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PACS Workbench at Mallinckrodt Institute of Radiology (MIR)

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Initial components of a Picture Archive and Communication System (PACS) workbench have been installed at the Mallinckrodt Institute of Radiology (MIR) providing a set of basic "utilities" which facilitate comprehensive design studies and experiments. Each of the primary areas of picture acquisition, transport, processing, archiving and viewing are addressed by the PACS workbench.

INTRODUCTION

ARCHITECTURAL SPECIFICATION, DESIGN AND IMPLEMENTATION of enduring solutions for the digital electronic radiology environment are likely to evolve as experience is acquired with prototypical systems and components. Decisions related to system capability, performance metrics, and operational constraints require comprehensive design studies and experiments. Current views of "acceptable" radiology protocol and practice are likely to be modified as additional emphasis is placed on the quantitative aspects of imaging. Increased availability of dynamic imaging modalities for both structure and physiology suggests an expanding environment.

Image acquisition, processing, archiving, display, and patient information systems are all fundamental aspects of system solutions. A distributed picture archive and communication system (PACS) provides the substrate for continued and orderly progress toward the perceived objectives. The canonic form of a PACS (Figure 1) includes three classes of nodes (picture sources, picture archives, and picture viewing stations) interconnected by a high-bandwidth picture network. Early efforts to address the definition and specification of PACS components and configurations were reported at the 1982 PACS Conference.[1]

We have adopted an experimental approach to the development of a digital electronic radiology environment for MIR through the installation of a "workbench" for the testing of both techniques and modular components.

This PACS workbench at MIR utilizes a broadband CATV-based local area network (LAN) to support both analog and digital picture transmission. The network serves a twelve-story building, which houses the radiology division, as well as several clinical and laboratory areas remotely located within the medical center. Custom picture processing is supported by a host computer/image processor located at the cable head-end: The archive function is realized with rotating magnetic media managed by the host computer. A link to the existing radiology patient management system has been established to facilitate a realistic environment for clinical experiments.

PICTURE NETWORK

The picture network component of our PACS workbench supports both conventional analog picture transmission and digital picture transmission modes. The geographic distances spanned by the network are on the order of thousands of feet, thus suggesting its categorization as a local area network (LAN). Also

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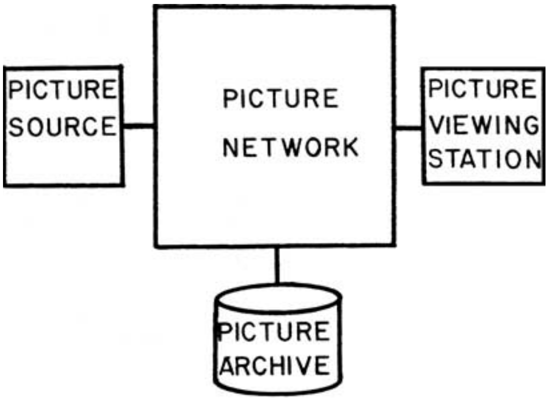

Fig 1. Canonic Elements of a Picture Archiving and Communication System (PACS).

paralleling the development of LAN commercial offerings emphasis has been placed on definition of the first three layers of the International Standards Organization (ISO) Reference Model.[2]

The *physical layer* is implemented using broadband CATV coaxial cable technology. Economies of scale have already been achieved for this technology due to the large production volumes involved in the installation of cable networks which support multi-channel television broadcasts. Frequency division multiplexing makes possible multiple channels on a single physical cable. A dual-cable structure[3] provides a nominal 400 MHz of bandwidth on both the "inbound" and "outbound" paths. The logical topology of a dual-cable tree structure is shown in Figure 2. The inbound and outbound coaxial cables are installed as a pair. Transmission is initiated by a device coupled to the inbound cable (for example, the analog T.V. signal labeled 1); the signal is routed to the *head-end* and distributed to receivers via the outbound cable (as shown by tracing the signal path labeled 1). Additional utility has been provided by subdividing the outbound cable bandwidth. A subsplit of the bandwidth (5-30 MHz *inbound* and 50-400 MHz *outbound*) along with a channel converter facilitates the use of currently available digital modems ($\leq$19.2k bps) which transmit in the low frequency bands (T) and receive on the higher frequency bands (H). The low-speed digital modems support remote access of the picture processing/archive resource. A high-speed signal path is labeled 2.

The topology of our current picture network is shown in the block diagram of Figure 3. The main trunk system spans the twelve floors of the MIR building. The cable head-end is located on the twelfth floor adjacent to the computing resources which support an operational patient information system. Dual-cable feeders service remote clinical and laboratory areas. Considerable spare capacity has been designed into the basic system to allow for expansion as the needs for use of the workbench evolve.

Extension or expansion of a broadband cable LAN which requires insertion of new components may necessitate "rebalancing" the gains and equalizations of the amplifiers. A software tool has been developed to assist in this calculation. The software is written in VAX BASIC and operates under VMS on a VAX-11/750. Component specification tables and connectivity tables are provided as input. Studies to verify and refine the accuracy of the tool are in progress.

We remain committed to wide band transmission (>1 Mb/s) for picture service.[4] The utility of the standard 6 MHz bandwidth television spectrum allocations must be balanced against the achievable bit-rates. Nominal ratios of between 0.5 bits/hertz and 2 bits/hertz are achievable. Modems of 1 Mb/s or higher rates are available but remain rather expensive. Theoretical studies are in progress to analyze, and simulate alternatives for both the *picture link layer* and the *picture network layer*.

PICTURE PROCESSING AND ARCHIVE MODULE

The picture processing and archive components of the PACS workbench are centralized. A host machine with ample primary storage for large array manipulation, rotating magnetic memory for archive experiments and a versatile image processing/display system are the key elements contributing to the flexibility of the workbench facility. The specific system implementation utilizes a VAX 11/750 with 2 Mbytes of primary storage, and two 300 Mbyte disks of secondary storage allocated for picture archive. A Gould-DeAnza IP8500 raster graphics image processing system with a 1024×1024 byte display memory is coupled to the VAX via a high

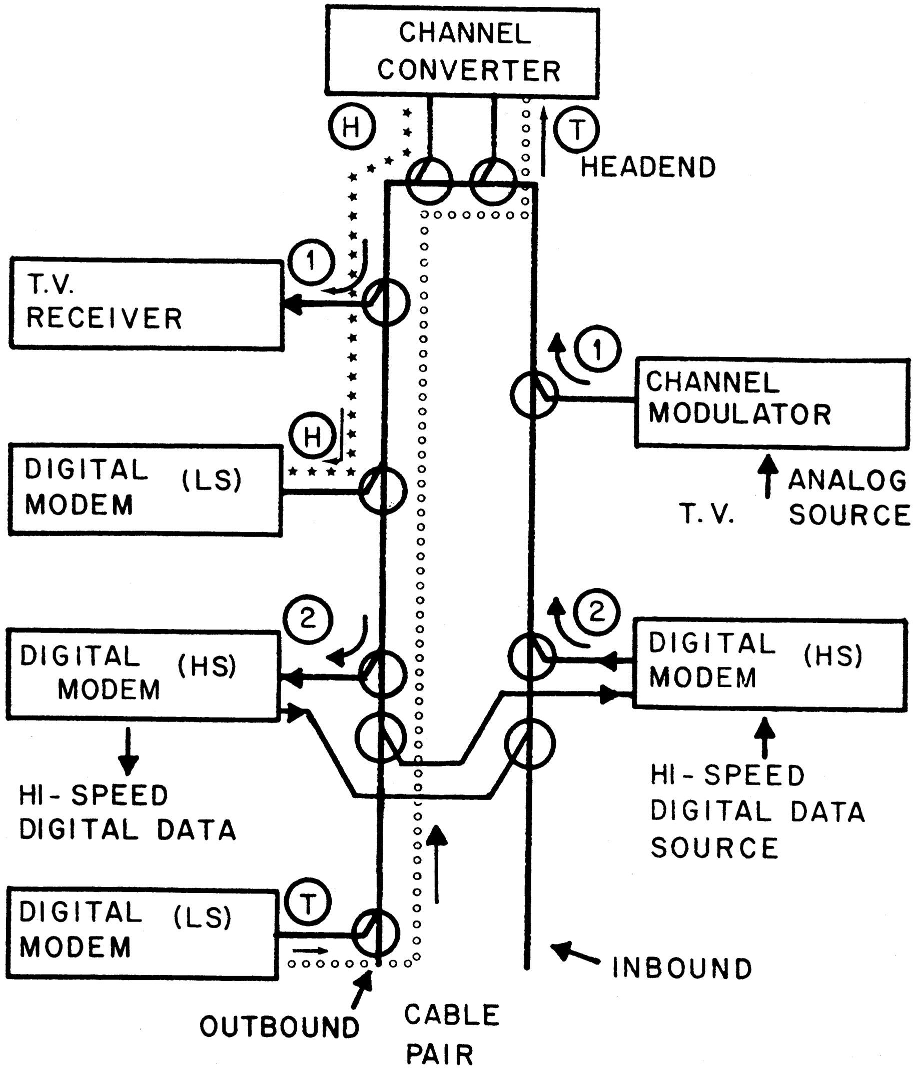

Fig 2. Logical topology of a broadbased CATV-based local area network. A subsplit of the frequency spectrum (5–30 MHz/50–400 MHz) permits full-duplex transmission for modest bandwidth digital modems connected to the outbound cable. A low-speed (LS) simplex path, channel Ⓣ to converter (○) channel Ⓗ to receiver (*) is shown. The high-speed (HS) simplex example is labeled 2.

bandwidth parallel port. The VAX 11/750 is one node of a seven-computer network operated at the MIR to support an extensive patient information system.[5-8] Utilizing DECNET protocol on a 56k bit communication link, a VAX user has access to any available patient biographical information, information pertaining to specific exams performed, and diagnostic radiology reports. In addition, if images are available for a specific patient visit they can be retrieved and displayed using the IP8500. Video output from the IP8500 is distributed over the broadband picture network giving a user with a VAX terminal and a separate TV monitor remote access to the image database.

A pilot picture database has been developed at MIR for the purposes of demonstrating the utility of such a system, providing a resource for selected projects of limited scope, and refining ideas and techniques for picture storage formats, picture distribution, and picture presentation methods. Selected images from several modalities have been acquired and stored on the system using batch mode techniques. These include digitized radiographs, CT scans, DVI images, ultrasound scans, and nuclear medicine

Table 1. Examples of parameter sets used to describe some representative picture types. Offset and scaling factors are helpful to utilize the full range, but not exceed the eight bit per pixel in the IP8500 image memory

	# of Pixels					Display Mode*			
Type of Image	x by	y	Bytes per Pixel	Blocks per Header	Images per File	t/b	b/t	Offset	Scaling Factor
Digitized radiographs (1 spf)	512	512	1	1	1	X		ϕ	1
CT scans (1/2 spf)	256	256	2	1	1		X	−512	1/8
Ultrasound scans (1/4 spf)	256	256	1	ϕ	1	X		ϕ	4
Nuclear medicine study (1/32 spf)	64	64	2	4	32		X	ϕ	1

*t/b = top to bottom
b/t = bottom to top

studies. A picture management system, (separate from the current patient information system) is maintained on the VAX 11/750. A set of parameters arranged as a table describes each of the images in the database. Table 1 shows some parameters for four example modalities. These parameters allow for efficient data packing in the archive through utilities that are transparent to the user. A brief description of the images stored for each study and the parameters associated with the image storage format may be reviewed by the user. The image retrieval utilities give the user options to expand or condense pictures and direct them to any portion of the IP8500 display memory.

DISCUSSION

The PACS workbench at MIR has been designed and installed primarily as a laboratory for picture networking experiments. Our broadband picture network utilizes frequency division multiplexing to allow study of concurrent analog and digital transmission.

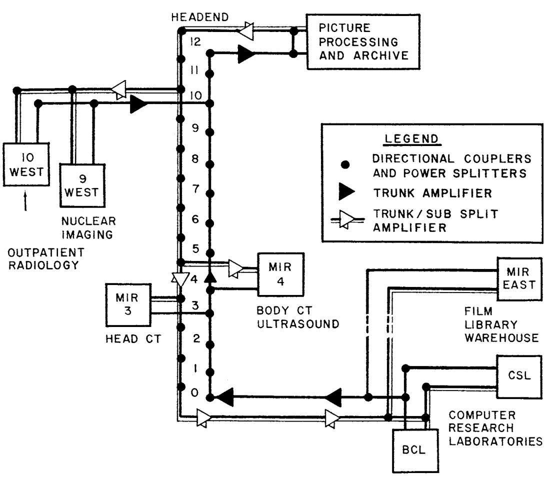

Fig 3. PACS workbench picture network block diagram illustrating topology of the MIR broadband local area picture network.

Analog Picture Distribution

Several ways that real time analog distribution of video images can be useful in an active radiology department have been identified.

1. A number of imaging devices, such as CT and ultrasound, produce video output as the primary method of image display. By adding a modulator to the video sources, these clinical studies can be distributed on the broadband picture network system. CT studies can be viewed and evaluated from a remote location; fluoroscopy performed in the operating room can be reviewed in the radiology department. Video distribution is not limited to standard NTSC signals; technology for modulating and broadcasting high resolution 1000 line video is available. Video conferencing is possible for the discussion of studies which require consultation. A radiologist in his office can have access to each of the image sources broadcast on the cable system, and hence it is possible for him to provide consultation on several cases from a single location.

2. The local transfer of digitized images from an archive to a digital picture buffer can be accomplished at very high rates and then converted to a standard video signal for distribution using inexpensive commercially available equipment. The image can then be viewed by conventional television receivers served by the picture network. By linking image planes from the IP8500 through modulators to the video

distribution network, it is possible for anyone with a computer terminal and a TV receiver within reach of the picture network to retrieve and process images stored in the picture archive.

Analog video distribution of images may prove to be suitable in two situations; a) when the original image (CT or nuclear medicine for example) does not contain more information than can be faithfully represented with the allowable video bandwidth, b) when a reduced resolution image is adequate for the purpose of review. Normal resolution video images are not likely to be satisfactory for the primary interpretation of most standard radiographic images, but once a primary interpretation has been made, the ability to recall that image immediately for review at key locations throughout the hospital has important medical value.

Digital Picture Distribution

Digital transmission of images to and from remote locations is critical to preserve data quality. Broadband coaxial cable technology now commercially available offers limited digital capability: a) low-speed multichannel serial transmission, most suitable for the support of standard computer terminals, b) high-speed serial digital transmission (up to 6 Mbits/sec) within a single TV channel and c) high-speed serial transmission (>10 Mbits/sec) utilizing more than one TV channel. In the near term, products being developed for metropolitan area networks promise high-bandwidth components at modest cost.[10] Yet while broadband cable provides a flexible inexpensive laboratory for evaluating various transmission protocols, it is clearly not the only alternative which is suitable for PACS. Microwave, fiberoptic and baseband cable offer digital transmission alternatives which are under study.

Archive

The 600 megabytes of rotating magnetic storage which currently serve as the archive for our PACS workbench provides a temporary implementation. Even this limited archive has proved capable of serving a useful clinical function. The most clinically relevant radiology images are those which are only a day or two old. Six hundred megabytes of storage provides for archiving 2400 SPF of uncompressed image data. Thus, for example, this prototype system makes it possible to store and retrieve several days worth of CT scans from any point in the radiology department. We anticipate the introduction of larger, lower cost digital archive media, both optical and magnetic, in the immediate future. Proper organization, design and distribution of these image database modules as well as the evaluation of image compression techniques,[9] can be facilitated using the PACS workbench.

Image Acquisition and Display

The analog picture network can be used for image acquisition. A centrally located video digitizing system makes it possible to acquire many of the images distributed on the CATV system. Averaging subsequent frames provides a simple technique for noise reduction. This has proved to be an inexpensive and readily accessible method for digitizing a variety of image sources, subject to the resulting limitation of image quality. Picture transport facilities will soon be augmented by digital data transmission channels.

The effective distribution of digital images will be accelerated by the development of low-cost digital buffer/display modules. Satisfactory replacements for the x-ray view box must be developed with adequate techniques for representing multiple images from a single study. Questions to be addressed by use of the workbench include: image resolution, display design, the usefulness of zoom and scroll capability, and the quantitative aspects of image processing techniques.

CONCLUSION

A major goal at the Mallinckrodt Institute of Radiology has been the development of a workbench for the evaluation and assembly of the components of a PACS network. It has been our intention to provide suitable tools to model, study, build and evaluate the various components for network, archive and display. Many of the tools for the workbench are now in place. Components of a PACS are being developed and installed. It does not leap ahead to any one solution, but rather, gathers an important commodity-experience in a real clinical environment. It is too early for us to say confidently what the complete architecture of a picture archiving and communication system should be. A measured, scientific approach is called for in an environment where there are the resources and the inclination to evaluate several alternatives.

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