A Digital Imaging and Communications in Medicine (DICOM) Print Service for Chest Imaging

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Large-scale picture archiving and communication systems (PACS) have not been widely implemented in this or other countries. In almost all radiology departments film remains the medium for diagnostic interpretation and image archive. Chest imaging is the dominant screening examination performed within most imaging departments and as such, is an extremely high-volume, low-margin examination. Digital technologies are being applied to chest imaging to overcome limitations of screen-film receptors (limited latitude) and current film management systems (single-image copy). Efficient management of images and information is essential to the success of a chest imaging program. In this article we report on a digital imaging and communications in medicine (DICOM)–based centralized printing network for chest imaging. The system components and their operational characteristics are described. Our experience integrating DICOM-compliant equipment supplied by several vendors is described. We conclude that the print model supported by DICOM is adequate for cross-sectional (eg, computed tomography and magnetic resonance) imaging but is too simplistic to be generally applied to projection radiography.

KEY WORDS: mini-PACS, digital imaging and communication (DICOM), laser cameras, print spooler.

PICTURE ARCHIVING and Communication Systems (PACS) were originally proposed as replacements for film in diagnostic imaging departments. A recent survey revealed that 23 imaging departments around the world have implemented "large" PACS, defined as systems that 1) are used routinely for a single modality, 2) have workstations both inside and outside of the radiology department, and 3) have storage capacity for >6 months of image storage on-line.[1] These systems rely on laser-printing solutions for situations that require film, ie, when a patient is moved to another facility that does not have a PACS or when an outside consultation is required. As the radiology community moves into the digital future it is expected that the volume of film produced will decrease and that efficient, centralized printing solutions will become practical. Clearly, it will be years before systems of this caliber become commonplace.

"Mini-PACS"[2] and teleradiology[3] applications are much more common than departmental PACS. Mini-PACS are characterized by the application of digital imaging technology to the resolution of a specific image management problem. For example, implementation of imaging systems that address needs of the intensive care unit (ICU)[4,5] and surgical suites[6] have appeared in the literature. Computed tomography (CT), magnetic resonance imaging (MRI), and nuclear medicine have also benefited from mini-PACS. Teleradiology systems enable users that are separated by time and geographic distance to share patient image and demographic information in a timely and efficient manner. Both mini-PACS and teleradiology systems frequently do not implement all components of a PACS. They may capture, transmit, and display images, but they often rely on film to provide a permanent archival record.

Digital technology has made significant inroads into chest roentgenology.[7] The radiographic examination of the chest is considered to be one of the most technically challenging examinations to perform, and several novel technologies have been developed to overcome the limitations of screen-film receptors. Systems have been developed to reduce the dynamic range of the patient-transmitted beam. Solutions range from simple beam-shaping filters to sophisticated beam modulating systems that employ real-time feedback control.[8] An alternative approach is to employ digital detector systems that have broad dynamic range. Research systems have been developed[9] with commercialization of at least two dedicated chest imaging systems that use digital receptors.[10,11] Although this line of work is dominated by direct digital capture devices, asymmetric screen-film combinations[12] represent an analogue solution to improving the latitude of the chest imaging system detector.

Despite the advances in digital imaging systems and ongoing development of "soft-copy" image interpretation,[13,14] film-based images remain the

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standard for diagnosis and archival storage in nearly all radiology departments. Laser cameras are currently the standard by which film-based images are produced from digital data. In early implementations, an individual laser camera was physically connected by one or more cables to a single image-producing device. Image data and control information were transferred using ad hoc, proprietary protocols agreed upon by the manufacturers of both the imaging device and laser camera.[15] More recently, data transfer protocols have become standardized, and device manufacturers have developed multi-input interfaces, allowing a single camera to service more than one input device. In this model, preferred by most data acquisition and laser printer device manufacturers, the imaging devices remain directly connected to the printer, and data are transported with a standardized proprietary communication protocol.[16]

The DICOM standard[17] proposes a printing model that does not rely on a physical connection between the image capture device and the laser camera. DICOM establishes a standard protocol for communicating control and image information over a generic communication network. In this article we investigate the feasibility of developing a centralized print service for digital chest images using DICOM printing services. In the following section we explain the DICOM model for print services and describe the equipment that we are using. The third section reviews the results of our efforts. We conclude this article with a discussion of the results and our thoughts on the feasibility of using DICOM print services for projection radiography.

MATERIALS AND METHODS

DICOM Print Model

DICOM defines standard protocols for computer systems to provide and use different types, or classes, of radiographic services over computer networks. Services defined by DICOM include study and report management, image storage, and image printing. Each service is defined in terms of an asymmetric relationship between the provider of the service, referred to as a *service class provider* (SCP), and the user of the service, referred to as a *service class user* (SCU). DICOM models the data that are passed between the SCU and the SCP by a computer formalism called *objects*. Taken together, the service and the data it operates on are referred to as a *service-object pair* (SOP).

Take the example of using DICOM to implement a system that prints images, produced by a digital image acquisition device, on a remotely located printing system. In this example the acquisition device must implement software compliant with DICOM print management SCU, and the remote printing system would implement DICOM print management SCP software. Here, it is easy to think of the print SCP as a single piece of hardware and software. There are, however, two logical tasks that are performed by the SCP; these tasks may be implemented on a single or multiple systems. The first of the two tasks is performed by the printer, hardware, and software that renders the digital image onto film. For simplicity, the DICOM model parallels that implemented by most laser printer manufacturers.

The second of the two tasks in the DICOM print model is responsible for providing communication services between the network and printing devices. We refer to this task as a *spooler.* The spooler is responsible for listening for incoming print jobs from SCUs, transferring data and control information, and terminating the connections when finished. Because this happens in a networked environment, multiple print SCUs may be using a single SCP simultaneously. The spooler is responsible for serializing the requested print jobs and forwarding them to the laser printer in an orderly fashion. This is the network equivalent of the multi-input interface and multiple physical cables used to connect several imaging devices to a single laser camera.

An important aspect of the DICOM print model is that the SCU does not directly communicate with the laser printer. The SCU cannot have detailed knowledge of the printing device's physical characteristics (output pixel size, digital value to optical density mapping, and so on). It is the responsibility of the spooler to assure that the images are rendered correctly by the printer. Therefore, the SCU must provide sufficient information to the spooler to accomplish this task, including the image data, overlays, layouts, and lookup tables. DICOM does this by creating the concept of an idealized printed image, which is modeled with object-oriented technology.[18] DICOM defines several objects that relate to entities in the real world; DICOM objects exist that correspond to a print job (Basic Film Session SOP), an individual sheet of film within the print job (Basic Film Box SOP), and individual images rendered on film (Image Box SOP). Other objects exist that allow the SCU to define lookup tables and graphic overlays.

Devices

At our institution we have installed a Fuji Imaging Systems, USA (Stamford, CT) Model 9501 (9501) for dedicated chest imaging. The 9501 is directly connected to a Fuji Medical Systems, USA (Stamford, CT) Model 2636 laser printer for producing hard-copy images. The 9501 uses photostimulable phosphor detector technology.[10] In addition to the 9501 we have purchased a dedicated image acquisition system, Model IM-2000, from DeJarnette Research, Inc (Towson, MD) to provide processed digital images to our PACS network. The IM-2000 is interfaced to the 9501 by a Digital Acquisition Systems Manager (DASM) device supplied by Analogics Corp (Peabody, MA).

For every patient exposure performed on the Fuji 9501 a hard-copy image is produced on the attached laser camera. Digital image data are simultaneously downloaded to the IM-2000 through the DASM. Data that are downloaded in this manner are unprocessed; no frequency or contrast enhancement has been applied to the data. The IM-2000 has software that performs contrast and frequency manipulation of the raw data similar to that performed by the 9501. In addition to the image processing services, the IM-2000 provides SCU support for two DICOM classes: CR storage and print management.

Two different DICOM print management SCP have been installed at our institution. One device is the MergeAPS (Merge Technologies Inc, Milwaukee, WI). This system communicates with commercially available laser cameras using either Kodak (Rochester, NY) printer control language (KCL) or Minnesota Mining and Manufacturing (3M, St. Paul, MN) 952 printer control language. In our configuration we have connected the MergeAPS to a Kodak Ectascan Laser Printer Model XLP-100. Data are transferred from the MergeAPS with both a proprietary digital interface for data and an RS-422 digital interface for control information. The KCL signaling protocol is used.

The second printing systems tested is an Imation (St. Paul, MN) Model 9400 Print Server for DICOM (PSD) connected to an Imation DryView 8700 Laser Imaging system. The Model 9400 PSD is a DICOM print management SCP. It uses a proprietary fiber-optic connection (FOSSIL) to transfer data to the Model 8700 DryView laser. The 3M 952 printer control language is used for signaling. The DryView 8700 Laser Imaging system is novel in that it does not use conventional chemical development of the exposed film.[19] Figure 1 is a schematic representation of our DICOM print network.

DICOM conformance statements for all devices involved in this evaluation were obtained from the device manufacturer before equipment selection. Statements were compared to assure that interoperability could be achieved.

A computer network is maintained by the department for the purpose of providing computer interconnectivity. Both desktop users (Macintosh and Intel-based personal computers) and imaging devices (CT, MR, computed radiography [CR]) are currently connected to the same logical network. The network is predominantly 10-Mbit/sec ethernet with twisted pair wiring. Multiple network protocols, including Transmission Control Protocol/Internet Protocol (TCP/IP), DECNet, and AppleTalk are in service. Direct connection to the Internet is also provided by this network. All of the network devices (SCU and SCPs) evaluated in this report are connected to the aforementioned network.

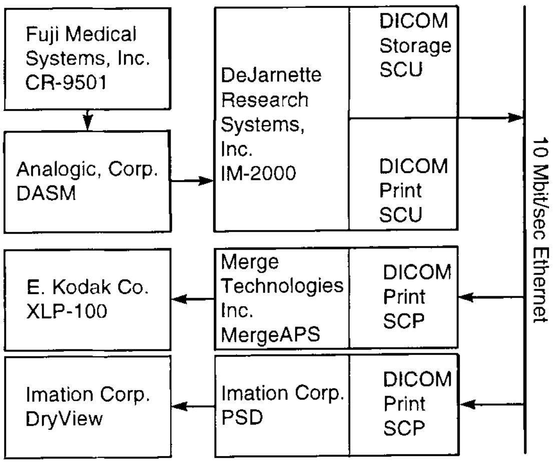

Fig 1. Schematic representation of DICOM print network implementation.

RESULTS

All devices evaluated in this report were configured and installed by representatives of their respective companies. Kodak service representatives were present to facilitate the connection of the MergeAPS to the laser camera. The installations of the three devices were not, however, accomplished at the same time. Before the installation of each print system, representatives from Merge Technologies Inc, Imation Corp, and DeJarnette Research Systems, Inc, tested the DICOM interoperability at their own manufacturing sites. This was done in order to ensure smooth installation and minimal on-site debugging of hardware and software. As a result, each installation was performed in a single day.

With the installed equipment, images produced by the Fuji 9501 are able to be printed on either of the two DICOM printing solutions. Multiple print formats, including one-on-one and two-on-one images, are supported (Fig 2). Configuration of the DICOM interface software to optimize the image print quality, including the configuration of printer look-up tables (LUTs), is a nontrivial exercise that is beyond the scope of this article.

Controlling the size of the image rendered to film has proven to be difficult with both output devices. This is the result of two factors. First, both laser printers force a border to be printed on each sheet of film. The Kodak prints a border that is 0.5-in (1.3-cm) wide, and the DryView prints a border that is 0.7 in (1.7 cm) wide. With either device, the border density can be set to either minimum (clear) or maximum (black) density. The second problem is that the DICOM attribute that controls the size of the rendered image ("requested image size," group 2020, element 0030) is considered an optional element by both the SCU and the SCP. Therefore, a printing solution can be considered DICOM compliant without providing the printing client control of the size of the rendered image.

In lieu of direct control over output size, the attribute "image magnification" (group 2010, element 0060) indirectly controls the rendered image size. The value of this attribute can be NONE, REPLICATE, BILIN, or CUBIC. When NONE is selected, the image is printed with 1 pixel on the output device corresponding to 1 pixel on the input

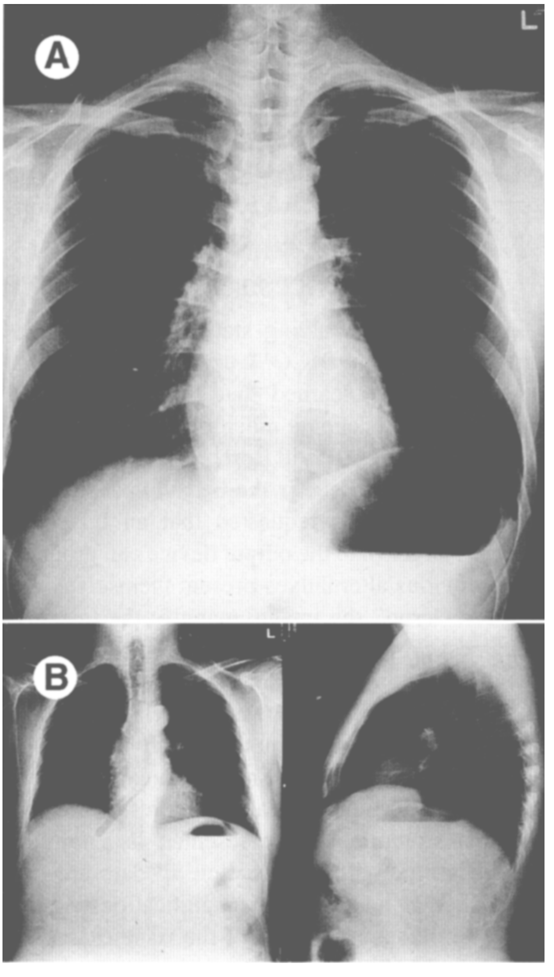

Fig 2. Posterior-anterior (PA) and lateral images from a routine chest examination printed with DICOM print network. (A) one-on-one presentation, PA view; (B) two-on-one presentation, PA and lateral views.

device. The size of the rendered image is controlled by the number of pixels per row and column and the size of the pixel on the output device. If REPLICATE, BILIN, or CUBIC are selected, the image data are magnified to fill the printable surface area of the output device, with each value specifing a different pixel interpolation algorithm. REPLICATE magnifies the image by setting new pixel values equal to the value of nearest adjacent pixel. The BILIN algorithm employs a bilinear interpolation of four adjacent pixels, and CUBIC uses a third-order spline interpolation algorithm. For the tested printers, the size of the resulting image is 14 × 17 in (35 × 43 cm) minus the corresponding image border. For the identical image printed on the Merge-Kodak and the Imation solution, different image magnifications result. Neither of the resulting images is equivalent to a chest radiograph obtained on a conventional chest imaging system.

DISCUSSION

With significant economic pressures faced by medical institutions and the slow development and acceptance of departmental PACS, we think that targeted mini-PACS will continue to be implemented. Our institution supports imaging devices that are distributed over a large physical plant. The amount of time and effort necessary to collect, organize, and collate films from all locations is significant. We think that centralized printing is a cost-effective alternative. Rather than send people after film, centralized printing will enable us to produce film where the film is needed. We expect improved departmental efficiency by reducing time and labor necessary to transport film images to their proper destination.

Although we were able to quickly and easily establish our centralized DICOM printing service for chest images, it has been much harder to get the resulting images to print in a manner that is considered adequate. As discussed, in the DICOM print model, the print user (SCU) does not talk directly to the printer but rather talks to the SCP, which mediates the conversation. The data that are transferred between the SCU and SCP are modeled with DICOM print management objects. These objects are derived from experience printing cross-sectional images (CT and MR images) by directly connected printer interfaces. It is our experience that these objects are simplistic and do not, in their current state of development, provide sufficient flexibility to adequately support printing of projection radiographs.

A glaring omission from the DICOM print model is the inability of the SCUs to adequately describe the output pixel size to the SCP. With DICOM print in the current form, the size of an image rendered on film is controlled by the laser camera, not the printing client. There exists only one required parameter that indirectly controls the rendered image's size. This parameter is the "magnification type," Group 2010, Element 0060. Values of the magnification parameter include NONE, BILIN, REPLICATE, or CUBIC. In all of the latter three cases, the image data are scaled to the maximum printable area of the selected media. In the case of chest imaging, using 14 × 17 film, this would be adequate if the entire surface area of the film is available for printing. Unfortunately, this is not the case. Both of the laser cameras we have installed force a border to be placed around the outside of the printed film, reducing the printable surface area by 8% to 10%. An informal survey of several other laser printer manufacturers indicates that most devices force the film to be produced with a border.

For the purposes of system integration, the print SCU cannot (and should not) know the detailed operational characteristics of the printer on which the image will be rendered. The printer cannot be expected to know how to correctly size every type of image that may be printed (CT, MR, angiography, a hand, a foot, a chest, and so on). The majority of imaging devices connected to laser cameras are CT and MR scanners. In neither of these devices is size correspondence between the captured data set and the image produced controlled. The printed image size is relative and dictated by the film size and the image presentation format (4 rows of 3 images, 5 rows of 4 images, and so on). In this scenario, it is important that a given image printed today and next year be rendered in the same manner.

In radiography, however, image size is closely controlled by the imaging geometry and receptor size. Radiologists are keenly aware of the normal size of structures within the body at standard magnifications. When image magnification changes, and hence the rendered image size changes, this baseline information must be relearned, and longitudinal image comparison is made more difficult. This fact was witnessed with the introduction of Fuji CR devices that rendered images on a single size film by varying image magnification. Although this altered size has been tested and shown to not significantly affect the diagnostic power of the imaging system,[20] the radiological community is not completely satisfied with these altered presentations. At our institution we use both conventional and digital chest imaging systems. The ability to control, and thus standardize, image presentations would represent a significant improvement.

CONCLUSION

DICOM is an evolving standard. In conversations with several DICOM committee members, the authors have learned that control of printed image size has occupied much of the conversation at recent meetings (David Best, personal communication, 1996). At issue is the behavior of the SCP when the SCU has requested that an image be rendered larger than the output device can produce. Three obvious alternatives present themselves: the SCP can "crop" the image, magnify the image to the largest printable size, or fail to print the image. It is our opinion that failure to print should not be an option. This will only result in delaying patient care. The remaining alternatives each have advantages and disadvantages. Cropping image data can result in the loss of clinically significant information, but structures are represented in a familiar magnification. With minification all data are presented but at an arbitrary magnification. At this time no obvious resolution of the issue exists and further study of the issue is needed.

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