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TELERADIOLOGY, TELECONFERENCING, AND TELECONSULTATION

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ABSTRACT

The University of Virginia is building a ATM-based network to support the exchange of radiographic images between the Uva hospital, UVa outpatient facilities, a rural hospital, Walter Reed Army Medical Center, and the George Washington University Medical Center. The network will connect several digital imaging modalities (e.g., CT, MRI, x-ray, nuclear medicine, ultrasound) and a variety of high-performance computers with high-resolution displays to a commercial PACS system. Our research contribution will be the development of new software to support image exchange and display, plus live digital teleconferencing with real-time tools for image annotation.

1. THE PROBLEM

In a conventional hospital with conventional imaging modalities such as computed tomography (CT) and magnetic resonance imaging (MRI), patients are scheduled on the various scanners (e.g., one per hour per MR machine), technicians instruct the patient and supervise the scan, and the resulting images are printed on radiographic film using a laser film printer. Depending upon the physical proximity of the scanners to the radiology department, either a staff radiologist is assigned to one or two machines to provide near-real-time interpretations of the resulting imagery, or else the film output is returned to a centralized reading room for analysis on a non-real-time basis.

The former situation results in low utilization of the radiologist, since interpreting an MR image may take five minutes but the scanner itself only produces one image set per hour. Increasing the radiologist's utilization in this situation requires assigning him or her to read the output of multiple co-located machines (if there are any) or having the radiologist walk a continuous circuit among physically distant machines. The latter situation of returning the films to a central location introduces a long delay (typically one day) between the time the image is acquired and the time its interpretation is available to the referring physician. In addition, the latter case introduces an increased probability that either the images or their interpretation will be lost, delayed, or misplaced since it involves the physical transportation of film and paper from place to place within the hospital.

Yet another problem arises when a research hospital such as UVa attempts to support the medical needs of the surrounding community, or attempts to provide subspecialty support to the defense medical services. For lack of an ability to share images and engage in real-time consultation, either images are physically exchanged (e.g., film jackets sent by overnight courier) or else the radiologist becomes a "circuit rider," physically driving from place to place to read films and provide consultative support. We can reduce this aspect of health care costs by moving the images rather than the people, and providing the electronic consultative tools which permit effective collaboration without physical co-location.

2. THE SOLUTION

A Picture Archiving and Communications System (PACS) will provide digital data storage and retrieval, radiographic display stations will provide high-resolution display capabilities for on-line image interpretation, and an Asynchronous Transfer Mode (ATM) network will interconnect the image acquisition, image storage, and image display hardware. The ATM network will provide seamless connectivity among the various devices: within the hospital it will function as a local area network, shuttling images electronically from specialist to specialist as needed; within the city it will function as a metropolitan area network, connecting outlying facilities (e.g., Northridge clinic, rural hospital) to the hospital's information infrastructure. Via commercially provided fiber optic circuits it will operate as a wide area network, connecting UVa to the Walter Reed Army Medical Center and the George Washington University

Medical Center, and supporting real-time image exchange and live teleconferencing between the institutions. Finally, with the addition of satellite channels, the network will support image acquisition from places not served by fiber optic lines (e.g., accident scenes, front lines of war).

3. THE BENEFITS

Our goal is to build a telemedicine capability which will allow radiologists to quickly and accurately acquire digital images, engage in live teleconferencing with other specialists, and provide rapid and accurate interpretation to the referring physician. Our facility will be a dual-use activity, serving the civilian needs of the UVa environment and providing consultative support to the military. We see the following opportunities to improve the quality and availability of health care while at the same time reducing overall cost:

(1) *Geographic independence.* The radiologist rarely needs to see the patient, so there is no advantage to having physical proximity between the radiologists and the imaging hardware if the images can be moved electronically. The ATM network will interconnect the MR and CT scanners with the PACS and the image display stations. Display stations need not be centralized, but instead are deployed wherever necessary to make them convenient to people. Any stored image may be accessed from and displayed on any appropriate viewport, thus freeing the radiologist from any proximity restrictions from the PACS or the imaging systems. Likewise, moving the images electronically eliminates the need for "circuit riders" who drive from one outlying location to another.

(2) *Increased physician utilization.* If MRs process one person per hour and interpretation of the output requires five minutes, then one radiologist can process the output of several MRs without undue stress. Physician utilization can go up and staffing requirements can go down with no loss in quality.

(3) *Faster interpretation.* The digital images produced by the scanners will be available in the PACS moments after the scan is completed. By the time the patient is released from the scanner and returns to his primary physician, the image interpretation could be completed and added to the patient's hospital record, ready for retrieval by the referring physician. This should help with patient compliance by eliminating the situation where the patient must make two trips to the hospital, one for the imaging procedure itself and a later one to discuss the results.

(4) *No lost data.* The digital images themselves, as well as the textual interpretation of those images, are all moved electronically with negligible chance of loss. The PACS system stores the images and the Hospital Information System (HIS) stores the interpretation as part of the patient's record. Images can be recalled at any time for rereading, additional analysis, comparison with a patient's previous images, or for research purposes such as compilation of an atlas for a specific disease. By making the images electronic, we trade the cost of film for the cost of storage, but we gain the capability to reproduce, distribute, and analyze the image any number of times at no incremental cost.

(5) *Remote consultation.* Images collected at Walter Reed (either from imaging equipment located there or transmitted via satellite from remote locations) can be transferred to UVa, or vice versa, a clear advantage in time of conflict when transient loads might overwhelm the Walter Reed staff. The inter-exchange carrier (US Sprint) can provide connectivity among any sites reachable by fiber optic cable. For truly remote sites (e.g., deserts, islands, or war fronts) an ATM-based satellite channel (furnished by the military) can be used to establish connectivity.

4. THE RESEARCH

This project will sponsor research in four major areas:

(1) *High resolution image presentation.* Our ATM network will connect our digital image sources

(initially CT and MR, but expanding within two years to include nuclear medicine, ultrasound, digital fluorography, diagnostic radiography, mammography, etc.) to the PACS. Now, instead of handling films, the radiologist will retrieve an image set from the PACS for display on a radiographic display station suitable for the type of image being analyzed. Display capabilities will vary by resolution (e.g., 256x256x12 for MR, 512x512x12 for CT, 512x512x6 for ultrasound, 1Kx1Kx10 for digital fluorography) and we will experiment with the user interface (e.g., keyboard, mouse, light pen, touch screen, voice command) to determine which combinations are most effective.

We believe that the required processing power and display technology will all be available within the time frame of this project. Therefore, we will concentrate on those research areas which, without additional work, will not be available in the near future:

(a) Communications protocols. Although the proposed ATM network is very fast (155 Mbps), the typical communications protocols used on LANs and WANs (e.g., TCP/IP, ISO TP4) are not. One outgrowth of our past research is a new communications protocol, called the Xpress Transfer Protocol (XTP), which has all the functionality of TCP or TP4, plus some very important added features which are especially attractive for multimedia applications. XTP's unique features include transport layer message prioritization, rate and burst control, multicast, and latency control. XTP does not impose its own network addressing scheme, so it can operate over its own private LAN, or across the Internet, or across an OSI-compliant network.

(b) Privacy and security. The electronic transmission of medical data requires that data be available to authorized persons only. We will be investigating the use of data encryption and authorization protocols to assure that medical data remains private. Of particular concern is the fact that, given a secure system which provides one image per minute and a non-secure system which provide one image per second, human users will always opt for the latter. Thus we will be looking at real-time encryption/decryption hardware, such as the new Clipper and Capstone chipsets sponsored by the U.S. government, as a part of the solution.

(c) Software reliability. The user services we propose are predominately provided by software. For instance, when two physically separated physicians use marking tools to annotate an image, how can they be assured that they are each seeing the identical image with the identical markings? We will be using modern software engineering, validation, and reliability techniques as we develop our software-based services.

(d) User/machine interface. The type of computer input devices commonly used by computer scientists are unlikely to be appropriate for physicians. We will experiment with a variety of input devices (e.g., keyboard, mouse, light pen, touch screen, voice input) to determine which methods are most effective.

(2) Real-Time Teleconferencing.

To the maximum extent possible, the radiographic display stations will be COTS hardware running COTS software. Where COTS software does not yet exist (e.g., 3-D reconstruction, live teleconferencing, electronic blackboarding), we will work with our commercial partners to assure that all technology developed by this project eventually becomes a COTS product.

One example of this procedure is our plan to develop a real-time teleconferencing capability than runs alongside the image display/manipulation software. With the click of a button the physician can open a teleconferencing window to permit simultaneous, bidirectional, audio/video communication between two parties. For instance, the referring physician and the consulting physician, physically located at separate sites, may each access and display a common image on their respective workstations. Then they may open a teleconference window to discuss the patient's history. We will provide full color, full speed (30 frames/sec), TV-style video and full-bandwidth digital audio (64 Kbps) so that each physician sees and hears the other in real time. Having established a teleconference and having identified one or more images to review, the physicians next use pointing tools (see next section) to identify areas of interest on the images.

Note that a teleconferencing service is also the basic service required for dynamic images such as ultrasound or EKGs or digital fluorography. Our workstations will support not only static images, but also dynamic ones.

At this moment we can transmit 320x240x8 color images across a local area network from any NTSC video source to any file storage device located anywhere on the network; image access, storage, retrieval, and display all operate in real time, i.e., at the 30 frames/sec rate of NTSC audio/video, using standard JPEG compression. The research issues which now arise include: (a) increasing the resolution of the image, (b) removing the file system to make the image transfer interactive, and (c) determining what type of compression, if any, is necessary or desirable. While an ATM network operating at 155 Mbps will clearly transmit images without compression, today's desktop processors can not source or sink information at that rate. Compression algorithms are probably required to reduce the bandwidth required from the network to the display, and it is our task to determine how much compression is scientifically permissible and how it should be implemented.

(3) Electronic Blackboarding.

The power of the teleconferencing tool becomes apparent when one envisions two physicians being able to view, examine, isolate, and point at image features, knowing that both physicians are seeing the identical image and annotations. This will be accomplished by using an electronic blackboard in which the image itself (either static or dynamic) becomes the surface on which the physician will write. Using a mouse or light pen or even a touch-sensitive screen, the physician will be able to draw arbitrary shapes (e.g., circles, arrows) on the image and have that overwriting impressed identically on the other physician's image. The blackboard will be bidirectional so that both physicians may point simultaneously (e.g., using different color lines).

The research issues here are: (a) how best to acquire pointing input (e.g., mouse, light pen, touch screen), (b) how to overwrite a moving image (e.g., ultrasound), (c) how to synchronize the images and the overwriting in the two workstations, and (d) what other tools (e.g., zooming) are necessary to facilitate rapid and accurate information transfer.

(4) Secure Access by Referring Physician.

In a typical referral, the referring physician orders a radiographic procedure and the radiologist interprets the result, with that result typically being a textual recitation inserted into the patient's hospital record. Therefore, the referring physician always needs access to the interpretation and, less frequently, may wish to see the diagnostic images themselves. Retrieval of the actual images by the referring physician may be useful for prognosis (e.g., how much has the tumor grown in the past six months?) or for patient education (e.g., here is the tumor which we will surgically remove).

The research issues involved are: (a) privacy and security of the patient record and image database, (b) privacy and security of data during transmission, potentially across long distances, (c) authorization procedures to permit a physician to view data, and (d) procedures to determine if a potential viewer is an authorized viewer. While many data encryption/decryption algorithms are well known, it is a research issue to determine how to encrypt and decrypt data in real time to avoid creating a bottleneck in either the database or the network. Similarly, it is a research issue to determine how to enforce viewer authentication without creating an undue burden on the physician.