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A TELERADIOLOGY SYSTEM BASED ON COLLABORATORY TECHNOLOG

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ABSTRACT

A novel Java-based teleradiology system for Internet is presented. Using this system, an on-call off-duty radiologist can make diagnoses and consultations easily by reviewing the transferred images at home. Its image accessibility also allows us to assist an affiliate rural hospital without a full-time radiologist. All clients of this system are designed coincident. Their users may retrieve images, manipulate images and perform remote consultations. For remote consultation, screen synchronization is achieved by the command-passing technique and local command execution to reduce the network bandwidth and transmission time, and user interaction goes through a synchronized indicator for indication and dialog windows for conversation. Since Java programs may run on heterogeneous platforms, the need for system maintenance and user training can be minimized.

Keyword:collaboratory, teleradiology, PACS, Internet, JAVA

1. INTRODUCTION

Imaging is very important in current medicine. Advanced technologies produce state-of-the-art high-resolution images that enable radiologists to play an important role in the diagnoses and treatments. The complicated physics and anatomy are needed for reading medical images, which urges the clinicians to consult radiologists for further management of patients. To solve the problem of consultation, especially in remote rural areas and congested inner cities, teleradiology was introduced in 1972 (1). Formerly, analog video modulation and telephone lines were used for transmission. The ongoing development of high technology electronics and computers has permitted an economical and high-speed transmission of radiographic images (2,3). A picture archiving and communication system (PACS) may be set up to increase the quality of service (1). Consultation within the hospital can be achieved by a local area network (LAN), with reasonable efficiency and cost. However, if the communication is beyond the bounds of the LAN, it might be fulfilled by a wide area network (WAN) technique, but this is significantly slower than the LAN. For convenience, we usually utilize the Internet as our WAN instead of proprietary networks.

In recent years, Internet has become a very popular and convenient international network of computers for exchanging information. Images can be easily managed by this global networking and software (4). Many researchers have already designed some successful teaching file systems on Internet (5,6). A teleradiology system using the web was also announced to allow remote consultation with expert radiologist (7). Our hospital developed a PACS in 1993 (8), and has already extended it to a hospital-wide PACS (9). In order to facilitate better service outside the hospital, we proposed a practical, applicable and economical teleradiology conferencing system using Java technology (10) via the popular platform-independent and hospital-independent Internet.

2. METHODS

2.1 Why Java?

Java is platform-independent. There are various popular platforms avalable currently, such as Pentium (Intel, Santa Clara, CA) and Macintosh (Apple, Cupertino, CA) personal computers (PC) for hardware and Unix (AT&T, Red Bank, NJ) and Microsoft windows (Microsoft, Redmond, WA) for operating systems. Although these platforms can be connected by networking, a special version of any program has to be designed for each platform and a lot of investment is needed to develop the software for different platforms to communicate with one another. Java is a new programming language developed by Sun Microsystems (Sun, Chelmsford, MA) for the World Wide Web (10). A Java program will be compiled into byte codes and class libraries in a standard form, which can be supported by all platforms. Many Java run-time environments have been provided on Internet. For example, Microsoft IE (Microsoft, Redmond, WA) and Navigator (Netscape, Mountain View, CA), the Internet browsers, are already approved as Java compliant. Using this language, we can create a teleradiology system independent of the platform used to develop it (10).

Java will dramatically reduce the cost of software distribution and maintenance. A Java program can be executed on any platform, ether using a local program or a program downloaded from an Internet server. This feature allows us to maintain an up-to-date version of our application system in the server instead of each client storing and updating it independently. In addition, the capability of Java in multimedia, animation and interaction has facilitated the function of displaying and processing medical images for the clients. Therefore, we chose to use Java to design our teleradiology system.

2.2 System Design

There are several important aspects in designing a teleradiology system. Teleradiology, in the most general sense, means the transmission of radiographic images from one place to another (1). It may further be supported by video conferencing (telemedicine) so that the medical personnel at each end of the link can converse with each other and make annotations on the images being reviewed (2). Thus, a sophisticated teleradiology system should include: 1. synchronous consultation from both ends; 2. connection with the PACS for accessing images; 3. basic functions for image processing; 4. teleconferencing for interactive conversation. (11,12).

We designed this system as an alternative to the teleradiology within our hospital. It is particularly useful for imminent radiological reporting and consulting for an urgent condition when a doctor is at home, and for a remote affiliate veterans hospital with an immediate diagnosis. This system provides remote consultation in a way that both clinicians can review the same images and discuss with each other on a dialog window or by telephone. The screens displayed at each end coincide with each other. If the image on one end is changed, whether by user manipulation or by performing some processing functions, that on the other end will be refreshed simultaneously. In order to let the remote user easily follow what you are concerned about, a specific indicator was designed to concurrently point to the interesting image area at both ends (Figure 1). In addition, a user may put annotations, such as text, line segments, rectangles, or polygons on interesting areas of the displayed image and these annotations will be simultaneously displayed on both monitors (Figure 1). A dialog window was also designed as an alternative to the telephone for on-line conversation (Figure 2).

The system consists of three components: the image server subsystem, the data base (DB) server subsystem, and the client subsystem (Figure 3). The image server subsystem is used to store images. The DB server subsystem provides the patient's demographic data and locations of relative images stored in the image server. These two server subsystems together serve as the image source in a rural hospital, but are substituted by the interface to the PACS in our hospital. The client subsystem allows users to retrieve images, manipulate images, and perform remote consultation.

A client subsystem is composed of a viewer program, a stream listener and a local image file. The viewer program requests the DB server subsystem and the image server subsystem to acquire images and provides a graphic user interface (GUI) to process acquired images. The local image file is used to store the retrieved images. Since the two users communicate through an Internet/Intranet, the stream listener will provide on-line two-way communication with the other client for synchronization. When any change of the screen is made by a user on one end, it will simultaneously refresh the other to maintain a consistent view at both ends.

The DB server subsystem offers the location of a required image to the client. Whenever the server is activated, it passively waits for a request from the client. If the DB handler receives a request, it will query the patient DB for related demographic data and image location and reply to the client. The client will then request an image transfer from the related image server according to the image location.

The image server subsystem is responsible for providing required images to the client. Since images may be retrieved from the PACS of our hospital or an image file of a remote rural hospital, there are many distributed image resources. However, all images are stored in DICOM format. According to the specified image location, the server will easily get the requested image from the exact image resource and return it by a file transfer protocol (FTP).

2.3 System Operation

Any user operates the system through a client subsystem. When a client subsystem is activated, its stream listener is triggered at the same time to wait for the connection from other remote clients. Otherwise, it may actively connect to a remote client if the user specifies an IP address (Figure 1). After the connection is completed, a synchronous channel will be set up between the two clients to send the messages to each other. Any user may query a patient's information from the DB server, acquire related images from an image server, and select one of the acquired images for further manipulation. These operations are instantaneously notified to the other client by passing commands through the synchronous channel. The remote client will immediately execute the received commands to present the same operations.

The system is used not only for image consultation but also for image reporting. We have designed the system as an alternative to a remote PACS. If a radiologist wants to report images at home, he may initial the process without specifying an IP address since he does not have to communicate with any other user. The system allows a user to acquire a single image or a file of images that may belong to many patients. These acquired images are returned from the image server by FTP and stored in the local image file. In this way, a radiologist may pre-fetch all required images before reporting.

2.4 System Implementation

Two connected client subsystems become symmetric. The symmetry is achieved from identical implementation of all clients. There is no master-slave concept between connected clients. Any client may actively connect to or passively be connected by another client. Every operation of one client will instantaneously be replayed at the other by passing the same command through the communication channel between them. The symmetric property of our client design has simplified user operations and the complexity of implementations.

In order to maintain identical contents of screens at both ends, the system is implemented to provide a synchronized display during consultation. There are two synchronization methods for screen display, i.e. the screen-sharing strategy and the command-passing strategy. The former, which is used by Intel ProShare and is commonly applied in teleconferencing, transmits the whole updated screen to the other even though there are only few changes. Since any change on one end will cause a screen dump to the other, network transmission is heavy. For example, if we want to enhance the displayed image by adjusting its window-level, the screen-sharing strategy will send almost a whole screen of data to the other side. This will introduce roughly a million bytes of data to be sent on the network. However, in our system, we adopt the command-passing method, which only transmits a command code and parameters of the operation to the synchronized client. It takes only a few bytes to represent the command code and parameters. After the remote computer has received the command code, it will execute this command and obtain the same screen display immediately. The command-passing strategy will tremendously reduce the volume of transmitted messages and the response time for synchronizing displays. All operations, including image manipulation, annotation, and dialog, are implemented under this strategy in our system.

However, synchronized display has some drawbacks, such as operation conflict and insignificant moving of the cursor. Operation conflict happens when two users activate some operations simultaneously, causing an inconsistent screen display. We solve this conflict by a token-passing strategy, which means the user who needs to activate a command should. press an icon first to get the control token to execute the operation.

Moving of a mouse cursor results in a string of insignificant events for computers, and this will increase the volume of message transmission during synchronized display. This will dramatically slow the performance of the system. This problem can be solved by introducing a synchronized indicator (Figure 1). Since users move the indicator to point to the interesting area for discussion using the command-passing strategy, we may omit transmission of all moving events of the mouse cursor.

Our system was implemented using JDK 1.1.4 (Java Development Kit), and can be executed on JRE 1.1.4 (Java Run-time Environment) or later versions. The Java applets for Web browsers such as Microsoft IE (Internet Explorer) or Netscape Navigator were not adopted in this system, because our program has to access local files and download images into local disks, and doing this would violate the security constraints of Java applets. The computers of our users are all Pentium-based with Windows 95, which are very popular in our country.

3. RESULTS

This system provides for consultation by viewing the radiological images directly. The acquired images can be browsed on a side panel and an interesting image is selected by clicking the mouse to display the image on the main window (Figure 1). The displayed image can be manipulated using the following functions: brightness and contrast adjustment, window level and width settlement, image inversion, zooming in / out and measurement. A user can utilize a synchronized indicator to locate the interesting anatomy or lesion, which can also be annotated. A dialog window can be opened for interactive communication (Figure 2).

In mid 1997, our first experimental system was established for radiologists, who were consulted at home for emergency cases. By using a telephone modem, a doctor can access the medical images from the PACS of our hospital and communicate with the consulting clinicians. Although this teleradiology system was convenient, the bandwidth of the transmission line became a bottleneck, because the size of medical images is very large. For example, it took about 18 minutes to send a compressed 4M-byte X-ray image through the telephone line. To reduce the transmission time, a cable modem technique was introduced, by which the transmission speed was more than 128K bits per seconds, and the transmission rate can be increased three times.

In mid 1998, we installed this system at an affiliate rural veterans hospital, which is 70 km away from our hospital. This hospital is a rest-home hospital without a full-time radiologist. They had already setup a mini-PACS containing a DICOM-compliant CT and a plain-film digitizer. When a service of radiology reporting or teleconsultation was requested, our radiologists can communicate with the remote clinicians using this system. The affiliate hospital is connected with a 64K leased line, so a compressed 4M-byte X-ray image will take about 10 minutes to retrieve.

The response times of the various image manipulation functions of a local computer are within a second, however it takes a few seconds for the remote computer to redo the same operation through the command-passing method.

4. DISCUSSION

One of the shortcomings of a Java system is that the system response seems too slow. Since some instructions supported by Java are not native to the platforms, such as Windows NT / 95 or Unix, it will not utilize the most efficient way to invoke system intrinsic functions. The Java interpreter runs somewhat slowly as well. However, employing the Java just-in-time compiler or the Java chips for executing the Java byte codes may improve the performance. In addition, the frequent upgrades of Java means most programmers are not familiar with its new versions and most Java run-time systems do not support all of the new features. Newly released Java class libraries or run-time environments could also be incompatible with the Chinese versions of operating systems. In order to avoid these problems, we should choose the class libraries carefully and test them under different run-time environments in advance. However, this would increase the maintenance cost for our system.

For on-line consultation, the necessary equipment for this system is the network interface or modem for making an on-line connection. However, the system may employ a microphone and a sound card for audio conversation to replace telephone dialog. Because not all computers are equipped with an audio device, the dialog window is used as an alternative to let the remote user follow what you are typing or drawing (Figure 2). Furthermore, there would have to be a video camera for teleconferencing. The video conversation must be in a unified, non-proprietary, platform-neutral format. In fact, there is no natural way to implement a video conversation environment in Java now. But a new feature of the Java platform, called the Java Media Framework (JMF), is going to be integrated into our system in the near future. It will become a great support to the media capture and conferencing function of this system.

The greatest advantage of this system is to provide a platform-independent telemedicine service through Internet. A consultation can be accomplished easily and cost-effectively. However, the drawback of Internet bandwidth still exists. In order to obtain images faster, we are looking for a faster Internet networking technique. An alternative to solve this problem is using the prefetch function of this system to get images in advance, so the consultation time itself can be reduced.

5. CONCLUSION

A physician may transmit clinically useful images and consult with an expert radiologist at a different location using the World Wide Web on the Internet (7). The ever-growing power of personal computers, combined with inexpensive yet sophisticated software, frequently provides a useful method for analysis of radiological data (13). Using the web browser on a PC is an optimal choice for remote communication. In this paper, we describe the designe of a Java technique on Internet for teleradiology. This system is platform- and hospital-independent, since most computer companies support Java. The clinicians in our hospital and the affiliate rural veterans hospital will be satisfied with this new implementation, if transmission speed is reduced.

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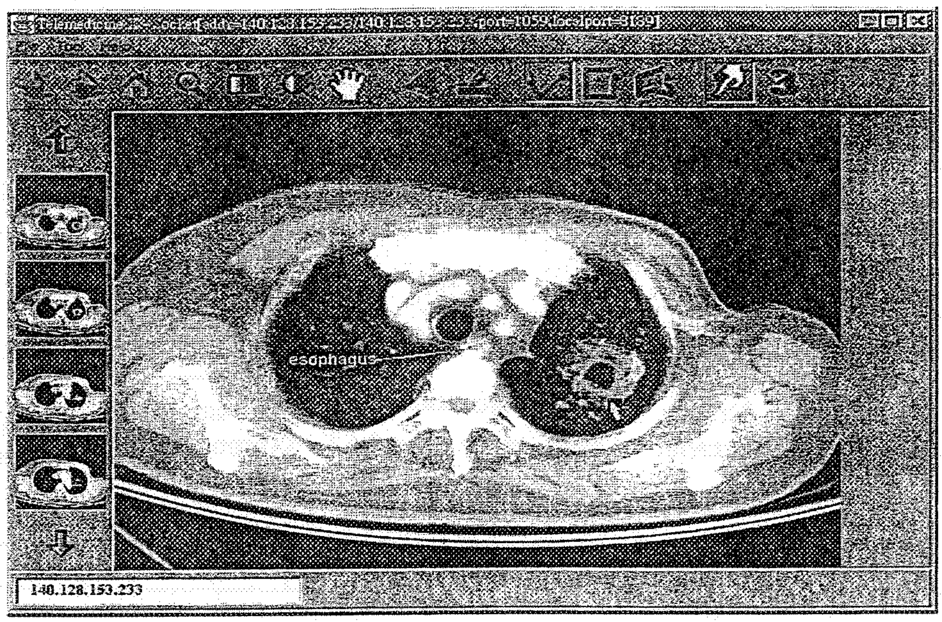

Figure 1. A coincided CT image of chest displayed on the monitors during consultation. The synchronous cursor or pointer is pointing to the mass lesion in the left upper lobe lung. An annotation to the conspicuous structure (esophagus) is indicated within the image. The connected site is indicated by the IP address showing in the left bottom of the image window.

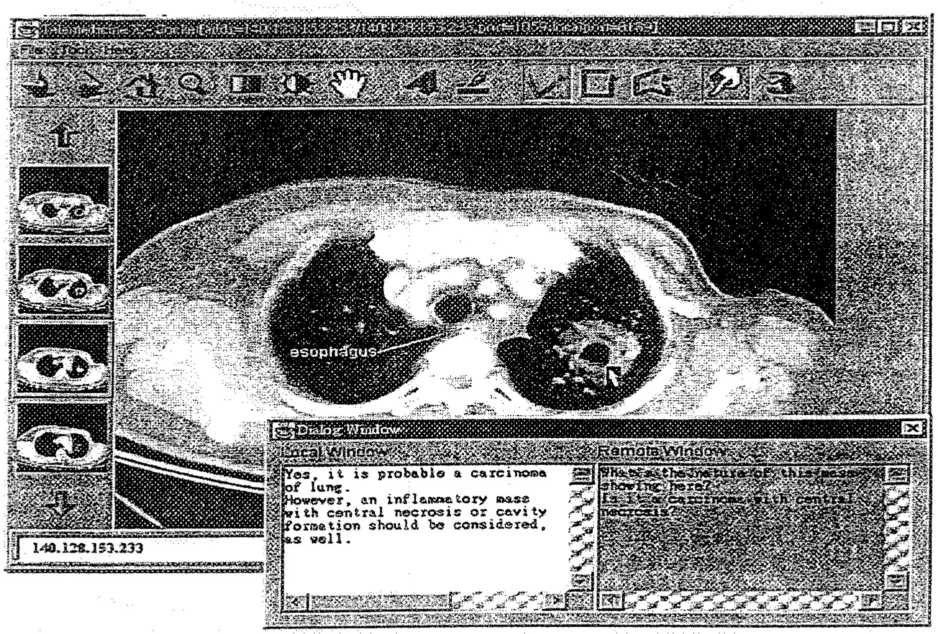

Figure 2. The interactive dialog box is presented on the coincided CT image during teleconsultation.

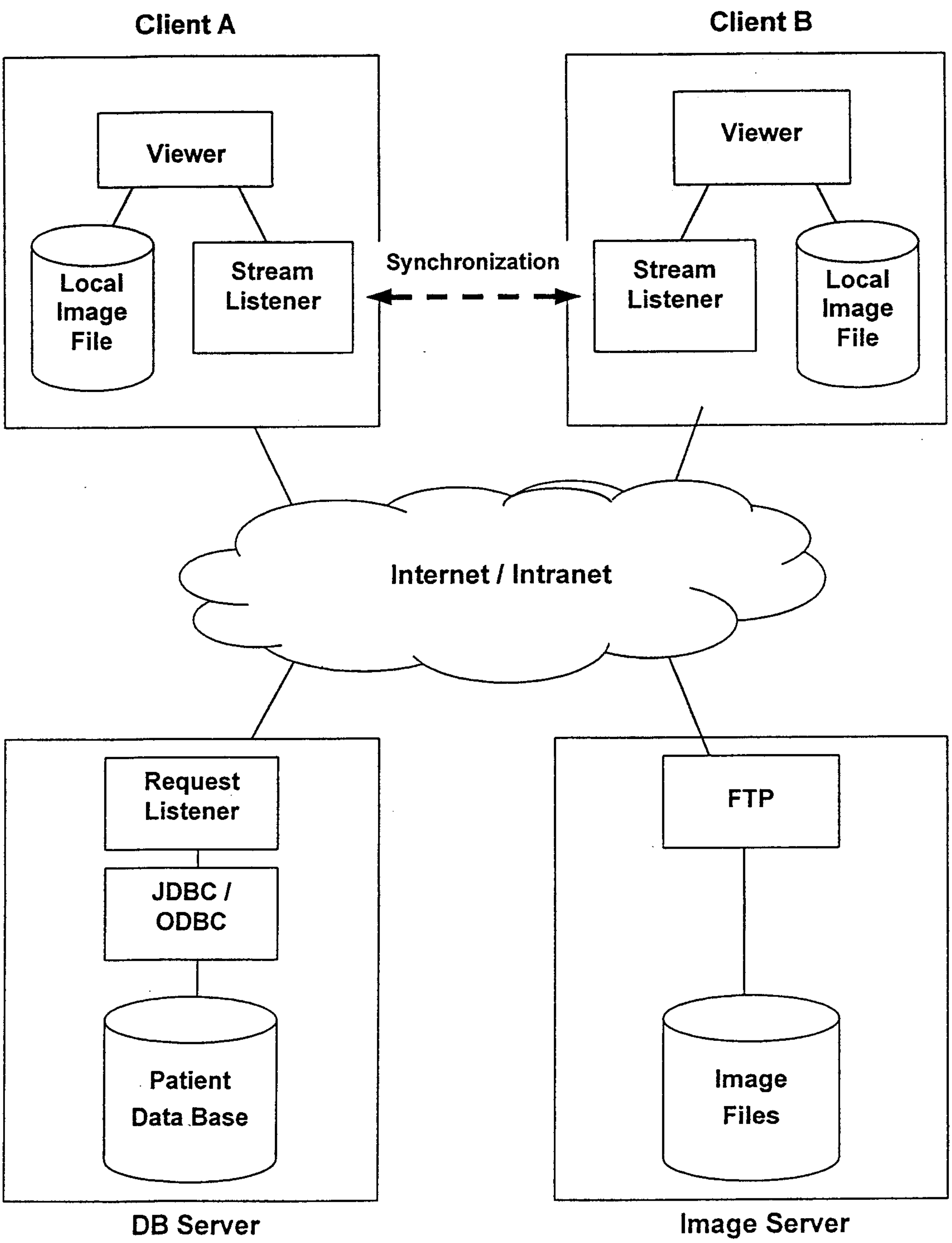

Figure 3. A scheme of the infrastructure of our Java teleradiology system.

FTP = file transfer protocol, *JDBC* = Java data base connectivity module, *ODBC* = open data base connectivity module