A New Approach to Teleconferencing with Intravascular US and Cardiac Angiography in a Low-Bandwidth Environment[1]

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A common problem in radiology teleconferencing is the difficulty of transmitting a large volume of data over communication channels with a relatively low bandwidth. Although videoconferencing systems are easily implemented, they generally require lossy image compression, which can lead to significantly altered findings. A teleconsultation and teleconferencing system was developed that uses a store-and-forward approach with high-quality dynamic medical images obtained with intravascular ultrasonography and cardiac angiography. The system allows use of high-resolution dynamic images while preserving their original quality and can be adapted to different clinical applications with varying requirements. The system involves a standard preparation procedure to transmit images from one location to another prior to a conference; once the conference starts, however, the system becomes fully automatic and synchronizes the display and manipulation of images in both locations without further image data transmission. In general radiologic applications, the system is superior to videoconferencing systems in that it does not require specialized hardware and dedicated high-bandwidth communication links. Further investigation with large-scale studies will be required to determine whether these benefits can lead to more widespread acceptance of such a system in routine clinical practice and whether teleconferencing itself can enhance the effectiveness of clinical procedures.

Abbreviations: DICOM = Digital Imaging and Communications in Medicine, LAN = local area network, LCD = liquid crystal display, MPEG = Moving Picture Expert Group, PC = personal computer, VHS = Video Home System

Index terms: Computers • Computers, diagnostic aid • Computers, multimedia • Digital imaging and communications in medicine (DICOM) Radiology and radiologists, design of radiological facilities • Teleradiology

RadioGraphics 2000; 20:1495–1503

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Introduction

The American College of Radiology broadly defines the term *teleradiology* as "the transmission of radiological images from one location to another for the purpose of interpretation and/or consultation" (1). In this article, we use the term *teleconsultation* to describe a process during which two or more physicians hold a consultation regarding doubtful or problematic cases over a certain distance by means of telecommunication. Teleconsultation consists of two components: the exchange of multimedia documents (eg, images, video, text) and the interactive verbal and graphical discussion of the related findings and their consequences. In addition, we use the term *teleconferencing* to describe a consultation in which both parties present cases as peers, in contrast to the asymmetric physician-consultant relationship usually seen in consultation. The system described in this article was originally designed for teleconsultation but has been extended to include teleconferencing.

We use the term *dynamic images* to describe a sequence of images displayed in rapid succession so that the human eye perceives continuous motion. The most commonly used dynamic imaging modalities in radiology are ultrasonography (US) and angiography. We prefer the term *dynamic images* to the term *video* because the latter is very closely associated with the analog video format used in television and videocassette recording equipment. Dynamic angiographic images, for example, are not necessarily compatible with this format.

Conferences and consultations are a natural part of clinical practice. For consultations requiring the presentation of materials to a specialist in a more or less distant location, it has been traditional to use regular mail or couriers or to travel to the conference in person. Teleconferencing and teleconsultation might help reduce the time and cost associated with these procedures. However, although teleconferencing and teleradiology systems have been available for a number of years, they are still not as widely accepted by general radiologists for high-quality dynamic imaging as was anticipated at their inception.

A common problem in radiology teleconferencing is that a large amount of data must be transmitted, but the available communication channels have a relatively low bandwidth. At present, increasing the bandwidth (eg, using an asynchronous transfer mode network) is often not an option due to high costs and limited availability of high-bandwidth connections. Two basic strategies exist to avoid this bottleneck. If the images need to be transmitted in or near real time, image compression—possibly resulting in a loss in quality—must be applied. If a time interval between image transmission and display is acceptable (eg, if the conference is scheduled to take place after the examination), the images can be transmitted in advance (eg, overnight) without compression. This procedure is often referred to as store-and-forward teleradiology.

For static radiologic images, store-and-forward teleradiology is a well-established method. For dynamic images, most solutions published to date have used real-time transmission by means of videoconferencing systems, which digitize analog video signals and send them digitally over the network. These systems are easy to set up and use; however, they invariably require lossy image compression, unless costly high-bandwidth networks such as asynchronous transfer mode are used. This compression can result in significant alteration of the findings (2). Concerns about compromised image quality might be one of the reasons why teleconferencing with dynamic images is not yet widely accepted for clinical procedures.

In this article, we present a prototypical system for store-and-forward teleconferencing with dynamic medical images. We outline implementation details, present preliminary clinical experience, and discuss the advantages and disadvantages of such a system.

Background and Objectives

The authors' institutions operate two major academic medical centers 30 miles apart. Cardiologists in both centers use intravascular US, a relatively new imaging technique for the planning and assessment of coronary intervention (3). As part of a cooperative effort, educational conferences involving participants from both centers are held on an irregular basis. During these conferences, both sides present recent interventional cases studied with intravascular US and cardiac angiography and discuss possible strategies, interpretations, and outcomes.

Thus far, these conferences have been held using conventional methods. Cardiologists travel the 30 miles between the centers by car and transport the materials on Video Home System (VHS) tapes and 35-mm celluloid film. Our goal was to develop a high-quality teleconferencing system that would not only reduce travel time and facilitate the conferencing process but also allow a level of quality and interactivity similar to that possible with conventional methods. Initially, the installation of a videoconferencing system was discussed. However, it became evident during these discussions that the image quality requested by the cardiologists could not be achieved with the available network bandwidth (two T1 lines [1.5 Mbits/sec each]).

As we looked for alternative solutions, it became obvious that a store-and-forward solution would be ideal because the schedule of planned conferences allowed sufficient time between image acquisition and the conference. Because we could not locate a system for store-and-forward teleconferencing with dynamic images, we decided to design our own system based on an existing teleconsultation system for static radiologic images (4).

Materials and Methods

Images

We used images obtained with two modalities: cardiac angiography and intravascular US. The intravascular US studies were always recorded on S-VHS videotape in National Television System Committee format. The cardiac angiography studies were recorded digitally in the Digital Imaging and Communications in Medicine (DICOM) format (5) (512 × 512 pixels, 8-bit gray scale, lossless compression). DICOM-compatible cardiac angiography studies were stored on recordable compact disks or could be retrieved electronically through a local area network (LAN).

For materials to be used in a digital conferencing system, they must be available in digital format. Although the DICOM cardiac angiography studies were already recorded digitally, we had to convert the analogous intravascular US sequences. The video signal was digitized and compressed into Moving Picture Expert Group (MPEG)–1 format (352 × 240 pixels, 24-bit color, lossy compression) (6) using a personal computer (PC) with a video digitizer board (Data Translation, Marlboro, Mass).

Hardware and Network Architecture

The conferencing system consists of two PCs with Intel Pentium II 400-MHz processors, 128 Mbytes of RAM, and 10 Gbytes of disk storage (Dell, Round Rock, Tex). The system at one location is equipped with a liquid crystal display (LCD) projector (1,024 × 768 pixels) (Proxima, San Diego, Calif), whereas the system at the other location includes a regular 21-inch cathode ray tube monitor for viewing. Both systems are equipped with Matrox Millennium II graphic adapters (Matrox Graphics, Toronto, Ontario, Canada) that provide real-time video scaling functions. For fast, lossless decompression of DICOM images, we used a commercial high-performance decompression library (Pegasus Imaging, Tampa, Fla).

The conferencing systems are installed in the conference rooms of the two cardiology departments. The systems are connected to the LAN (100 Mbits/sec) of their institutions, which are linked by two T1 lines (1.5 Mbits/sec each). The LAN also provides a connection to the DICOM catheterization laboratories and to the PC used for image digitization. For voice communication, we simply use a standard conference telephone equipped with a speaker. Digital voice-over-Internet solutions that we tested as possible alternatives were difficult to configure and provided inferior sound quality.

Software Architecture

A large number of technologies and software products are available for displaying dynamic images. With regard to medical images, these products may be regarded as either general-purpose or specialized. General-purpose video software can display a large variety of digital video formats (eg, MPEG, AVI [Microsoft, Redmond, Wash], QuickTime [Apple Computer, Cupertino, Calif]) (6). In contrast, specialized medical viewers with enhanced functionality are available for DICOM images. Architectural differences between the two groups make it difficult to integrate them in a single application.

For our project, however, it was desirable to use a single display architecture that could be used for both general-purpose video and DICOM multiframe images. Because the DICOM format is relatively simple compared with advanced digital video formats, we decided to start with a general-purpose video tool kit and then add DICOM support, rather than vice versa.

Because our system was designed for the Windows NT platform (Microsoft), we used the Microsoft DirectShow technology. DirectShow is a general-purpose multimedia tool kit that uses a filter graph model to build various kinds of multimedia applications (7). We found DirectShow to be ideally suited for our purpose because (*a*) it utilizes PC hardware resources very well and provides high-quality images, (*b*) it supports a large number of common video formats and can easily be extended for specialized medical formats (eg, DICOM), and (*c*) it provides a high level of control over the playback process (eg, frame-accurate positioning, slow motion, zooming/panning).

We added the dynamic image capability to the teleconsultation system described earlier. This system provides basic teleradiology services such as store-and-forward file transmission and a remote control component with real-time dual cursor functionality that are compatible with the dynamic image component. The system uses the DICOM protocol for image transmission. We implemented a private service-object-pair class that allows transmission of the MPEG video files, which are not DICOM-compatible.

The dynamic image component provides the user interface for the DirectShow pipeline (Fig 1). The pipeline is dynamically assembled from the available filters, depending on the type of media to be presented (Fig 2). This is transparent to the application, so that for the dynamic image component there is no difference between DICOM angiography and MPEG US. DICOM sequence files are handled within the DirectShow pipeline with a custom filter that we developed.

During the conference, the dynamic image component communicates with its counterpart at the remote site so that both can display the same image sequence in synchronicity. Start/pause commands, display parameters, playback speed, and sequence position are transmitted over the network and used to generate the same output on both computers. This works in both directions, so that either side can assume control at any time.

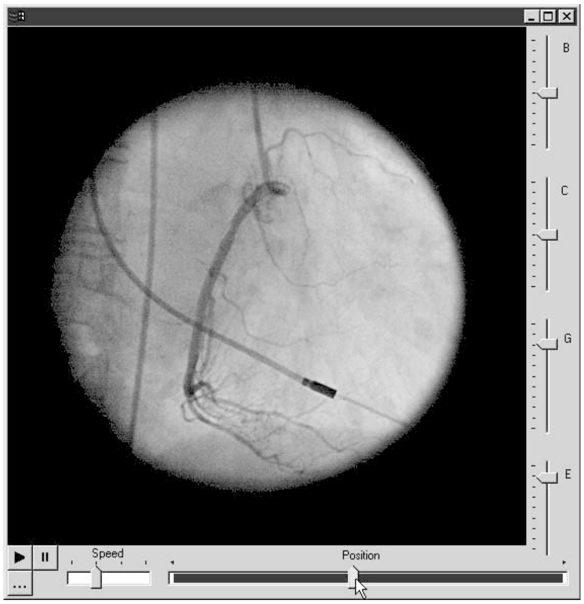

Figure 1. User interface for the DirectShow pipeline. The controls include play/pause (buttons in lower left-hand corner), playback speed, sequence position, brightness (*B*), contrast (*C*), gamma correction (*G*), and edge enhancement (*E*).

The software package can be set up and configured on any PC within minutes if sufficient hardware resources are available.

Teleconferencing Procedure

The teleconferencing procedure consists of three phases: data preparation, data transmission, and conferencing.

Data Preparation.—DICOM sequences are transmitted over the LAN to the teleconferencing workstation, and analog videotapes are digitized. Because digitization of analog materials relies on time-consuming manual operation, DICOM-compatible modalities are to be preferred because they greatly simplify and automate the process.

Data Transmission.—Prior to the conference, the necessary documents are exchanged between the two locations over the wide area network. This process may take a considerable amount of time depending on the available network bandwidth; however, it is fully automated in unattended mode and may, for example, be performed overnight. The selection of materials and the start of transmission are achieved in a matter of minutes. At the end of the data transmission phase, the workstations in both locations possess identi-

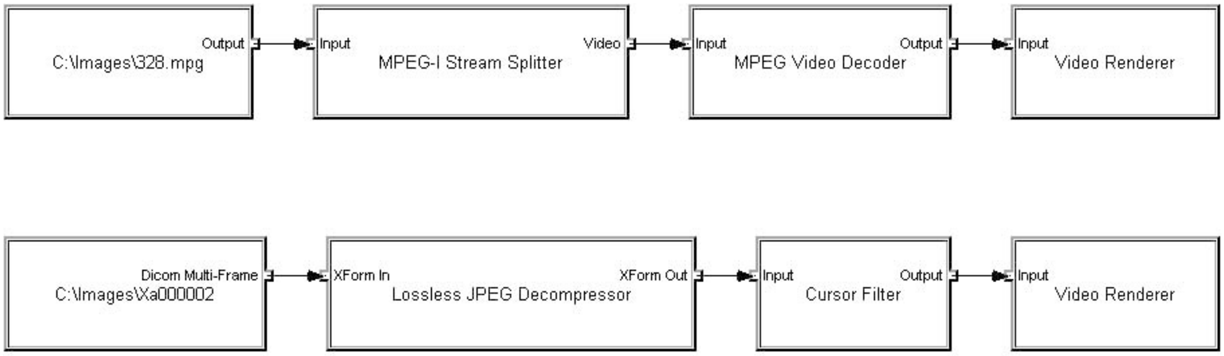

Figure 2. DirectShow pipelines. The filter graph for MPEG-encoded video sequences (top) consists of an MPEG splitter, a decoder filter, and a video renderer (Microsoft). The filter graph for the DICOM angiography files (bottom) includes the DICOM multiframe filter and the JPEG decompressor filter provided by the authors as well as another custom filter (cursor filter), which embeds the remote pointer into the video data.

Conferencing.—During the conference, the workstations operate on identical sets of locally stored image data so that only the control information has to be exchanged. Thus, the bandwidth requirements during the conference are very low. Even a dial-up modem (33.6 Kbits/sec) would be sufficient to maintain real-time communication.

It is assumed that during a conference session, the time available for image presentation is very limited. Therefore, it is necessary to spend some time in preparation to ensure that all images and image sequences are immediately available at the time of the conference. This is very similar to preparation for traditional clinical conferences, during which all needed materials are to be collected. The preparation time required with our system is comparable to that required for a conventional conference.

Results

Laboratory Results

We performed a number of laboratory tests to objectively assess image quality and system performance. For the DICOM images, we subjectively compared the image quality produced with the teleconferencing system with that produced with the commercial DICOM viewing software running on the same computer. As expected, there was no noticeable difference in image quality because the DICOM images are lossless compressed. However, there was quality degradation between the DICOM images and the original images because the modality scans the images at 1,024 × 1,024 resolution and subsamples to 512 × 512 resolution for export to DICOM. This is a limitation of the DICOM interchange format rather than the teleconferencing system.

The MPEG video sequences were compared side by side with the original S-VHS tapes played on a professional videocassette recorder. There was noticeable quality degradation caused by reduction of resolution from about 800 × 420 to 352 × 240 and compression-induced artifacts. However, because the spatial resolution of the intravascular US technique itself is rather poor, the cardiologists found that the visibility of anatomic details and pathologic findings such as calcification and soft plaque was still adequate for conferencing purposes. We did not verify these results with a formal quality evaluation because they are consistent with the results from other studies that compared MPEG-1 with S-VHS for echocardiography and found major discrepancies in only 2.7% of cases (8).

The frame rate for the MPEG-1 video was 29.97 frames/sec, which was identical to that for the original sequence. For the DICOM images, we could match the 30-frames/sec frame rate of the original sequence only when the optional image edge–enhancement algorithm was deactivated. With active edge-enhancement, the maximum frame rate was 22 frames/sec, which could

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