

REQUIREMENTS FOR PACS WORKSTATIONS

Y. Kim, Ph.D., H.W. Park, Ph.D., and D.R. Haynor*, M.D., Ph.D.

Image Computing Systems Laboratory
Department of Electrical Engineering, FT-10

* Department of Radiology, SB-05
University of Washington
Seattle, WA 98195, U.S.A.

Abstract

An electronic system for image (and other multimedia data) distribution, archiving and transmission represents the future of radiology and modern hospitals. Among many components comprised in the PACS (Picture Archiving and Communications System), workstations are the point of contact to the radiologists and referring physicians. Therefore, the level of success of PACS is highly dependent on the successful implementation of the workstation. This paper describes the requirements for a future clinically acceptable PACS, in particular, PACS diagnostic workstations, which will efficiently handle the large volume of images that are generated, add new functionality to improve productivity of physicians, technologists, and other health care providers, and provide enough flexibility to allow the system to grow as medical image technology grows.

1 Introduction

As medical procedures become more complex, and financial pressures for shortened hospital stay and increased efficiency in patient care mount, several shortcomings of the present film-based systems for managing medical images have become apparent. Maintaining film libraries is labor intensive and consumes valuable space. Film is expensive (typical costs for a 350-bed hospital are on the order of \$700,000/year). Because only single copies of radiological examinations exist, they are prone to being lost or misplaced, and consuming additional valuable time and expense. It is difficult for radiologists to deliver diagnoses in a timely fashion.

An electronic system for image archiving and transmission offers a solution to these problems. Multiple copies of images can exist and can be viewed simultaneously without conflicts. Image loss can be eliminated, as can film cost. The space required for archiving can be significantly reduced. In addition, many enhancements become possible. Image processing or

artificial intelligence can be used to improve the conspicuity of lesions or to screen images for particular abnormalities. The task of comparing multiple radiologic studies can be made significantly easier. Interactive on-line references, containing both text and images, can be developed.

Those who are familiar with current picture archiving and communications system (PACS) implementations will recognize that the list of requirements presented below goes considerably beyond anything available today. In fact, no fully digital radiology departments exist, and only very limited digital subsystems are currently operating. This paper is directed towards the design of a system that might be available for clinical testing within five years, and that would come close in implementing a *filmless department*. Figure 1 conceptually describes a diagram of PACS [1].

2 Image Formats

The images obtained must be accurately linked to the patient and to the study request. In most hospitals today, some type of electronic RIS (radiology information system) exists. The patient information and information about the exam (for later transcription and billing purposes) is typically entered into the RIS at the time the study is performed.

A PACS must support computed radiography, nuclear medicine, digital fluoroscopy, CT, MRI, and digital ultrasound. Image input from laser digitizers would be important primarily as a way of importing non-digitally acquired images into the PACS.

The common image sizes for MRI, CT, and ultrasound are 256 x 256 and 512 x 512. Nuclear medicine images range from 64 x 64 to 256 x 256. MRI and CT images are 12 bits deep; ultrasound images and nuclear medicine images are typically 8 bits deep. Computed radiographs and laser-digitized radiographs are much larger, approximately 2k x 2k, and 10-12 bits deep. However, many CR and laser digitized images

are not square; aspect ratios may instead range approximately from 3:4 to 3:1 (vertical:horizontal).

A variety of alphanumeric information is associated with each image. This includes a number that identifies the examination, the number of the image, its location within the patient, and various parameters associated with image acquisition. Some images may have up to 100 numbers associated with them. Most of this information is series- or study-specific while a small part varies from image to image. All, or most, of this information should be available to the viewer on request; only a small proportion of it, however, need be displayed by default.

The format for the complete data set consisting of the demographic information, the modality information, and the images, is defined by the ACR/NEMA (American College of Radiology and the National Electrical Manufacturers Association) message or data set structure standard [2].

3 RIS/PACS Interface

The task of keeping track of patient information (demographic data, lab results, clinic appointments, billing information, etc.) is increasingly performed by computers in the United States and Europe through what are called hospital information systems (HIS). Typically these consist of a single central node with a large computer and extensive data storage capacity and a distributed network of terminals (these terminals may also be personal computers instead of dumb terminals, and then may also be used for other purposes). These systems are text-based and the user interface is of the familiar forms- and menu-oriented type. A radiology information system, or RIS, is typically included in most HIS's; however, a large number of standalone RIS's have also been developed. The RIS manages exam ordering and scheduling, reporting/transcription, and billing. Integration of these standalone systems with independently developed HIS's has often been difficult. In the future, however, smooth integration between the RIS and the HIS will be the rule.

A PACS differs fundamentally from a RIS/HIS in that, although a great deal of textual information is also stored in the PACS, the bulk of the information (as measured by number of bytes) is stored in images. This has different implications for workstation capacity, monitor quality, network bandwidth, etc., and consequently most current PACS development is being carried out with dedicated image-transmission and viewing systems.

Requirements for RIS/HIS/PACS communication are as follows:

- A PACS workstation should be capable of functioning as a RIS/HIS terminal. If a PACS workstation can function as an HIS terminal, any physician in the hospital has access to demographic information about the patient, clinic visits, laboratory and pathology results, and electronic mail.
- Certain information in the RIS and HIS is needed for PACS operation. The most important piece of information is the unique examination ID assigned at the time of exam scheduling by the RIS. This unique ID in turn provides access, via the RIS, to the patient name, date of birth, and sex (all essential for accurate radiologic interpretation), to the stated reason for obtaining the examination, and to the date and time of the examination (which may not necessarily be identical to the date and time at which the examination was acquired into the PACS).
- The interface must be robust, and methods must be provided for maintaining the compatibility of the RIS/HIS and PACS databases. If the PACS and RIS/HIS are not fully integrated, but communicate instead via a network interface, the potential arises for internal inconsistencies in the distributed database of patient and exam information.
- In addition to the HIS, it will be necessary for PACS in the future to communicate with other computer networks. An example is a PACS-PACS communication. If a patient customarily receiving care at one hospital is transferred to or seeks emergency care at a second hospital, or if remote consultation on patient care is sought, it is convenient to be able to electronically transfer selected images from the first hospital.

4 Image Archiving and Distribution

Insuring adequate network and archive performance and sufficient archive capacity at acceptable costs has been among the most difficult problems in PACS design today. It appears highly likely that the next generation of fiber-optic connections will have adequate bandwidth to meet PACS requirements, and so the goal of network design is primarily one of achieving adequate performance and reliability at reasonable cost [3]. In contrast, the issues underlying archive and database design are far less clearly formulated.

4.1 Archive capacity and requirements

The image database in a PACS actually contains many different types of items (records) and generally is stored on multiple devices. In most systems, at

least three levels of image storage are present. The first level consists of those images present on the mass storage device of the user's workstation, typically a Winchester disk. The second level consists of a central store of images on a large Winchester disk farm. These typically represent current studies and associated cases such as the prior studies are needed for comparison. The third level has the highest capacity and slowest access time and is typically a write-once optical device (usually an optical jukebox). Much of the success of PACS is related to the smoothness with which the system handles transfer of images and other information between these three levels.

The inflow of data in a prototypical 350-bed hospital amounts to 1.5-2 Tbytes/year; assuming that 2:1 recoverable compression is performed, about 1 Tbytes of new information must be stored each year. Typically, images are retained for seven years (although children's images must be retained at least until age 18), so a capacity of 7-10 Tbytes is desirable in the third level archive. Presumably, the optical media containing older images might be retained off-line indefinitely. An index of all studies and their locations must also be maintained, typically on the same devices used by the second level image store (since access to the index must be rapid).

The required capacity for the second level archive is about 15 days worth of images. This is based on the assumption that the active file should contain about 7 days worth of new studies and that, on the average, about one comparison study is needed for each new study (although less than 70% of studies will have comparison studies, some may have more than one).

4.2 Network design

Just as the archive function is implemented with several different types of hardware, the image transmission network will also consist of several different components. The highest performance is required within the radiology department, with the network possibly extending to key high-volume clinics (orthopedics, neurosurgery, etc.). A lower-capacity network might then link all zones within the hospital (operating room, emergency room, nursing stations, etc.). Access from outside the hospital will typically be over telephone lines. In view of the timetable of this project, it is reasonable to assume that this will be over either dialup T1 lines or over ISDN. Also, network design should be flexible and utilize a modular approach, in which changes in configuration can occur without disabling the entire system.

4.3 Image compression

Image compression is an area in which currently no

consensus exists within the user community. However, image compression has the potential for greatly reducing archival and communication/networking requirements. Approximately 10:1 compression for CR images, and 4-5:1 compression for MRI and CT images, may be obtained with essentially no visible change in image quality. If only recoverable compression is allowed, 2:1 or 2.5:1 compression rates are the maximum attainable.

5 Image Display - Radiology Department

This section discusses the diagnostic workstation requirements to be used in making primary diagnosis in the radiology department and ways in which the diagnostic process could be enhanced by a PACS, relative to a conventional film-based system.

5.1 PACS in the radiology department

The viewing of images which is provided in the conventional radiology department must be supported by any filmless viewing system. This produces a set of minimal requirements for a radiology workstation.

Hardware

Display characteristics: To compete with current alternators, a radiologist's workstation must have multiple monitors, each with a pixel matrix of size at least 1024 x 1280. "2k" monitors (approximately 2048 x 2560) are strongly preferred and recommended, particularly for the viewing of plain films. The screen size should be at least 19 inches and fully support 256 separate gray levels. The brightness should be no less than 50 foot-Lamberts. Current implementations include between 4 and 8 monitors. The exact number of required monitors depends on the number of images to be displayed, with CT and MRI studies generally containing larger numbers of images and, therefore needing more monitors. The faster the rate at which new images can be displayed, and the more natural the user interface, the smaller the number of monitors that can be tolerated. Displays should be a minimum of 60 Hz noninterlaced with minimal flicker (perceptible to 5% of the users or less).

Ergonomics: While many of the ergonomic issues associated with single-monitor workstations are well understood (from experience with personal computers and conventional workstations), the introduction of multiple monitors creates some new problems.

Local storage: Local (Winchester) storage should be sufficient to allow the storing of all images, including likely comparison studies, that would be required for a single diagnostic session. This typically requires 500-1000 Mbytes of local hard disk storage. In addition,

a higher-speed (RAM) cache must be provided that is adequate to contain a single study and associated comparison studies (a total of 40-60 Mbytes). Two seconds or less is an adequate time for each complete screen to fill when a study is first accessed.

User Interface - General

Raw hardware speed, while important, is insufficient. If selecting a function is awkward or time-consuming, the fact that it can be performed rapidly, once selected, is irrelevant. Overall speed of the entire diagnostic process is of particular importance in the design of the radiologist's workstation, and is the standard by which the user interface is ultimately judged.

Good help must be provided. An electronic manual, easily searchable, should be available online, as well as a tutorial (there is, in many large hospitals, a constant turnover of personnel). Because the radiologist must frequently interrupt his work, it should be possible to save the current working environment to allow access to a new patient's images.

Image Selection and Arrangement

Logon and logoff: The user should be required to log on to the workstation, using a password, at the start of a viewing session. This improves system security. Logoff after a prolonged period of inactivity should be automatic; however, the current working environment(s) should be saved for each user (for a limited period of time, say 24 hours).

Study selection: The user interface must support a clinically useful view of the image database. It must be possible to select studies by patient number or name or portion thereof. Once a patient has been selected, differing views of that patient's folder should be available, with studies sorted by modality, date and body part (at the user's option). Once a particular study has been identified, the possible comparison images should be automatically identified.

Study layout: Once a study is selected, a default study layout (the way in which the study images are arranged on the monitor) should be invoked. The goal should be to emulate the process performed by the file clerk who places films on the alternator.

Image rearrangement: It should be possible to move images about freely across multiple monitors, or change the way in which multiple studies are displayed on the workstation. Some kind of image "cut and paste" function is useful. A minified overview of the entire study, from which image selection and arrangement can be performed, is also useful (gallery or survey mode).

Cine viewing: The ability to arrange images in stacks and then view them as a movie loop (at se-

lectable speeds) is quite useful, particularly if the process of assembling the stack is easy.

Image marking: It is useful to be able to mark selected images for later viewing.

Image Processing

Window and level adjustment: The workstation needs to provide for dynamic window and level adjustment, either for a single image, a single monitor, or for an arbitrary selected or marked subset of the displayed images. Inverting the gray scale for a selected set of images is occasionally useful.

Magnification/minification: The workstation will be required to be able to enlarge the image two or four times and display it by simple replication of pixel values. It shall also enlarge the image two or four times and display it by interpolating intermediate pixel values in a smooth continuous manner. Similarly, it should be possible to reduce the size of the image by a factor of two or four. Providing intermediate levels of zoom, although useful, is not essential.

Image reorientation: Occasionally, particularly for conventional X-rays, it may be desirable to change image orientation. This usually is done because of some error made during image acquisition. Therefore, the ability should be provided to change image orientation (flip, mirror, rotate 90/180/-90 degrees).

Image roam: If the entire image is not viewable at the specified screen resolution, it must be possible to smoothly roam the entire image. The zoomed images then would be viewable by the image roam function.

Digital magnifying glass: It must be possible to roam a user-specified rectangle over the image and provide two- or four-fold magnification of the central portion of the image within the rectangle.

Image mensuration: The user must be able to compute point-to-point distance measurements with automatically calibrated, user selectable scales. He also must be able to perform angular measurement, area and perimeter measurement for elliptical and rectangular regions of interest. It should be possible to compute statistics (mean intensity, standard deviation, range, number of pixels) for any selected region of interest. It should be possible to designate irregular regions of interest with a cursor and perform similar measurements.

Advanced image processing: Some examples are adaptive histogram equalization, unsharp masking, texture measurements, filtering, mathematical morphology, and the use of snakes for contour tracing.

Image Annotation

The placing of marks on films is an important way in which physicians communicate with one another

about images. These marks may be used to identify significant images or to point to or encircle significant areas of pathology within an image. The workstation must offer the radiologist or other physician the capabilities to mark images, create pointers and notes, and store the annotations as an overlay.

Consultation

The radiologist spends a significant proportion of his working day consulting with referring physicians. The PACS workstation should provide tools to facilitate this task. This includes the ability to set the current working environment aside and examine a different study and/or patient.

Miscellaneous

Hard copy generation: The radiologist will occasionally want to print the contents of a selected monitor on a hard copy device. The ability to print textual information (worklist, old reports, etc.) is also useful. The ability to produce 35 mm slides for teaching or archival purposes is also desirable.

Use of color: Color displays are routinely used in nuclear medicine and color photographs are used for Doppler imaging of flow with ultrasound.

5.2 Enhancements

In this section, a few functionalities uniquely possible with electronic viewing systems are briefly sketched.

Three-dimensional viewing: Two-dimensional images taken as parallel slices through a three-dimensional object can be reformatted and viewed in a variety of ways to better display three-dimensional relationships. This capability is of undeniable utility for certain diagnostic problems and particularly for surgical planning.

Teaching files and reference cases: Efforts are already underway at multiple institutions to create a variety of CD- or videodisc-based teaching resources in radiology. These resources typically include a mixture of radiologic images, anatomic photographs, photomicrographs, text, line drawings, etc.

Voice recognition: It would have a large impact if the transcriptionists' function could be replaced, since the bulk of the delay associated with the reporting process would then be eliminated.

6 Data Display and Processing - Clinics and Hospital

The needs of the user (usually a referring physician) viewing images outside the radiology department are broadly similar to those of the radiologist reporting a study. Ideally, the referring physician would like to have access to the radiologist's report at the time he

views a study. He may wish to view primarily those images the radiologist has marked as containing interesting information. He will typically have immediate access to workstations with fewer monitors than those in the radiology department. If he examines images before they are seen by a radiologist, he may wish to record his impression so that, if there is a significant variance, the radiologist can contact him for further discussion of the case.

Improving the access of physicians to images outside the radiology department is one of the areas where PACS may have a large impact, since this change has the potential for speeding up decision-making [4] and possibly shortening length of patient stay. This improved access, and the associated time savings, are the principal potential advantages most referring physicians cite for PACS over conventional systems.

The clinical workstation has the same requirements as the radiologist's workstation except for the following:

Display characteristics: The resolution of the clinical workstation shall be no less than 1024 x 1280 pixels. The screen brightness should be at least 60 foot-Lamberts. For the most part the clinical workstation will have one or two monitors.

Annotation of clinical actions: The physician shall be able to record his impression of a study when the workstation indicates that the images have not yet been reviewed by a radiologist.

Input devices: The use of a keyboard may not be convenient or even desirable where a relatively limited set of review functions are needed. Alternate input devices may be more suitable in such cases.

7 Conclusion

We firmly believe that PACS represents the future of radiology and modern hospitals. The declining costs of PACS components, the increasing sophistication of software, and better integration of all the necessary PACS components will make hospital-wide systems a viable commercial undertaking within this decade, most likely within five years.

We also believe that the potential of PACS has barely been tapped. Workstation and database software can be developed that can substantially increase physician productivity, improve diagnostic accuracy, and make a large amount of knowledge and patient information available on-line to the physician in the hospital or in his office. Development of these features will require a substantial period of prototype development and testing in close collaboration with end-users. It is expected that hardware improvements

and cost savings will be incorporated in parallel during this development period. We hope that this paper has indicated some of the directions in which this development must proceed.

References

- [1] W. Lee, R.J. Gove, Y. Kim, and T. Alexander, "Image Computing Requirements for the 1990s: from Multimedia to Medicine," Proceedings of SPIE Medical Imaging V, Vol. 1444, in press, 1991.
- [2] National Electrical Manufacturers Association, "digital imaging and communication," ACR-NEMA Standards Publication, No. 300-1985, 1985, and No. 300-1988, 1988.
- [3] R.K. Panwar, C.S. Wang, L.A. Desoto, H.W. Park, and Y. Kim, "UW PACS prototype performance measurements, computer model, and simulation," Proceedings of SPIE Medical Imaging IV, Vol. 1234, pp. 869-880, 1990.
- [4] R.L. Arenson, S.B. Seshadri, H.L. Kundel, D. DeSimone, F.V. Voorde, W.B. Gefter, D.M. Epstein, W.T. Miller, J.M. Aronchick, M.B. Simson, P.N. Lanken, S. Khalsa, I. Brikman, M. Davey, and N. Brisbon, "Clinical evaluation of a medical image management system for chest images," American Journal of Roentgenology, Vol. 150, pp. 55-59, 1988.

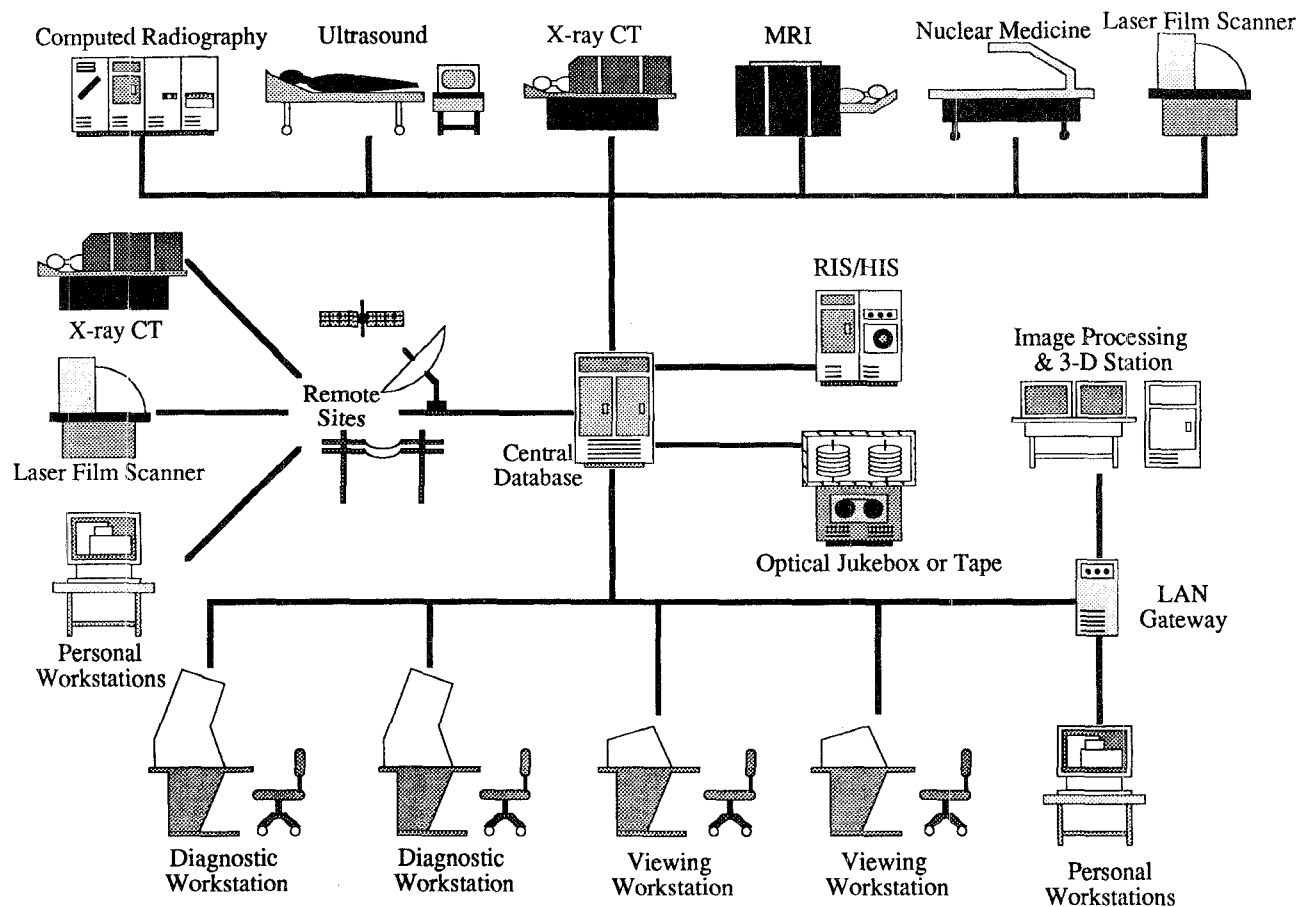


Fig. 1. A schematic diagram showing major PACS components and connections