Experience in the Use of an Image-Processing Workstation for a Photostimulable Phosphor Radiographic System

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Photostimulable phosphor radiographic (computed radiographic) systems are being installed and evaluated by radiology departments. The use of interactive image-processing workstations are a major advantage for any computed radiography system. An interactive image-processing workstation enables rapid image retrieval, reduces the examination repeat rate, provides for image enhancement, and rapidly sets the desired display parameters for laser-printed images. The authors have conducted over 2,500 radiographic examinations using a computed radiographic system equipped with an interactive image-processing workstation. Their experience supports the necessity of such a workstation.

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A DIGISCAN computed radiographic (CR) system (Siemens Medical Systems Inc, Iselin, NJ) installed at the University of Kansas Medical Center (Kansas City) is illustrated in Fig 1. The radiologic technologist performs the examination by exposing an imaging plate in a cassette.¹⁻⁴ Standard radiographic techniques are used. The reception terminal (Fig 1A) is used to enter the patient's identification data. These data are recorded onto a magnetic strip attached to a plastic card. The examination room terminal (Fig 1B) reads the patient data from the plastic card into the system. The technologist selects the type of examination (head, neck, chest, breast, abdomen, pelvis, or extremities) from a screen menu. The bar code on each imaging plate is read by the examination room terminal and included in the corresponding patient data file.

The cassette containing the exposed imaging plate is inserted into the laser reader (Fig 1C). The cassette is automatically opened on its hinges

by a mechanism in the laser reader. The exposed imaging plate is separated from the cassette and mechanically moved to one of the plate stackers in the laser reader. An erased imaging plate from the stacker is inserted into the cassette and returned to the technologist. This erased imaging plate may then be used for additional x-ray exposures. The laser beam scanner initially performs a low-laser-power, low-spatial-resolution scan of the exposed imaging plate. These low-level laser scan data are processed by the laser reader's microcomputer system to set the final full-power, high-resolution, laser-scanning parameters. A full power laser scan of the imaging plate is then accomplished in approximately 60 seconds. These acquired digital array data are then processed by preset algorithms for unsharp-masking enhancement and gray-scale mapping. The original digital data are transferred by a parallel interface to the optical-disk archiving system (Fig 1F). The processed image data are transferred to the laser printer and film processor unit (Fig 1D).

The laser printer exposes 362 × 257-mm laser-sensitive film at 10 pixels/mm using an 80-μm spot size. The infrared laser operates at a wavelength of 833 nm. Cycle time on the laser printer is 180 seconds. This laser printer generates hard-copy recordings from data generated by the laser reader (Fig 1C) or by the interactive image processing workstation (Fig 1F).

An interactive image-processing workstation (Fig 1E and F) processes the 2,000 × 2,000 × 10-bit digital image archived on the optical disk. The digital image data are archived on the optical disc using a compression algorithm. The data-compression algorithm used for archiving on the optical disk is the S transform, a hierarchical compression scheme.⁵ This linear transform decomposes the original 2,000 × 2,000 × 10-bit digital image data in a stepwise manner into a coarse matrix of sum coefficients and an ordered set of matrices. The sum coefficients matrix represents the image at half the original resolution. The ordered set of matrices are the vertical, horizontal, and diagonal difference coefficients of

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Fig 1. A Digiscan storage phosphor-screen digital radiography system illustrating (A) the reception terminal, (B) the examination room terminal, (C) the laser reader, (D) the laser printer and film processor, (E) the image processor, and (F) the interactive workstation (F).

every 2×2 -pixel ensemble in the image. The difference coefficients are quantized, coded, and stored. The interactive display station initially displays the coarse image and in subsequent inverse steps adds increasingly finer details until the original $2,000 \times 2,000 \times 10$ -bit image is fully restored but partially displayed on the $1,000 \times 1,000$ -pixel gray-scale monitors. Because of the speed of implementation, this method of displaying $2,000 \times 2,000 \times 10$ -bit images on a $1,000 \times 1,000$ -pixel display has proven very efficient. A Micro VAX-II (Digital Equipment Corporation, Boston, MA) computer provides a data base for managing the image data files.

Interactive image-processing workstation display monitors (Fig 1F) are $1,000 \times 1,000$ -pixel gray-scale monitors (1,023 lines, noninterlaced, 60-Hz refresh rate). The display data presented are 12 bits wide, with an additional 4 bits for overlay graphics. The $2,000 \times 2,000 \times 10$ -bit digital images to be displayed are transferred

from the 16-Mbyte random access memory in the interface and processing unit (IPC) into the 2-Mbyte memory in the display unit. Available menus are controlled by a mouse-interactive device. Image-processing algorithms are executed by a special-purpose microcomputer image processor (Fig 1E). Hard-copy recordings of the gray-scale images displayed on the workstation are produced by the laser printer and film processor (Fig 1D).

Transmission of the digital images is accomplished using interfaces available in the image processor (Fig 1E). A DECnet-Ethernet interface (Digital Equipment Corporation) is available for transferring digital images to a local area network. The data rates of the Q-bus of the MicroVAX-II limit the practicality of transferring data from the optical disc through the MicroVAX-II. All interfaces used in transferring image data are high-data-rate devices connected to the image processor (Fig 1E) and

produce a digitized matrix of $2,510 \times 2,000 \times 10$ bits with a nominal pixel size of $100 \times 100 \mu\text{m}$.

The laser film printer (Fig 1D) and film processor generate formats of one-on-one, two-on-one, and four-on-one. The laser film printer uses Fuji CR (Fuji, Tokyo) type 780 film ($362 \times 257 \text{ mm}$). For the two-on-one image format, the left image is similar to standard screen-film images. The right image is selectively spatially and contrast enhanced. The user menu will print a one-on-one format to ensure adequate detail and sharpness for the use of the HR-III (high-resolution) imaging plates. The laser-image printer records all of the imaging parameters for each printed image.

INTERACTIVE IMAGE-PROCESSING WORKSTATION

The architecture of the Digiscan interactive image processing workstation is illustrated in Fig 2. The interfacing and processing unit has two 16-Mbyte memories which are divided into a

displayed image and a background image (called "A" and "B"). Depending on the selected menu and chosen image-processing functions, different regions of the image memories are loaded into the monitor memories. All filter functions are accomplished using hardware filter boards. A host computer may be attached. A DECnet-Ethernet interface is available for local area network connection.

The user interface to the image processor is accomplished with available menus (Fig 3) selected with a mouse device. The MAIN menu is available on the monitor after the system starts. Individual menus are reached by shifting the mouse upward or downward. The ARCHIVE submenu searches for a patient's images on the optical disc or the data-base record on the MicroVAX-II. The search function will display on the monitor the patient data directory on the current side of the running optical disc. Once a patient is selected, a set of low-spatial-resolution images is displayed on the monitor. This provides

Fig 2. Interactive image-processing workstation.

Fig 3. Image-processing workstation menus.

the user with an opportunity to browse the complete image file. If an image is selected for display, the compressed image is displayed followed by the uncompressed image.

Activation of the CHANGE submenu moves the main menu to the second monitor. In the event that the user is interactively processing an image, the processed image will be erased if an image plate is digitized. However, the CHANGE submenu provides a means of saving the processed image.

The DISPLAY submenu provides the interactive functions needed for displaying digital images. The window-level settings are adjusted using MANUAL and the mouse. The SHUTTER function allows the user to mask certain portions of the displayed image. The INVERT function reverses the video, providing a "bones-black" gray-scale display. Viewing a $2,000 \times 2,000 \times 10$ -bit image on $1,000 \times 1,000$ -pixel

display monitors is provided by the OVERVIEW function. Two decompression stages are used. From the stored, compressed image, pixel values in the display are calculated by adding the average pixel value to the difference coefficients. One stage decompression generates a $1,000 \times 1,000 \times 10$ -bit image. The second stage of decompression produces a $2,000 \times 2,000 \times 10$ -bit image. For a compression ratio of 1:1, each pixel of the image background memory is displayed on the image monitor. In the DETAIL mode, a region of 880×880 pixels of an image can be displayed. The user is required to select the DETAIL region to be displayed.

The FILTER submenu provides the required interactive image enhancement functions. The image data in the background memory location are reconstructed by the selected filter consecutively in the horizontal and vertical direction to produce a two-dimensionally filtered image. EN-

HANCEMENT is produced by an unsharp-masking algorithm,⁶

Enhanced image = Original

$$+ K(\text{Original} - \text{Low pass}) \quad (\text{Equation 1})$$

where the low-pass filter is the unsharp mask. The K value is between -9.99 and $+9.99$. Three low-pass filters are provided. The first is a rectangular function (FiltR $<$ $>$) with a width of L ($-L/2$ to $+L/2$) and a height of $1/L$. A SIGMA value, which is a measure of the width of the blurring (standard deviation), is displayed on the screen. The SIGMA value is interactively adjusted with SIGMA equal to $L - \sqrt{1/3}$. A triangular function low-pass filter (FiltT $<$ $>$) is available with a width of L and a height of $2/L$. The SIGMA adjusted value is given by $\text{SIGMA} = L - \sqrt{1/6}$. A gaussian low-pass distribution (FiltG $<$ $>$) is available with height of $2/\sqrt{\pi L}$ and $\text{SIGMA} = L - \sqrt{1/12}$.

The PROCESS submenu provides for special image processing commonly used in Digital Subtraction Angiography. Using the LOG function the contents of the background memory are translated to logarithms. The ADD function is accomplished by the equation

$$\text{ADD Image} = A + BN + 2048$$

where N is selected from the range of -9.99 to $+9.99$. The use of negative values of N provides for image subtraction. Shift LR and Shift UD are pixel-shift operators. The IMAGE A and IMAGE B functions select and display one of the following image data sets: an image data set from the optical disk; an image data set from the laser reader; or an image data set copied from a background image memory. The GRAPHICS submenu provides the required interactive image functions for graphic operations.

A USERDEF submenu is provided for selecting combinations of image-processing algorithms. This enables the user to activate a set of previously chosen image-processing algorithms for sequential processing of an identified image. The IMA 1000 function provides for reading in images from the optical disk in the compressed form of $1,000 \times 1,000 \times 10$ bits. The IMA 2000 function provides for obtaining the original $2,000 \times 2,000 \times 10$ -bit images. The HARD-COPY submenu provides for the production of

hard-copy recorded images using the laser film printer (Fig 1D).

DISCUSSION

Over 2,500 CR examinations have been completed on the Digiscan system using the interactive image-processing workstation (Figs 1E and F). The phosphor-imaging plate is an x-ray detector with a wide latitude (10,000:1) unlike the relative narrow dynamic range available with a film-screen combination.⁷ This wide dynamic range ($5 \mu\text{R}$ to 50 mR) enables the automatic laser-scanning parameters of the laser reader (Fig 1C) to provide similar image quality with varying x-ray exposures. The image-processing algorithms used by the laser reader (Fig 1C) are spatial-frequency enhancement (edge processing), using unsharp masking,⁶ and contrast enhancement (tonal processing), using gray-scale mapping look-up tables. The particular image-processing algorithm to be used by the laser reader is preselected when the type of examination on the screen menu of the examination room terminal is identified (Fig 1B). The interactive image-processing workstation allows the user to recall the patient's digital image data (unprocessed) and interactively process the image as many times as desired. The authors have found the interactive image-processing workstation to be of importance in reducing repeat exposures. Images that were improperly positioned or exposed may be salvaged by using the image-processing workstation.

The $1,000 \times 1,000 \times 12$ -bit interactive, menu-driven displays provide excellent gray-scale range and screen brightness. The workstation supports two noninterlaced video displays. The authors are considering using a $2,000 \times 2,000 \times 12$ -bit display system (MegaScan, Boston, MA) or an interactive $1,000 \times 1,000 \times 12$ -bit display with a powerful magnification algorithm.

A significant advantage of the CR system using a photostimulable phosphor-imaging plate is its ability to provide diagnostic-quality images at a reduced exposure dose compared with screen-film examinations. The authors' experience and that of other investigators⁸ suggests that an exposure reduction of at least 30% to 50% is possible. Typical screen-film exposures for chest

examinations are 141 kV (peak) at 8 mAs. Similar chest-image quality is obtained with the Digiscan system at exposures of 141 kV(p) at 4 mAs, a reduction of one half. The authors have found that dose reduction for portable chest images are approximately 40%. A similar reduction has been obtained for mammographic examinations. However, musculoskeletal examinations limited by the marked variation in body thickness are exposed with techniques equivalent to conventional radiography. These include the portable lateral cervical spine, swimmer's view of the cervical spine, "shoot-through" lateral hip, and lateral thoracic spine. Dose reduction in these types of examinations is achieved by eliminating repeat exposures, which are often necessary with the screen-film technique. The authors have found that the image-processing workstation can improve display of anatomic features such as the cervicothoracic junction. In addition, magnification available by use of the DETAIL mode can improve evaluation. Graininess is increased and spatial resolution decreased in the image data as the exposure dose was decreased. The authors have used the image-processing workstation to decrease graininess in digital images acquired at reduced exposures.

Each side of the optical disk used to archive the compressed images can store 495 images. We have been surprised to learn that storage of our 2,500 examinations require both sides of three optical disks. Considerable time is spent in inserting and removing optical disks into and from the drive to review previously acquired cases. The MicroVAX database has proven essential in

locating a particular patient's images. In the event of an error writing image data to the optical disc, there is a recovery mechanism that consists of writing around the pointers to the image data. It would be beneficial if the Digiscan system offered a temporary magnetic disk buffer between the laser reader and the optical disk. The magnetic disk would speed the storage of images and provide temporary backup.

The laser printer and film processor (Fig 1D) has proven very valuable. The user of the interactive image-processing workstation can print any displayed processed image. The image-processing algorithms in the workstation are not the same as those used by the laser reader (Fig 1C) during the initial processing. The authors have prepared software emulating the original processing occurring in the laser reader for comparison with the workstation algorithms. This study is in progress.

CONCLUSION

The image-processing workstation allows interactive improvement in image quality, particularly through use of filtering and magnification functions. This allows salvaging of images improperly obtained from the original digital data. This reduces the repeat rate for CR studies and further increases the dose-reduction capability of these systems. The high-quality laser printer interfaced to the workstation generates hard-copy recording of the processed images. The authors believe that the interactive image-processing workstation is an essential component for the optimal use of a CR system.

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