Design and Implementation of PC-based hospital-integrated PACS in Seoul National University Hospital

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Abstract

The SNUH has started a PACS project with three main goals : to develop a fully hospital-integrated PACS, to develop a cost effective PACS using open systems architecture, and to extend PACS' role to the advanced application such as image guided surgery, multi-media assisted education and research.

In order to achieve these goals, we have designed a PACS architecture which takes advantages of client-server computing, high speed communication network, computing power of up-to-date high-end PC, and advanced image compression method.

We have installed ATM based communication network in radiology department and in-patient wards, and implemented DICOM compliant acquisition modules, image storage and management servers, and high resolution display workstations based on high-end PC and Microsoft Windows 95 and Windows NT operating systems. The SNUH PACS is in partial scale operation now, and will be expanded to full scale by the end of 1998.

1. Introduction

The SNUH is a representative university hospital in Korea which consists of an main hospital building with 1,249 beds and a children's hospital building with 259 beds. Table 1 summarizes some statistics of two hospital buildings.

The SNUH started a project for the development of a large scale, hospital-integrated PACS in January, 1995. The SNUH PACS project has three main goals : to develop a fully hospital-integrated PACS, to develop a cost effective PACS using open systems architecture, and to extend PACS' role to the advanced application such as image guided surgery, multi-media assisted education and research.

To achieve these goals, a task force team was organized and has been operational, being in charge of the system design, development, installation and integration.

We have designed a PACS architecture that is easily upgradable, expandable by using industry standard hardware and software components. We use MS Windows95 and MS Windows NT operating systems and high-end PCs for every computers in this architecture.

We have developed DICOM compliant image acquisition modules for various modalities, image communication and management module, and high resolution display workstations. Currently, our system is in partial installation and evaluation phase, and will be expanded to full scale by the end of 1998.

2. Architecture design

The important issues considered in the design of SNUH PACS were data safety, system reliability, response speed, and global accessibility. It was requested that the image data should be kept safely in any possible situation, the system should continue to run even when a part of components failed, and any patient's image should be accessible at the display workstation, and the response speed has to be acceptable. In order to meet these requirements, we have devised a number of unique features in our architecture design.

2.1. Hybrid storage management mechanism.

One of the unique features of SNUH PACS is the hybrid storage management mechanism that takes advantages of both the central and distributed storage management mechanism. In our design, the images are stored first on the central storage server after acquisition, and then are distributed to each workstation's local disk according to the request table pre-configured by the workstation user.

Thus the central storage keeps all the images acquired, and the each workstation' local disk keeps the partial set of images that is to be frequently retrieved. The workstation keeps dual paths to the central and local storage units in its database - when the user selects a patient whose images have already been sent to the workstation, the images are retrieved from the local disk, otherwise the images are retrieved from the central storage. Once the images are stored in the local disk, they can be retrieved faster as well as they remain accessible regardless of the server or network failure.

2.2. Three-tiered Image Storage Scheme

While pre-fetching is compulsory to avoid the delay in the image retrieval from the archive at the user's access time, the primary reason for bottleneck and the users' dissatisfaction has also been due to the pre-fetching in today's PAC systems. In our design, however, we took an approach in which the need for pre-fetching could almost be eliminated.

We introduced the concept of mid-term storage to the conventional short-term storage and long-term archive architecture making the image storage architecture three-tiered. The mid-term storage resides between the short-term storage and long-term archive and acts as a cache to reduce pre-fetching from the long-term archive.

With this scheme, the new exams that have been read by radiologists are sent to the mid-term storage server and stay there for a year in wavelet compressed format[1]. When these exams are requested, they are decompressed and sent back to the short-term storage unit by the mid-term storage server.

Therefore pre-fetching occurs only when exams aged over one year are to be retrieved. Since most of the pre-fetching occurs for exams generated within recent 1 year, the occurrence of pre-fetching will be drastically reduced with this approach.

The wavelet compression method[1] achieves average 20:1 compression ratio without perceivable degradation, which makes the capacity of mid-term storage for one year term that of only 15 days in uncompressed case, which is economically feasible.

2.3. Parallel Server Architecture

Fast image delivery and fault resistant operation were two important issues in our design of server architecture. In order to meet these requirements, we adopted parallel server architecture in which multiple servers run concurrently. In normal operation, work loads are balanced among the servers. In the emergency mode when one or more servers fails, the other servers take the extra work loads in the predefined order. This architecture not only resolves the bottle neck in the server at peak time, but also provides a strong mechanism for fault resistance. We use this parallel server architecture for acquisition servers and storage servers.

3. Implementation in SNUH

3.1. Acquisition

There are 7 CT/MR scanners, 4 CRs, 5 Angio units, 8 USs, and 6 R&F units in SNUH. Among the total of 30 imaging units, 19 units are currently connected to the PACS, and the others are in progress.

There are only three units that have DICOM 3.0 transfer function. Therefore we have developed or are developing custom interface modules to connect the rest of imaging units. The custom interface modules are basically DICOM gateways that acquire and reformat the images to send them through the DICOM protocol. Thus the image acquisition part has been implemented to be fully DICOM compatible so that any imaging unit that use DICOM standard can be easily integrated into the SNUH PACS.

CT and MR

The 1 GE CT(Highspeed advantage) and 1 GE MR(Signa Advantage) are connected via DICOM protocol. We have developed custom interface modules for the Siemens CT/MRI scanners that do not support DICOM. These modules consist of a PC and gateway software running on Windows NT that automatically fetch images of newly generated exams from the Siemens scanners via DECnet protocol and transfer them to the acquisition server via DICOM protocol. It takes about 5 ~ 10 minutes to transfer a CT/MR exam using these modules.

Computed Radiography

Four FCR units are connected to PACS using custom developed interface modules. This interface module receives images from the FCR through digital acquisition system manager(DASM) box(DASM FDLR, Analogic Corp., MA, USA) with SCSI protocol, reformat and transfer the images in DICOM protocol. It takes about 30 seconds to finish the procedure for an image.

The features in CR acquisition module are automatic window width/level setting based on the pixel histogram, and semi-automatic study identification with on-line communication with RIS, optional film print out to the laser camera. We are acquiring all the in-patient studies with four CRs.

Ultrasonography

Eight ultrasonography units are connected to PACS using a custom developed video acquisition module. The video signals from the ultrasonography units are multiplexed and concentrated to this module, and are digitized with a video frame grabber. The acquired images are identified with on-line communication with RIS, reformatted as secondary capture of DICOM format, and then transferred to PACS with DICOM protocol. The acquired images are also printed out on film automatically with laser camera interface implemented within this module. We have developed a OCR function in this module for automatic image identification, which can be used as an option.

Angiography and Radio/Fluorography

One digital radiography system (FC 2000, InfiMed Inc., NY, USA) that covers two R&F rooms is connected to PACS via DICOM protocol. The two Siemens Polytron DSA units had been connected via network with DECnet inteface. However, the network transfer speed was too slow to be used in practice. Therefore a development work is undertaken that will speed up the image acquisition of angiography system by using digital frame grabbing method.

Film Scanner

Two film scanners(Lumiscan 100/200, Lumisys Inc., CA, USA) are connected to the in-house developed film scan station. The scanned images are reformatted as secondary capture of DICOM format, and then transferred to PACS with DICOM protocol.

3.2 Storage and Management

The HIS, RIS, and PACS in SNUH use the same kind of object oriented database engine(UniSQL/X, UniSQL Inc., TEX, USA) as they all have been developed in house. The communication between these systems has been established by network interface and communication processor using extended SQL[2].

The data flow in PACS such as image routing, aging, compression/decompression, pre-fetching, studies grouping is controlled by the event flow information from the RIS and HIS.

Four types of servers are used in SNUH PACS : database server, acquisition server, storage server, and archive server. All the servers are based on the Intel Pentium Pro CPU and Windows NT operating system. The database server(Revolution Quad6, ALR Inc., CA, USA) has 4 Pentium Pro 200MHz CPUs, 128 MB of RAM, and 16 GB of mirrored hard disk using a RAID controller. The two acquisition servers(MPP-200, MaroTech Inc., Korea) that have 2 CPUs, 128 MB of RAM, 9 GB of Ultra Wide SCSI hard disk, act as DICOM hubs to receive images transferred from the various imaging units and custom developed DICOM gateways.

The two storage servers(Revolution Quad6, ALR Inc., CA, USA) share the RAID-3 type disk array (Synchronix, ECCS Inc., CA, USA) of 90 GB capacity to support the access from the workstations.

Both the acquisition servers and storage servers run in parallel architecture to make load balancing and to enable fault tolerant operation. The archive server(Revolution Quad6, ALR Inc., CA, USA) has 32 GB capacity disk array for mid-term storage and a CD-juke box having 150 platters(Mercury-40, NSM Inc., IL, USA) for long-term archive. The archive server controls the image data flow between the short-term storage, mid-term storage, and long-term archive by performing the image compression/decompression, image pre-loading and pre-fetching.

3.3. Display Workstation

We have developed four types of display stations : diagnostic station, clinical review station, image verification station, and personal station.

The specifications of each station are described in table 1. All the display stations are based on the Intel Pentium or Pentium Pro CPU and Microsoft Windows95 or Windows NT operating system.

The image verifying stations have functions optimized for verification of images generated in each imaging modality and are installed in the simple X-ray imaging rooms, and CT/MR imaging rooms.

Two features in the diagnostic stations are the digital dictation support using a sound card, and background pre-loading of next waiting study in the reading queue to the memory for accelerated display.

Three clinical review stations are installed in the in-patient wards of neurosurgery, general surgery, and internal medicine departments of main building. The unique feature in the clinical review station is the capability of partial mirroring with which the pre-selected patients' images are mirrored on the local disk. We have programmed a communication processor that replicates the up-to-minute information and images of pre-selected patient folders in the central servers to the local disk of workstation. With this feature, the physicians are able to find the patient of interest quickly in the predefined inventory and view the images faster from the local disk, beside the basic function of exploring the global patient folders in the central server. In the event of the server or network failure, the workstation runs in stand alone mode and is still useable.

The personal station is very cost effective display station based on the general purpose desktop PC. It supports most of the functions in the clinical review station but is optimized to use less computing resources. There are two versions in the personal station : clinical version and academic version. The clinical version is for use in the in-patient ward and out-patient clinics while the academic version is to provide the image access service to the physician's personal desktop.

3.4. Networking

Three types of network are used in the SNUH PACS : 155 Mbps ATM, 25 Mbps ATM, 10 Mbps Ethernet. We use them in hierarchical manner for efficient handling of the communication traffic that varies depending on the various levels of data flow.

The 155 Mbps ATM is used to link between the servers and the diagnostic reading stations in the radiology department in order to support the intensive traffic for reading efficiently. The two 155 Mbps ATM switches(Collage 740, Madge Networks Inc., USA) in the main hospital building and children's hospital building are linked with fiber optic cable. The diagnostic reading stations are connected with UTP(unshielded twisted pair) category 5 cables, while the servers are connected with fiber optic cables.

The acquisition gateways, verifying stations, and clinical review stations are linked to the 25 Mbps ATM switches(Collage 280, Madge Networks Inc., USA), which are connected to the 155 Mbps ATM switch. The connections to 25 Mbps ATM switches are made with UTP category 5 cables.

Two segments of 10 Mbps Ethernet are used : one to connect the imaging equipments; one to provide image access service to the desktop PCs connected to the hospital area network.

We have installed 12 ports of fiber channel network within the PACS operation room, 24 ports of 155 Mbps ATM network in radiology department, and 84 ports of 25 Mbps ATM network in radiology department and in-patient wards.

4. Works in-progress and Future Development

An important advantage of in-house development of PACS is the ability to customize and add new special functions easily. We are developing some special image processing functions customizable to the specific needs of the workstation users. The functions include image enhancement with user customizable filter banks, semi-automatic segmentation to assist lesion area/volume mensuration, and several 3D display routines such as real-time MIP(maximum intensity projection), MPR(multi-planar reformat), and volume rendering. We are also going to integrate the two surgery planning systems in the neuro-surgery department and radiation therapy room into the PACS so that the requested images may be routed to the surgery planning workstations directly without intermediate procedures.

The SNUH PACS project is scheduled to be expanded to full scale by the end of 1998 to support the whole hospital including in-patient wards, out-patient clinics, and emergency room in both main hospital and children's hospital buildings. Around 300 workstations will be installed and used throughout the hospital at this time.

In the full scale implementation phase, we intend to fully integrate the PACS with HIS up to the workstation level such that the image and textual information generated in any department can be displayed at any computers in out-patient clinics and in-patient wards. A development work is undertaken to make an integrated clinical information display module that will support transparent access to the PACS servers and clinical information servers. Various imaging modalities such as PET, SPECT, pathology slide, video endoscope are also to be interfaced to the PACS in the full scale implementation phase.

5. Conclusions

We described the development works for a large scale, fully hospital integrated PACS which is in progress in SNUH. The SNUH PACS has an architecture that is easily upgradable, expandable by using industry standard hardware and software components such as MS Windows95 and MS Windows NT operating systems and high-end PCs. We have developed DICOM compliant image acquisition modules for various modalities, image storage and management servers, and high resolution display workstations. Several unique features in storage and server architecture such as hybrid storage scheme, three-tiered storage management, and parallel server architecture are devised and integrated into the SNUH PACS in order to provide fault resistibility and to improve efficiency in data flow control.

The SNUH PACS is in partial scale operation now, and will be expanded step by step to a full scale until the end of 1998. We believe that our development will make an essential infrastructure in the future patient care of SNUH.

6. References

[1] J.S. Song, S.J.Lee, H.J. Kim, J.H. Kim, C.W.Lee, "Wavelet Compression of Medical Image Using Tree-Structured Vector Quantization and High-Order Entropy Coding", Proceedings of SPIE, Medical Imaging 97: PACS Design and Evaluation, Vol. 3035, 1997.

[2] J.H. Kim, D.H. Lee, H.I. Cho, M.C. Han, "HIS/RIS/PACS Integration toward Total Hospital Information System", Proceedings of SPIE, Medical Imaging 97: PACS Design and Evaluation, Vol. 3035, 1997.

Table 1. Some yearly statistics of two hospital buildings in SNUH.

Main Hospital	Children's Hospital
1,249 beds with 90.7% occupancy	259 beds with 88.1% occupancy
429,437 admissions	84,604 admissions
803,840 patient visits	178,283 patient visits
18,424 emergency room visits	7,408 emergency room visits
358,113 radiology exams	88,912 radiology exams
4,497 giga bytes of image data	1,061 giga bytes of image data

* from 1995 survey

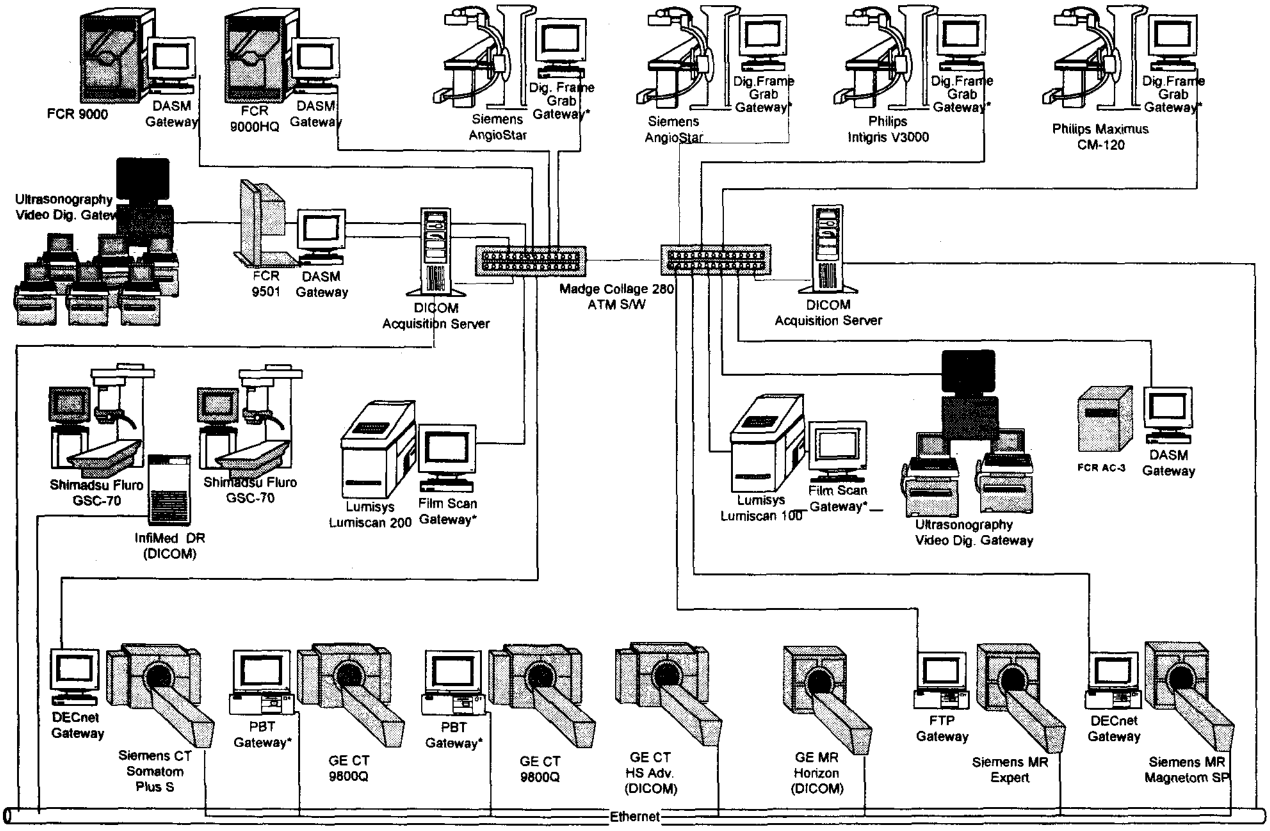

Fig. 1. Configuration diagram of acquisition subsystem (* : in progress).

Table 2. Specifications of display stations

Type	Specifications Description
Diagnostic Reading Station	2048x2560 resolution monitor(DR-110, Data Ray Corp., CO. USA) 4 head display adapter(Panther, Pixelworks Inc., NJ, USA) Pentium Pro 200MHz, 2 CPUs 128 MB RAM 2.5 GB hard disk drive Windows NT Workstation 4.0
Clinical Review Station	1200x1600 resolution monitor(DR-90, Data Ray Corp., CO. USA) Dual head display adapter(Panther, Pixelworks Inc., NJ, USA) Pentium Pro 200MHz, 2 CPUs 64 MB RAM 2.5 GB hard disk drive Windows NT Workstation 4.0
Image Verifying Station	1200x1600 resolution monitor(DR-90, Data Ray Corp., CO. USA) Single head display adapter(Panther, Pixelworks Inc., NJ, USA) Pentium Pro 200MHz CPU 64 MB RAM 2.5 GB hard disk drive Windows NT Workstation 4.0
Personal Station	17 inch multi-sync color monitor 1024x768 super VGA graphic card Pentium CPU(>100 MHz) >16MB RAM >1 GB hard disk drive Windows 95