DATABASE OF DIAGNOSTIC IMAGES IN HOSPITAL INTEGRATED PICTURE ARCHIVING AND COMMUNICATION SYSTEMS

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Abstract: Implementation of database management system in clinical open–architecture Picture Archiving and Communication System (PACS) is discussed. Standardization of communication protocols and file formats permit the equipment of various vendors to be linked. Main functions of the database management system at two levels of the system are introduced. Clinical experiences show three main advantages which cause an increasing interest in this concept. Access time, computer–assisted diagnosis, and cost–effectiveness are parameters describing the system efficiency.

Keywords: database, diagnostic medical images, image standardization, DICOM

1. Introduction

Development of digital radiography (including computed tomography, computed radiography, magnetic resonance, nuclear medicine, fluoroscopy, etc.) has changed the organization of radiology. A concept of Picture Archiving and Communication system (PACS) has been introduced in the 70s. Images, previously printed on films and stored in film library are acquired and transferred to jukeboxes and archived on short–term or long–term storage media. Management software permits an access to patient data as well as images. Access to patient data depends on the user access permission. Local and remote access to the database becomes widely implemented in clinical practice and research. Main features causing an increase of clinical implementation of PACS are grouped in three categories [1]:

— more objective image analysis performed on a display station allowing window/level adjustment, thresholding, zoom, magnifying glass, rotation, filtration, etc., as well as quantifying analysis (distance, area and volumetric measurements, profile and histogram analysis, region of interest, etc.). Image fusion permits a superimposition of anatomical and metabolic images;
— significant decrease of time response and fast access to results of former examination procedures permits monitoring of treatment and early detection

of abnormalities, as well as access to a large volume of data for research and education;
— significant cost effectiveness.

2. Database in PACS

2.1. PACS open architecture

The 1st generation Picture Archiving and Communication System (PACS) is described [2] as a module able to transfer images via a communication network from acquisition units to an archive station. Then, images are distributed to workstations for display and manipulation. Thus, four major components are included in PACS (Figure 1):

— image acquisition;
— image storage;
— image display stations;
— network.

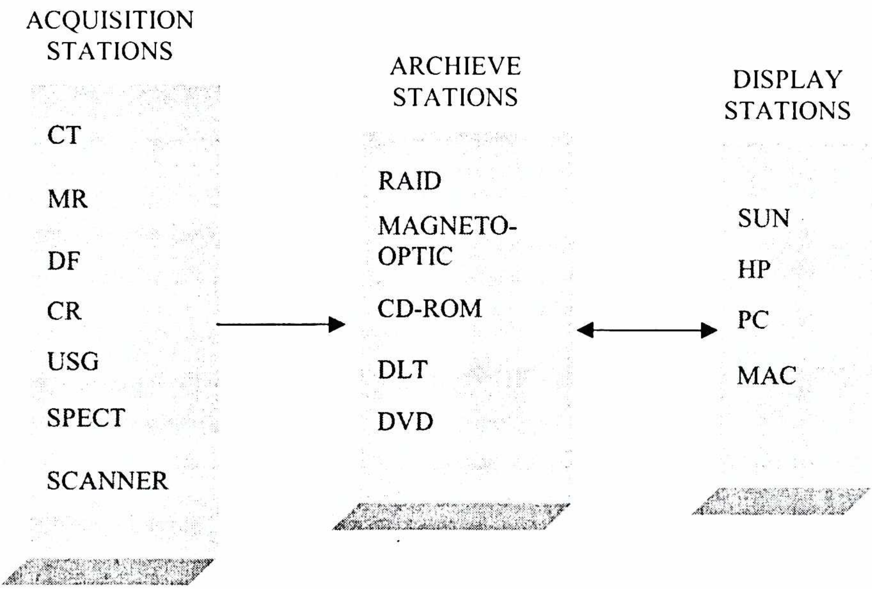

Figure 1. Picture Archiving and Communication System. DATABASE module is located at the ARCHIVE station

Image acquisition units deliver digital images referred to as database elements. They can be grouped into two classes. Some units, used for radiological examinations, convert a radiographical projection into a digital image. Others, permit radiographs from outside PACS to be accepted and processed by the system.

The first class includes units used clinically. They may deliver one or multiple images per a study. Scanners, using various sources of radiation, reconstruct the internal structure of an object from multiple projection and deliver a serial of images per each study. A serial of digital images is obtained by an X–ray Computed

Tomography (CT), Magnetic Resonance (MR) concentrating on the spin–echo technique, emission tomography injecting a radionuclide (being the source of radiation) to a patient. Single image projections are acquired by Computed Radiography (CR) systems which use photostimulable phosphor as an image receptor.

Conventional radiography uses X–ray film as the image receptor. The exposed film is then developed and viewed. A phosphor coated screen is contained in a cassette similar to a standard film–screen cassette. A radiographic exposure is made using conventional X–ray equipment. The photostimulable phosphor absorbs some of the energy. Electrons are excited into higher energy states creating a latent image. While scanning this latent image by a laser beam, the trapped electrons return to the valence band with the emission of light. The light is viewed by a photomultiplier tube, whose output constitutes the signal. It is fed to a computer for further processing. Digital fluoroscopy (DF) is another method able to produce a digital X–ray image by a modification of the conventional fluorographic procedure. Ultrasonograph is yet one more real–time acquisition device.

The second group of the acquisition devices permits radiographs acquired outside PACS to be incorporated in PACS and processed by its software procedures. Digital images can be generated by high resolution film digitizers which convert conventional x–ray films to a digital form maintaining the diagnostic quality of the original film. Finally, a magnetic tape driver reads images acquired by imaging modalities not connected to the network.

Digital image storage depends on the size and volume of digital images to be stored. It relies on fast magnetic disk arrays, optical disk library, CD–ROM or tape storage technologies. The former solution is used as a short–term storage. Latter technologies are used as long–term storage units. Multidisk jukeboxes are implemented as very large mass storage devices archiving giga– and/or terabytes of data.

Image *display stations* which permit access to the database are located within the radiological department as well as in clinical departments. Each station consists of one or several video monitors, a computer, a magnetic or small optical disk storage. Video monitors may have a resolution of 512 up to 2048 lines. The 512–line monitors, being inexpensive, can be used for a preview or in the ICU for detecting and/or viewing gross abnormalities. The intermediate level monitors are basically used for the image analysis and/or diagnosis of CT, MR, or US. They have an adequate resolution for 90% of radiological examinations. The hi–resolution monitors are used for a detailed analysis of CR images whose resolution differs from 1670 to over 2100–lines or for a comparison study of multiple examinations.

Digital *network* transmits radiographic images from one location to another. A digitized 8 MB CR image is equivalent to 100 000 lines of information and is very time–consuming to be transmitted using conventional communication protocols. Currently, two types of networks are mostly used in clinical PACS: Fast Ethernet, and ATM (Asynchronous Transfer Mode).

2.2. Standardization

In order to make the clinical PACS vender–independent, in 1985 the American College of Radiology and the National Electrical Manufacturers Association published the ACR–NEMA Digital Imaging & Communication standard. An extended version was published three years later [3] and the third version, known as Digital Imaging & Communication in Medicine (DICOM) was published in 1992. The standardization includes three fields [4]:

— communication of digital images, regardless of source format or device manufacture;
— development and expansion of PACS and its interface with other systems of hospital information;
— creation of diagnostic information database that can be interrogated by a wide variety of devices distributed geographically in the hospital.

The file structures handle images and related clinical information to be used in multimodality image archiving and communication systems. Data are stored in a folder–like structure containing patient and study information, as well as references to image data sets. Each acquisition set (i.e. a sequence of dynamic images or a set of contiguous tomographic images acquired as part of a patient examination) is stored in a separate file. A full study (i.e. complete examination) may contain one or more acquisitions. Therefore, a complete examination may contain several files.

The interface standardization has to be considered at two levels. Firstly, due to the multi–vendor acquisition devices connected with PACS, a capture computer is interposed between the image device and PACS. It is required in order for CR, CT, MR, or US to operate independently from the communication with PACS. The complete acquisition process comprises:

— capture of the raw image data as well as patient and study information;
— conversion of the data into PACS standard format;
— transmission of this data file to PACS for archiving and distribution.

3. Database management

Database management software component performs several functions at various levels. At the lower level it is responsible for: receiving images from acquisition devices; extraction from the image a patient header and study information in order to upgrade the working list; image compression (if required); images archival; remote files removal from acquisition stations; autorouting; remote access to images. The database system comprises redundant servers running identical commercial database systems (e.g. Sybase, Oracle) with structured query language (SQL) utilities. A mirror database can be used to duplicate the data during each transaction involving the server. The mirroring feature provides the entire database with uninterruptible data transaction that guarantees no loss of data in the event of system failure or a disk crash.

At a higher level it integrates and organizes PACS images and related data, extracts image features and keywords, supports content–based indexing and retrieval, formatting and distribution for visualization and manipulation, as well as multimedia data model.

4. Clinical experiences

4.1. Clinical implementation

At the earlier stage of PACS development three strategies have been considered [17]. During the past five years health centers have learned to take advantages of good and discard bad features of each method. As a result, boundaries between those approaches have fused and a fourth implementation strategy has emerged [18]. Table I summarizes the advantages and disadvantages of all four approaches.

In many hospitals worldwide PACS is already implemented and is in daily clinical use. Several examples of large–scale PACS are discussed below.

The first approach — in–house built system — has been developed at the University of California (currently turning to the partnership approach), University of Geneva, and the Medical Center of Seoul (South Korea). Three main developmental stages are required: (1) project of PACS infrastructure, (2) link of equipment modules (acquisition stations, archive stations, jukeboxes, workstation, etc.), (3) clinical testing and implementation. In most cases PACS is first implemented in the Radiology and, then, extended to other departments (Cardiology, ICU, etc).

The two–team effort approach has been used in SMZO (Sozialmedizinisches Zentrum Ost) in Vienna, in four hospitals in the USA which have joined the MDIS (Medical Diagnostic Imaging Support Systems) project, Hammersmith Hospital in London, Hokkaido University Hospital in Japan.

PACS at SMZO is a result of collaboration of the hospital and Siemens AG, Erlangen (Germany).

A 2–level integration of PACS, HIS, and RIS have been developed by the Department of Medical Informatics and research groups of Siemens. Clinical requirements have been defined by the Department of Radiology.

MDIS is the largest PACS project whose main goal is: filmless radiology. The project has been based on three issues: (1) system functionality has to be clinically acceptable, (2) clinical evaluation of the entire system is based on its daily use, (3) a system of the best clinical performance is to be chosen.

PACS at the Hammersmith Hospital is based on the MDIS project. The choice has been justified by the system effectiveness. Several elements have been considered: films versus material used for archives, space and equipment. Separately, the man–power component has also been considered.

The third approach is based on a turnkey method in which a fixed system, developed by a manufacturer, is purchased and clinically implemented. PACS is offered by Siemens, Agfa, Philips, AT&T (COMMView) and many other vendors.

Table I. Advantages and disadvantages of four approaches to PACS implementation

Method	*Advantages*	*Disadvantages*
1. Home-grown system	• builds a specification • state-of-the-art technology • not depending on a single vendor	• difficult to assemble a team • long time of implementation process • difficult to service and maintain
2. two team effort	• specification written for defined clinical environment • implementation delegated to the manufacturer	• overambitious specification • technical and operational difficulties underestimated • manufacturer lacks clinical experiences • expensive
3. turnkey approach	• easier maintenance • lower cost	• too general • not meeting a stated clinical environment specificity • not state-of-the-art technology
4. partnership	• system keeps up with technology advancement • manufacturer has long-term contract to plan ahead	• difficulties for centers of lesser prominence to sign a partnership contract • longevity and stability of manufacturer has to be considered • expensive • legal issues when partnership dissolves

In all those cases a hospital installs a standard system which usually does not meet all the defined requirements.

After a four–year development of an in–house PACS, the University of California has reached sufficient maturity to permit a manufacturer to take over the continued rudimentary implementation. The system requires additionally [18] more storage devices and workstations, quality assurance of the daily clinical service. Thus, recently the University of California, San Francisco, partnered with a PACS manufacturer to continue its service to the expanding clinical enterprise.

4.2. System evaluation

Due to high costs of a PACS installation a question is often risen about efficiency and advantages of its implementation. Among the advantages the following are placed on the top: access time, performance, and cost effectiveness.

The access time, being an important parameters featuring database system, depends on the workstation itself and the network. The display time on a workstation depending on the image size varies from 3.5 sec for a 1K×1K images to 12 sec for a 2K×2K image. While introducing digital viewing stations, the mean time between X–ray exposure and physician viewing the study is decreasing from 78 min to 39 min [5] and for the most critical cases from 20 min to 10 min. It has been shown [6] that a rapid assess to radiographic images and other patient information can have a significant impact on patient stay in an intensive care unit (ICU). The common feature of this system is the ability to get information out of the radiological department to an ICU for review by a clinician. To shorten the access time, in some cases [7] images are digitized from conventional film by a laser digitizer. No additional effort is required while a CR system is used. Also, PACS modules being implemented in pediatric radiology, neuroradiology, and coronary care units show an image access time reduction.

For a secondary diagnosis the access time drops even more significantly. For a film system [8], 300 film images have been tracked from a film processor to their placement onto the alternators. The average delay of 20.1 hours is incomparable with 8 min while referring to CR images. For coronary care unit the delay from procedure to hard copy generation increases to 2.5 days. A decrease of access time has an impact on conferences. A faster access to images decreases the total length of conferences increasing at the same time the length of discussion on each case.

Performance is another important feature to be evaluated. Based on the receiver operating characteristic (ROC) CR images have been analyzed versus conventional analog film. The evaluation of diagnostic performance of 512, 1024, and 2048 monitors has shown [9] that the first two monitors perform below the analog film, whereas, the 2048 system is comparable to the hard copy. No statistically significant difference in the ability to detect pneumothorax or solitary noncalcified nodules [10,11] has been confirmed. Images with a pixel size of 0.1mm are sufficient [12] for mild interstitial infiltration and subtle pneumothoraces. A difference in image sharpness between hard and soft copies in digital mammography does not appear to degrade diagnostic content of images [13].

The major advantages in performance are a direct access to each patient case in contrast to the sequential access method employed by the light alternator [14], the availability of multimodality images, and the ability to perform image manipulation. Cost effectiveness while replacing a film–based by a digital–based system is the second issue to be investigated [15] saving of $200000 has been obtained [16] while performing all digital, filmless portable examinations which generate 400 GBytes of image information (about 40000 CR images). Savings can also be measured in terms of time that instead of being spent for the image archive and retrieval can be devoted to patient interaction.

5. Conclusion

Archival of patient information in PACS has changed the everyday clinical performance as well as research and education activities. Link to hospital information system (HIS) and radiological information system (RIS) yields information of all patients including their medical history, sequence of examinations and medical follow–ups. RIS performs all essential administrative functions i.e. scheduling examinations, storing and retrieving reports, billing, sometimes even film tracking. In the clinical environment, the access to the patient data is performed on two levels. The first request is posted by the acquisition device, demanding the patient list, which includes demographic information. It permits the technicians to register the examination based on information given automatically, rather than typing it. The second access to the information system is required in the diagnostic procedure. The images are accessed based on information about their location stored in the database. A prefetching mechanism initiated as soon as a patient is readdmitted, retrieves relevant information from PACS and RIS and distributes it to a designated display station. For a faster access to the data of a particular patient a platter manager system may be employed. For clinical research the medical database can be interrogated for questions combining different types of data including radiological as well as clinical data.

The development of computer–based problem–solving techniques, started in late 1950's, opens new doorways for the use of artificial intelligence. During this time, new programming languages that allow for the manipulation of non–numeric symbols as well as lists of data, yield a higher–level means of communicating with computers. Progress has been made in understanding of natural languages. Beside many computer systems for radiological report registration, there are also some on–going studies which attempt to bridge the gap between the natural — language expressions used in describing finding on the radiographs and the artificial intelligence (AI) methods, used in structuring the knowledge–based data. Machine understanding of clinical questions is an important feature to generate facts about patient cases which are used to decide on the relevance of images for prefetching. In the same way, diagnostic reports could be analyzed and converted into a set of data base attributes, which describe the patient case.

Multimodality PACS requires also multimedia communication service, which is the combined use of data, text, graphics, images, motion video, and audio (voice and sound). This information needs not only to be sent over a communication network within one hospital. A demand for a systematic access to resources outside the local organization is very strong. It provides a new telecommunication service.

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