의학물리. 제2권 1호 1991

Requirements for Future Digital Radiology System

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Abstract. An area of particularly rapid technological growth in the last 15 years has been medical imaging (conventional X-ray, ultrasound, X-ray computed tomography (CT), magnetic resonance imaging (MRI). As the number and complexity of imaging studies rises, it becomes ever more important to distribute these images and the associated diagnoses in a timely and cost-effective fashion. The purpose of this paper is to describe the requirements for a future digital radiology system which will efficiently handle the large volume of images that 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 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/uear). Because only single copies of 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 online references, containing both text and images, can be developed.

It is our belief that new developments in hardware will allow significant reductions in the costs of transmitting, archiving, and viewing medical images over the next decade, to the point where electronic systems will be cost-competitive with conventional systems. If, at the same time, software can be developed that significantly enhances the productivity and diagnostic accuracy of individuals viewing images electronically rather than in conventional film-based formats, it is likely that hospitals and radiology departments will invest in this new technology. Conversely, without imaginative hardware and software solutions to present-day bottlenecks in the dissemination of images and information, the high initial costs of all-electronic systems are likely to slow their acceptance in all but the most problem-ridden departments.

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 fully implement a *filmless department.* Figure 1 conceptually describes a diagram of PACS [1].

Most installed systems are currently teleradiology systems ; their goal is to make images acquired or processed at one point available at a distant point. They might be used, for example, to make bedside X-rays processed in the radiology department available in an intensive care unit, or to make it possible for a radiologist in his home to monitor a CT scan taking place at the hospital. It is likely that gradual growth from these base systems will take place over a number of years, and so designing a system to make it easily expandable and reconfigurable, without the need for wholesale discarding of existing equipment, is important.

It has been our experience that the amount of consultation between PACS designers and endusers of PACS (technologists, physicians, and hospital physicists and engineers) has been surprisingly small. This has resulted in the design and premature release of several systems that have been poorly matched to clinical needs and have turned into extremely expensive and unsatisfying experiences for both users and vendors [2]. We hope that consideration of some of the issues raised here will lessen the probability of this occurring in the future.

The following sections describe introductional explanations and requirements of image acquisition, data acrchiving, image processing, display and interface between radiology information system(RIS), hospital information system (HIS) and PACS.

2. Image Acquisition

In simpler cases, images may be obtained entirely by radiology technologists and only reviewed later by radiologists. In more complex cases (particularly ultrasound or those involving invasive procedures such as biopsy or angiography), radiologists obtain some of the images themselves. Certain requirements are universal. The images obtained must be accurately linked to the patient and to the study request. In most hospitals today, some type of electronic RIS 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. The images must be available for immediate review (i. e., prior to completion of the study) by the technolol-gist or radiologist to insure that the areas of interest have been fully covered, that the images

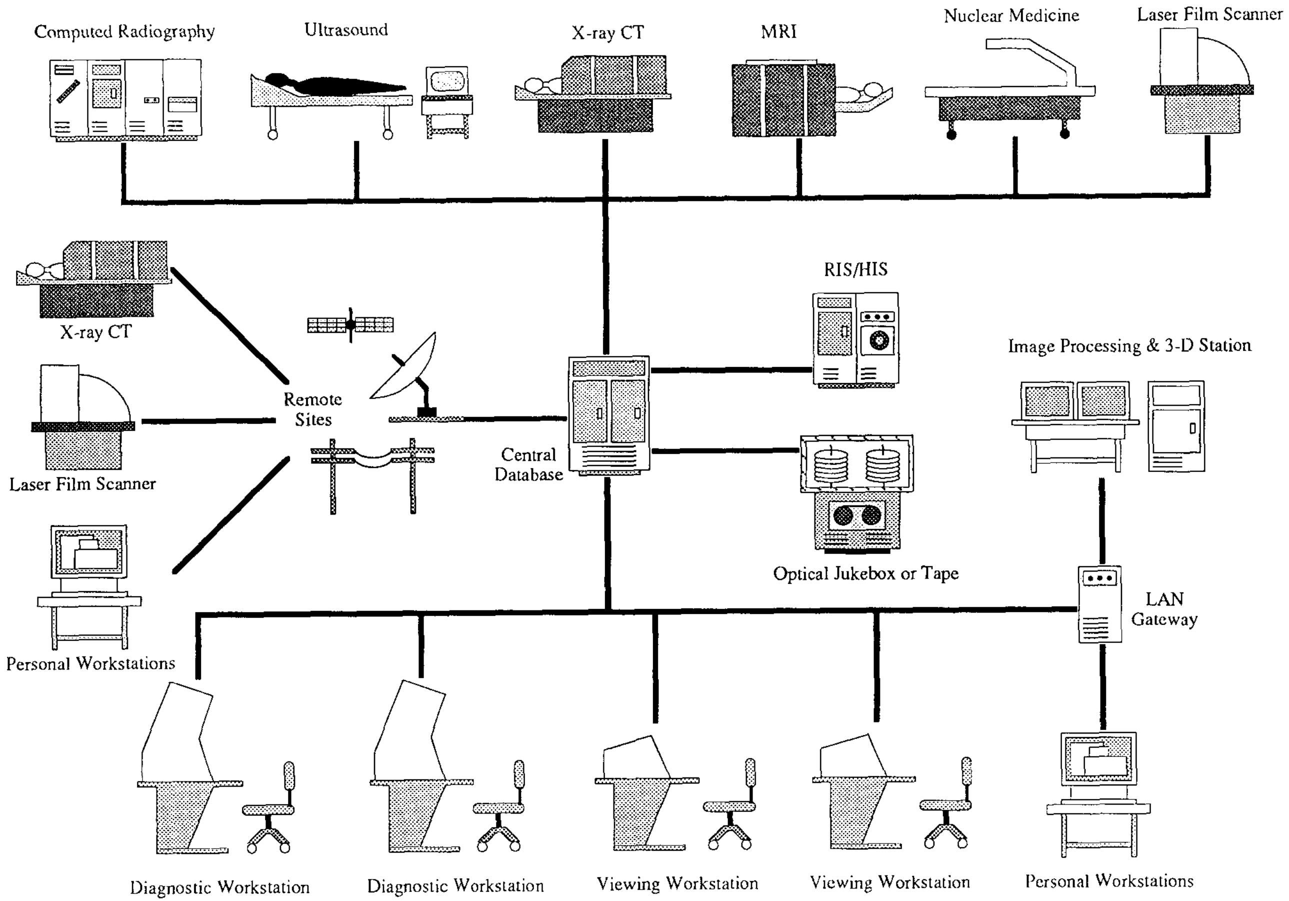

Fig. 1. A schematic diagram showing major PACS components and connections

are of diagnostic quality, and that no additional imaging is required. Finally, in the case of PACS, image transmission to the network and archive must be performed reliably and with minimal human effort.

2.1 Radiographic Modalities

The different types of imaging equipment in radiology departments are referred to as modalities. A brief discussion of the important features of the major modalities is given below.

X-ray examinations (General Radiology), also known as plain films, are made by exposing a sheet of film to X-rays transmitted through the patient. Typically, the radiation dose required is lowered by the use of a fluorescent screen, which amplifies the effect of the radiation. This film screen combination is designed to give both image quality and high sensitivity to radiation. In order to get conventionally acquired plain films into a PACS, they must be digitized. Typically this is done by a laser digitizer. The spatial resolution of conventional X-ray film is extremely high, and to fully capture the spatial resolution of conventional screen-film combinations, it would be necessary to digitize chest X-rays at least to 4k x 4k. In practice most vendors currently produce 2k x 2k images.

Computed radiography (CR) is a technology designed to replace plain films. The film-screen combination is replaced by a storage phosphor plate or image receptor which develops a charge density at each point which is a linear function of X-ray flux. This charge density is then read out by a scanning laser which produces fluorescence proprtional to the charge density at the point currently being scanned and, therefore, to the original X-ray flux. CR images are obtained by a technologist in a fashion identical to conventional radiography ; only the subsequent processing of the receptor is different. The transfer of data to the PACS occurs in the scanning device which reads the information on the storage plate. The advantages of CR include a much greater dynamic range than conventional film and a much more relationship between image intensity and X-ray flux.

X-ray computed tomography (X-ray CT or simply, CT) uses a digital computer to calculate a series of axial images, based on absorption of X-rays at various angles through the patient. The X-ray tube is rotated around the patient while the amount of radiation passing through the patient is measured at each angle. The image is then computed from these hundreds of thousands of data points. Typically, the patient is moved through the scanner in small steps, and a series of images is computed. Like CR, the output of a CT scanner is intrinsically digital. The number of images in a typical CT study (20-100) is much larger than with CR or plain films.

Magnetic resonance imaging (MRI) is similar to CT in that the image is calculated, rather than being produced primarily on film. However, it does not use X-rays, but instead uses magnetic field and radio frequency signal to generate a small amount of microwave radiation from within the patient, which is then detected and decoded to yield the image. Because the primary data is acquired directly in digital form (like CT), there is no loss of resolution in displaying MR images on a screen. A typical MRI study contains 4-8 series of images, each of which may contain up to 100 images (typically, 10-20).

Nuclear medicine examinations (planar, single photon emission computed tomography (SPECT), and positron emission tomography (PET) are made by injecting a small amount of radioactive isotope inside the patient, and observing the radiation that escapes from the body. Variations of this procedure call for the radioactive isotope to be inhaled or taken by mouth. The nuclear medicine images are inherently digital and of low resolution.

Uitrasound images the patient with high frequency sound waves. Currently the images are photographed off the screen and then printed on film, although direct digital interfaces to ultrasound machines are currently available, and will probably be more widespread in the future. An alternative type of interface to existing equipment is via a video digitizer. Video digitizers, even more than laser digitizers, are prone to degradation of image quality, however, and video capture of individual images is labor-intensive.

In summary, 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. Important differences between modalities exist in the size and number of images within a study, in the presence of multiple series within a single study, and in the types of relationships betwee images.

2.2 Image formats

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 ; ultasound 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 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 [3]. While there is continuing debate over minor details of this format, support of this standard is mandatory for any PACS which supports input from devices made by multiple vendors. By 1993, the vast majority of new inage acquisition equipment will support the ACR/NEMA standard.

The ACR/NEMA standard also specifies a hardware protocol for connecting image acquisition devices to a network. This connection standard must be supported by any PACS vandor who wishes to have full digital interfaces to multiple acquisition devices.

2.3 Requirements

The considerations described above determine the requirements for image acquisition in a PACS.

- Interfaces must be provided that can service acquisition devices from multiple vendors. Therefore, the ACR/NEMA message format and hardware protocol must be fully supported.
- A method for immediate review of the study currently being acquired must be provided. A technologist or radiologist reviews every study, as it is being performed, primarily for quality assurance (QA) purposes, since an unsatisfactory exam cannot be corrected once the patient has left.
- Image acquisition into the PACS must be as easy as possible. While this is primarily the responsibility of the designers of the acquisition device, several implications for the PACS follow For example, a patient name and other information should be automatically transferred from radiology information system (RIS) once a patient examination number is supplied to the PACS.
- Image acquisition into the PACS must be as reliable as possible. Several studies may be simultaneously in process in a distributed PACS, with images coming in asynchronously from each. Allowances must be made for the effects of breakdown in acquisition devices, links, or the PACS database manager. No images can be lost, and the complete acquisition of each study must be verified.
- Performance and buffering capacity must be such that the network interface unit (NIU) is not the bottleneck for image transfer to the PACS.
- It must be possible to produce hard copy directly from an acquisition device, even if the central archive nodes are not functional. This feature is sometimes useful in routine work and is mandatory in of system breakdown to allow individual acquisition devices to continue to produce images.
- The cost of interfacing new devices to an existing network should be reasonable. Provision of an ACR/NEMA-compatible output is the responsibility of the vendor of the acquisition device, and will probably be a routine contractual requirement on all new equipment within a few years.

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. The HIS contains subsystems for each of the major components of hospital operations ; a typical user may see only a fraction of the total system (for example, a billing clerk may not even be aware of, nor have access to, the system which reports lab results). 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 current PACS development is being carried out with dedicated image-transmission and viewing systems. Nonetheless, communication with the RIS (and also the HIS) is essential for a number of reasons which are detailed in the section which follows. The problems of communication between a PACS and an RIS are currently being addressed by a Working Group of the American College of Radiology and the National Electric Manufacturers Association [4].

Requirements for RIS/HIS/PACS communication

- APACS terminal 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 accesss 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 turns 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 patient customarily receiving care at one hospital is transferred to or seeks emergency care at a seond 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. Protocols for PACS-PACS

communication, based on th ACR/NEMA protocol, are currently under development. There is an increasing number of applications such as three-dimensional reconstruction and viewing, radiation therapy planning, and quantitative image analysis. In many cases, these applications may run on dedicated computers which then export their results in the form of images back to the PACS.

4. Image Archiving and Distribution

Insuring adequate network and archive performance and sufficient archive capacity at acceptable costs is among the most vexing 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 [5]. 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 need 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 our 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 highvolume 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 dial up T1 lines or over ISDN.

Radiology departments and hospitals are dynamic environments. Equipment is constantly being added, modified, or moved. In a large network (more than 100 nodes), there will be one or more changes in system configuration every month. Moreover, implementation of PACS is likely to be staged, due to high capital costs and the rapid changes currently taking place in all the relevant technologies. These mandate a flexible and modular approach to network design in which changes in configuration can occur without disabling the entire system.

Image compression is an area in which currently no consensus exists exists within the user community However, image compression has the potential for greatly reducing archival requirements. Approximately 10 : 1 compression for CR images, and 3-4 : 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

5.1 PACS in the radiology department-minimal requirements

The viewing of images which are 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 as follows.

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 preferred, 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 (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 prlonged 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. An 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 imges in stacks and then view them as a movie loop (at selectable speeds) is quite useful, particularly if the process of assembling the stack is easy.

Inage 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 90/180/270 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, unmber 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 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 briefiy sketched.

Three-dimensional viewing : Two-dimensional images taken as parallel slices through a threedimensional object can be reformatted and viewed in a variety of ways to better display threedimensional 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 impactif 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 referrig physician) viewing images outside the radiology department are broadly similar to those of the radiologist reporting a study. Ideally, the referring physician would like access to the raciologist'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[6] and possibly shortening length of patient stay. This improved access, and the associated time savings, are the principal advantages most referring physicians cite for PACS over conventional systems.

The clinical workstation has the same requirements as the radiologist's wokstation 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

The authors 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 APCS 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 hte physician in the hospital or in his office. Development of these features will require a substantial period of prototype development and teting 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 document has indicated some of the directions in which this development must proceed.

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