing, communicating, and storing diagnostic images (1,2,3). It is imperative for all diagnostic radiology departments to anticipate and prepare for this rapid technological change. A natural development in this direction is the emergence of the digital radiology department.

The UCLA Medical Center is a 685 licensed-bed hospital, and the Department of Radiological Sciences consists of ten diagnostic sections and performs an average of 110,000 procedures per year. At the present time our department is entirely film-based. The films from the past two months are stored within the departmental film library; films older than two months are stored at a remote library facility. Retrieval of these films is done through a shuttle service which requires one hour to deliver a requested film to the department. We use about 500,000 sheets of film per year and this film-based operation costs about 1.5 million dollars, about half of it for the actual film and the remainder for film-related costs. We have recently completed a feasibility study on converting our department from a film-based to a digital-based operation (4). This study indicates that the conversion should increase operational efficiency while reducing operating costs. This concurs with the results obtained by investigators at other major medical centers (5,6,7). In view of this positive result we are embarking on a five-year plan to move our department toward a digital-based operation. This plan involves: (1) establishing an Image Processing Laboratory (IPL), (2) increasing the proportion of digital-based diagnostic equipment within the department, (3) establishing interconnections between the Image Processing Laboratory and the diagnostic equipment, and (4) developing an environment which encourages research in diagnostic digital imaging.

This paper describes the present status of the IPL and, as an illustration, its capability in manipulating three-dimensional image data.

SYSTEM CONFIGURATION
The IPL is located in the vicinity of other diagnostic equipment and occupies about 1000 square feet. The laboratory is divided into two major areas, one for computer equipment and the other for image workstations. The computer equipment area has separate air conditioning and humidity control and is sound isolated from the image station area. The laboratory consists of a multiple user computer, an image processor, a digital image picture archiving and communication system, and image processing and communication software. The planning and construction of the laboratory took ten months and the dedication was in January 1983.

The following is a brief description of the system configuration shown in figure 1.

Current Hardware and Software

VAX-11/750 Computer: The Digital Equipment Corporation VAX-11/750 computer includes one megabyte memory and 16 terminal lines. The computer, which runs under the VMS operating system, is used exclusively for image processing and communication.

DeAnza IP8500 Image Processor: The DeAnza IP8500 has six 512x512x8 image memories, a real-time (1/30 second) image digitizer and a real-time digital video processor for image manipulation.
It has two 512 image stations and can simultaneously display six different 512x512x8 images on six video monitors. In addition, there is one high resolution station for displaying a true 1024 image on a 1024 monitor. The IPL has developed a very powerful image processing software package based on the original IP8500 Library of Image Processing Software (LIPS).

**Storage:** Data storage includes one 10 Mb removable and one 121 Mb fixed disk drive, and a high speed (125 ips) dual density (800/1600 bpi) tape drive.

**Video Scanner:** The Spatial Data Corporation EyeCom Scanner, together with the IP8500, can digitize an analog image into a 512x512x8 digital image in 1/30 second. Potential image sources include a microscopic slide, an x-ray film, or a photographic print.

**Communication Networks:** One of the most important functions of the IPL is the establishment of a communication system which allows the free movement of images from acquisition equipment to multimodality viewing stations (8). We have installed two sets of cables, one for a test broadband and the other for Ethernet. These connect the IPL to a digital fluorographic system with two cameras, an experimental projection digital radiographic unit, and a body CT scanner.

![Hardware system configuration of the image processing laboratory at UCLA](image)

**Figure 1.** Hardware system configuration of the image processing laboratory at UCLA. It consists of a VAX 11/750 computer and peripherals, a DeAnza IP8500 image processor and three image stations, a cable communication system, and a video scanner.

**Equipment Being Installed**

**A CT Independent processing and viewing research unit:** This Technicare HPS research unit under installation consists of a PDP 11/44 computer, two Analogic array processors, a hardwired back projector, a 160Mb disk drive, a 125 ips tape drive and a multiformat camera. It is connected to the VAX-11/750 through an Ethernet communication system.

**Multimodality Acquisition and Review System (MARS):** In order to manage and manipulate the many images required for diagnostic review we are experimenting with an image data base system and a dedicated digital image storage disk. The Multimodality Acquisition and Review System (MARS) from Gould/DeAnza allows us to easily access and display image data as well as maintain associated patient data. This system is designed around the high resolution image display and a touch sensitive screen. To implement this system two more high resolution monitors are being added. In order to store and quickly recall patient images the MARS system uses a real-time digital image disk which can store and retrieve a 512x512x10 image in 1/30 second. It has a capacity of 800 512x512x10 images or 200 1024x1024x10 images. This disk connects directly to the DeAnza IP8500 and the VAX-11/750. The MARS software runs on the VAX and manages the IP8500 and the disk. In addition to the disk and MARS we are adding six more image memories and some miscellaneous hardware which makes the high resolution MARS station fully operational.

**Manipulation of Three-Dimensional Image Data**

Most three-dimensional medical images appear in serial section form. Examples of these are CT and MRI scans, EM sections, gross anatomy segments and cell images taken from light microscope with different planes of focus. Sometimes it is desirable to manipulate these serial sections to extract additional information for various diagnostic purposes. We have developed some techniques at the IPL for manipulating this type of data. These techniques include digitization and alignment, contour extraction and smoothing, image warping, and three-dimensional (3-D) display.

**Input Data**

Two sets of serial sections, one from a cadaveric specimen and the other from CT scans, were used as input data.

1. **Cadaveric Specimen**

One cadaveric head specimen was sectioned at 20° from the orbital mental line at every one centimeter. Color slides were made from these sections (9) and the slides were then digitized to 512x512x8 with the Spatial Data vidicon camera and the IP8500. True color of the images was retained in the image processor with the use of red, green, and blue filters during digitizing. Alignment of the sequential sections during digitizing was done with the GRSUB program described below. Figure 2 shows ten digitized sections in black and white.

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Digitizing and Alignment

Relative alignment between two cadaveric slides during digitization is facilitated by the use of the GRSUB program. The first slide is placed on the light table, digitized, and stored in the image memory. This digital image now becomes the mask for alignment of the second slide. The second slide is placed on the light table and GRSUB digitizes and subtracts the image from the mask in 1/30 second. The resultant image is then displayed. GRSUB allows real-time digitizing and subtraction and will repeat itself until the user is satisfied with the result of the alignment based on the display. The new aligned image is then stored and can be used as the mask for aligning the next sequential slide.

Contour Extraction

Structures of interest within each sectional image can be extracted with the CONFIL program (10). This program outlines structures of interest either automatically or interactively with the operator choosing an edge threshold. For the purpose of this example, the external surface of the cerebrum and the cerebellum of the cadaveric specimen were extracted (see Figure 3). The acquisition of these data employed automatic contouring whenever the target structure was well enough defined to allow simple thresholding.

Contour Smoothing and Interpolation of Contours

Each extracted contour can be considered as a two-dimensional closed curve in the x-y plane. It should be smoothed further for 3-D display. To do this, the x and y coordinates of each point on the contour are expressed in their parametric representation. Then a cubic spline algorithm (11) is used to smooth this curve with two-pass one-dimensional curve fitting. Figure 3 shows the external surface of the cerebrum and the cerebellum after smoothing.

We can also interpolate contours in the z-direction between two adjacent contours sections in order to achieve better spatial resolution. This can be done by first determining the number of points on each of the two original contours. The number of interposed contours is specified and the new contours are then computed through a linear interpolation between the selected points in the original upper and lower contours.

Image Warping

Image warping is done with a procedure called AUTOWARP. This procedure reads a sectional image into the image display memory, it then uses a two-dimensional polynomial fitting to warp the image into its tilted, perspective representation. The sampling procedure accompanying this representation can optionally use the nearest neighbor technique or a bilinear interpolation when choosing the intensity of the warped pixel. Examples shown in this article use the nearest neighbor sampling since early experimentation showed no discernible difference between the two methods in this representation. In addition, the bilinear interpolation is more time consuming to perform. Once warped, the program uses the structure outlines to move only the image within the outline onto another display memory. This entire procedure is accomplished in a bottom-up fashion in order to display the planes as overlapping. The result of this procedure is a serial stacking of image planes in their original geometric configuration as shown in Figure 4. During this procedure the CT images were scaled in order to make them appear the same size as the cadaveric sections.

Three-Dimensional Display

Contours after smoothing and additional contours after interpolation can be stacked together for a 3-D display. To this end we have modified a graphics utility (ISOSRFHR) developed by the Scientific Computing Division (SCD), National Center for Atmospheric Research (NCAR) for this purpose (12). This package reads in serial contours, determines the relative position between the observer and the object, and display the serial contours with the hidden line removal. Figure 5 shows the results obtained from contours derived from ten cadaveric sections with a total of 50 interpolated contours.

The AUTOWARP image warping technique described earlier can also be used for a 3-D display. In this case the outline is drawn but no image data is moved. The result is a hidden line plot of the section stack. Figure 6 depicts results from the cerebral and cerebellar contours.

In addition we are in the process of implementing the MOVIE.BYU from Brigham Young University 3-D shaded surface package. This shaded surface representation presents another way of displaying 3-D image data.

CONCLUSION

Establishing an Image Processing Laboratory within the Department of Radiological Sciences allows us to prepare for the expected changes in the Department brought about by the arrival of high speed digital and communication technologies. The design of such a laboratory is based on the future requirements of the Department. The four basic ingredients in the laboratory include the computer, the image processor and display, the communication system, and the mass storage for images. The laboratory described in this paper consists of the most up-to-date technologies in these four areas. One future addition to the laboratory will be a mass storage device for images. This could be either a digital optical disk, a high density magnetic disk of up to 5 gigabyte (approximately 20,000 320x320 images).
Figure 2. Ten digitized cadaveric head specimens at 1 cm interval. This set of images is used as input data to illustrate some techniques of manipulating 3-D images.

Figure 3. Contours of the external surface of (a) the cerebrum, and (b) the cerebellum extracted from Fig. 2. Contours have been smoothed with a cubic spline algorithm.

Figure 4. Serial stacking of images after warping, left: digitized cadaveric images; right: CT scans.
storage capacity, a high speed, high density magnetic tape, or an analog storage device. All these new technologies are in development by industry and are almost ready for evaluation.

We have described one capacity of the laboratory, namely, the manipulation of three-dimensional image data. To this end, the techniques of digitizing and alignment, contour extraction, contour smoothing, interpolation of contours, image warped, and three-dimensional display are elaborated. Examples derived from each technique are also given.

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