International Journal of Medical Informatics (2003) **72**, 73—79

International Journal of Medical Informatics

www.elsevier.com/locate/ijmedinf

TECHNICAL COMMUNICATION

A real time collaboration system for teleradiology consultation

Jiann-Shu Lee [a,*], Ching-Tsorng Tsai [b], Chen-Hsing Pen [c], Hui-Chieh Lu [d]

[a] *Department of Aeronautical Engineering, National Huwei Institute of Technology, 64 Wen-Hua Road, Huwei Jen, Yunlin, Taiwan 632, ROC*
[b] *Department of Computer and Information Science, Tung-Hai University, Taichung, Taiwan*
[c] *Computer and Communication Center, Taichung Veterans General Hospital, Taichung, Taiwan*
[d] *Department of Computer and Information Science, National Chiao Tung University, Hsinchu, Taiwan, ROC*

Received 9 September 2002; received in revised form 7 July 2003; accepted 16 July 2003

KEYWORDS
Collaboration;
Teleradiology;
PACS;
Internet;
Java

Summary Real time collaboration systems, in which participants share multimedia data and applications in real time, have attracted many researchers in recent years. A teleradiology consultation system based on the real time collaboration technology is presented in this paper. Under the platform-independence consideration, Java technologies are employed to construct the system. Applying this system, an off-duty on-call radiologist can make diagnoses and report easily by viewing the transferred images at home. Owing to the accessibility of image, all users can examine and manipulate images consistently such that a secluded hospital can be assisted to hold remote consultation. To reduce the network transmission time, the command-passing and local command execution techniques are utilized to achieve the screen synchronization. A pointer function is also developed to maintain the cursor consistency in a more efficient manner during consultation when a detail indication of the examined image is needed. Besides, a dialog window is also designed for on-line conversation. Since Java programs can run on heterogeneous platforms, the need for system maintenance and user training can be substantially reduced.

1. Introduction

Collaboration has become practical because of the multidimensional communications usually employ both real time and non-real time tools. We can now access multiple modes data, which consists of text, files and multimedia, through communication. The primary facilitator of collaborative work is telecommunications. Without the telecommunications technology [1], the enhancement of productivity and the amplification of creativity become virtually impossible. Knowledge workers will need computing and communicating tools to assist them with collaborative work. The requirement is especially urgent in the health sciences domain, where work is characterized by geographic dispersion of co-workers and compressed time frame for work output [2—5].

Medical image play an important role in diagnosis and treatment in the modern medicine system [6,7]. The need of domain knowledge in analyzing the medical image urges the clinicians to consult with radiologists for further diagnosis. Teleradiology was introduced in 1972 [8] to solve the problem of consultation, especially in remote areas and

*Corresponding author.

1386-5056/$ — see front matter
doi:10.1016/S1386-5056(03)00130-8

congested cities. Analog video modulation and telephone lines were used for transmission. The modern development of electronics and computers has enabled the digital radiographic image transmission in a more economical and efficient way. The Picture Archiving and Communication System (PACS) [9,10] is the common technique for image transfer and storage in health care environment. The main goal of a PACS is to provide a standardized image archive, which can be accessed from various users among the defined user community, such as departments inside a hospital, through networks. 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 the wide area network (WAN) technique. The Internet has become a very popular and convenient telecommunications infrastructure for information exchange in recent years. The Internet is serving more and more user everyday for it is becoming more inexpensive on a day-to-day basis. The number of private users accessing the Internet from their home is rising very quickly. For convenience, we utilize the Internet as our WAN instead of proprietary networks.

In this paper, a teleradiology consultation system is proposed by employing the real time collaboration technology. The underlying collaboration environment is based on the Transmission Control Protocol/Internet Protocol (TCP/IP). The existing platforms are diverse. For hardware, the personal computer (PC) level equipments include Pentium and Macintosh and the popular operating systems such as Unix, Mac OS and Microsoft Windows. Although these platforms can be connected by network, special versions of programs still have to be designed for different platforms. Furthermore, the software development for the individual platform to communicate with each other will take great effort. Java is a new programming language developed by Sun Microsystems for the World Wide Web [11]. Introduction of Java as a platform-independence programming language for the Internet is one of the most significant software breakthroughs for the Internet-related technologies. A Java program is compiled into bytecodes and class libraries in a standard form which can be supported by most of the existent popular platforms. Many Java run-time environments have been provided on the Internet, for example the Microsoft IE and the Netscape Communicator have been approved of Java compliance. Using Java we can establish a teleradiology system which is independent of the underlying platforms. Besides, Java can dramatically reduce the cost of software distribution and maintenance. A Java program can be executed by using either a local program or a program downloaded from a server. One just needs to maintain an up-to-date version of our application programs on the server instead of individually updating programs on each client because of the before-mentioned feature. In addition, the capability of Java in processing multimedia also facilitates the manipulation of medical images on the clients. Based on the above benefits we adopted Java to develop our teleradiology system.

To reduce the network transmission time, the command-passing and local command execution techniques are utilized to achieve screen synchronization. A dialog window is also designed for an alternative on-line conversation. To make the remote user easily follows what one is concerned about, a specific indicator is designed for the consistency indication to the interesting image area. In addition, the annotation function is also implemented in our system to provide a more specific discussion environment.

2. Methods

2.1. 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. It may be further supported by video conferencing (telemedicine) so that the medical personnel at each end of the link can discuss with each other and annotate on the examined image. Thus, a sophisticated teleradiology system should provide the synchronous consultation, the connection with the PACS for accessing images, the basic image manipulation and processing functions, and the teleconferencing for interactive conversation [12,13].

The developed system is particularly useful in providing immediate diagnosis for a remote hospital and in assisting imminent radiological report and consultation in urgent conditions when a doctor is at home. The system provides remote consultation in such way that both clinicians can review the same images and discuss with each other by the dialog window or microphone. To hold the remote consultation the screen synchronization is needed. If the screen content of one end is updated then the screen content on the other end will be refreshed simultaneously. To let the remote user can easily follow what you are concerned about, a specific indicator as shown in Fig. 1 is designed for the consistency indication to the interesting image area. In addition, a user can annotate by using text, line segments, rectangles, or polygons on

Fig. 1 A displayed MR knee image during consultation. The synchronous cursor or pointer is pointing out the patella. An annotation is indicated in the image. The connected site is exhibited by the IP address shown in the left bottom of the window.

the interesting areas of the examined image. And, these annotations can be almost simultaneously displayed on both ends as shown in Fig. 1. A dialog window is also designed for an alternative on-line conversation as shown in Fig. 2.

Fig. 3 depicts our system architecture. The system consists of three components: the image server, the database (DB) server, and the client groupware. The DB server and the image server are both connected to the Internet/Intranet. And, clients are directly synchronized with each other through the Internet/Intranet. The image server is used to store images. The DB server provides the patient's demographic data and the corresponding images

Fig. 2 The interactive dialog box is presented on the consistent MR image during consultation.

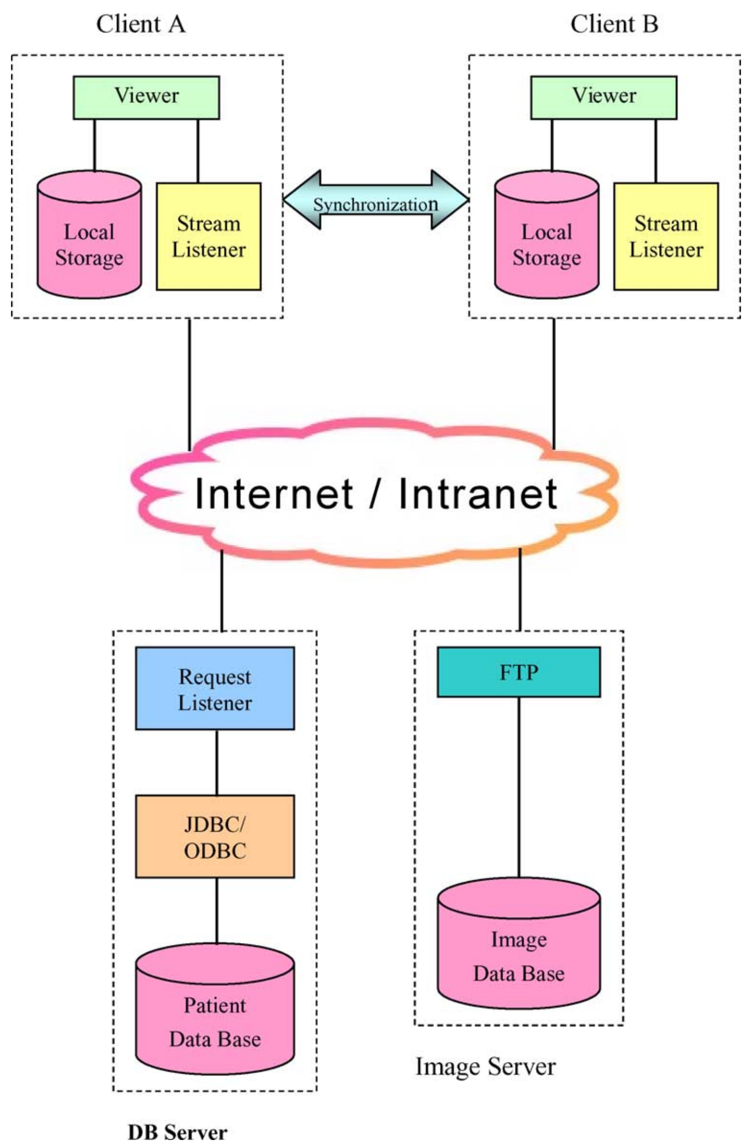

Fig. 3 The composition of our system.

locations in the image server. The client groupware enables users to retrieve and manipulate images, and hold a remote consultation.

The client groupware is composed of a viewer program, a stream listener and a local image file. The viewer program requests the DB server and the image server to retrieve images and provides a graphic user interface (GUI) to process the acquired images. The local image file is used to store the retrieved images. The stream listener provides two-way on-line communications and is executed to maintain the consistency between both ends.

The DB server provides the location of the required image to the client. Once the server is activated, it passively waits for a request from the client. When the DB server receives a request, it will query the patient DB for the corresponding demographic data and reply the image location to the client. The client will then request the image server to transfer the desired images by file transfer protocol (FTP).

2.2. System operation

Users operate the system through the client groupware. When a client activates, the stream listener is triggered at the same time to wait for the connection from other remote clients. However, if the user specifies an IP address it will actively connect to the specified remote client. After connection, a synchronizing channel will be established between clients. Users can query the patient information from the DB server and retrieve the desired images from the image server. These operations are instantaneously informed to the remote clients by passing commands through the synchronous channel. The remote clients immediately execute the received commands to carry out the same operations.

The system can be used for both image consultation and image reporting. We have designed the system as an alternative in remote PACS. If a radiologist wants to report his diagnosis of images at home, he can also initiate the process without IP specification, which enables a radiologist to pre-fetch the required images before reporting.

2.3. System implementation

There is no client—server concept between the connected clients. The connected client subsystems are symmetric. Any client can actively connect to or passively be connected by other clients. Every operation on one client will be instantaneously repeated on the others by passing the same command. The symmetric property simplifies the user operation and the implementation complexity.

For consultation convenience, the screen content synchronization is needed. There are two synchronization methods for screen display, which are screen-sharing strategy and command-passing strategy. The screen-sharing strategy is used by Intel ProShare and is commonly applied in teleconferencing, which can transmit the whole updated screen to others even though there are only few changes. Since any change on one end will cause a screen dump to the others, the network transmission load is heavy. For example, if we want to enhance the examined image by adjusting its window-level, the screen-sharing strategy will send almost a whole screen of data to other sides. This will induce 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 clients. It takes only a few bytes to represent the command code and parameters. Having received the command code, the remote computers will execute this command and obtain the same screen display immediately. The command-passing strategy tremendously reduces the volume of transmission data and the response time for synchronization display. All operations, including image manipulation, annotation, and dialog are implemented by this strategy in our system.

However, synchronization display has some drawbacks, such as operation conflict and insignificant cursor movement. Operation conflict happens when more than one user activates the operations simultaneously. This will result in an inconsistent screen display. This conflict is solved by a token-passing strategy, which means that if a user wants to activate a command he should press an icon first to get the control token.

Movement of a mouse cursor results in a string of insignificant events, and this will increase the volume of message transmission. This problem is solved by introducing a synchronized indicator, in which users move the indicator to point out the interesting area for discussion by the command-passing technique. Thus we need not transmit all movement events of mouse cursors.

Our system is implemented using JDK l.1.4 (Java Development Kit), and can be executed on JRE l.1.4 (Java Run-time Environment) or later versions. The Java applets for Web browsers such as Microsoft IE (Internet Explorer) or Netscape Communicator were not adopted in the system, because our program has to access local files and download images into the local disks. These actions violate the security constraints of Java applets.

3. Results

This system provides for consultation by viewing the radiological images directly. The acquired images can be browsed on a side panel. The interested image is selected by clicking the mouse and then the image is displayed in the main window. The examined image can be manipulated by the following operations: brightness and contrast adjustment, window level and width settlement, 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.

Our experimental system was established for the radiologist emergency consultation at home. By using a telephone line modem, a doctor can access the medical images from the PACS of the Taichung Veterans General Hospital and communicate with the consulting clinicians. Although this teleradiology system is convenient, the bandwidth of the channel becomes a bottleneck due to the massive data of medical images. To reduce the transmission time, a lossless compression scheme for medical images was applied, which is supported by the standard of Digital Imaging and Communications in Medicine (DICOM). The DICOM standard provides the mechanism for the use of JPEG compression through the encapsulated format. By this scheme, we can compress the file size of a medical image to a half or even to a quarter size of the original one. For example, an X-ray image with size of

1000×1000 pixels, 12 bits per pixel will take about 11Mb for the uncompressed case, and 4Mb for the compressed case. The popular dialup modem has a bandwidth of 56K bits/s. Normally, its transmission rate is about 4Kb/s. It will take 18 min to send this image. Alternatively, the cable modem and Asymmetric Digital Subscriber Line (ADSL) techniques are more efficient communication channels than the dialup modem. In general, a 4Mb X-ray image takes 2 or 3 min to send by these techniques. The system has been installed at a rural Veterans Hospital, which is 70 km away from the VGHTC. 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 the radiology reporting or remote consultation is requested, the radiologists can communicate with the remote clinicians by this system. The rural hospital is connected with a 64K leased line. It takes about 8 min to retrieve a compressed 4Mb X-ray image. The response time of the various image operations on a local computer is within 1 s, while it expends a few seconds for the remote computer to repeat the same operation through the command-passing technique.

4. Discussion

The greatest advantage of this system is that it provides a platform-independent teleradiology consultation service through the Internet. Remote consultations can be accomplished easily and cost-effectively. However, the bottleneck coming from the Internet bandwidth still exists. In order to speed up the image retrieval, we are looking for a faster transmission technique. An alternative in solving this problem is to apply the prefect function of our system to retrieve images in advance.

For on-line consultation, the necessary equipment for the system is network interface or modem which is connected with the Internet. The system can 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 in consultation assistance. Furthermore, for teleconferencing video cameras are needed. 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.

We should note that there are several types of medical images such as MRI, CT, and X-ray displaying on the typical home computer screens. The MRI and CT images with 512×512 pixels and 8 bits per pixel can be directly viewed on a common computer screen. For the X-ray image with 2048×2048 pixels and 12 bits per pixel, it cannot be shown on a home computer screen in its original gray-level depth and resolution. By rescaling the image size and resolution, the X-ray image also can be shown on screen properly. However, the X-ray image with this destructive operation will just be considered as a previewing one. If the radiologist wants to view the original image, he should go back to the hospital for diagnosis.

The data security for medical information crossing the Internet is another issue. This problem can be divided into server security and data transmission security. The former should be maintained by the Hospital Information Center, and be solved by firewall technology. The latter is considered as a data encryption problem. The encryption compatibility between hospitals should follow standards. We have not implemented the encryption mechanism in our system yet. However, the encryption implementation following the standard proposed by DICOM will be included in our system in the future.

The main shortcoming of a Java system is that the system response seems too slow. Since some instructions supported by Java are not native to the platforms, e.g. Windows NT/95 or Unix, this makes the instruction cannot be executed in the most efficient way. Besides, the Java interpreter runs slowly as well. However, the utilization of the Java just-in-time compiler or the Java chips will improve the performance. In addition, the frequent upgrades of Java means that most programmers are not familiar with the newest version and most Java run-time systems do not support all of the newest features. The newly released Java class libraries or run-time environments may 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.

5. Conclusions

The Internet has become a very popular and convenient telecommunications infrastructure for information exchange in recent years. More and more tools, including both real time and non-real time, have been developed to resolve the communication problems based on the Internet. The great progress in the Internet has made remote collaboration become possible. This function is especially urgent in the health sciences domain because their work is characterized by geographic dispersion of co-workers and increasingly compressed time frame for work output. In this paper, we propose a teleradiology consultation system applying the real time collaboration technique on the Internet. Based on the platform-independent consideration, Java technologies were employed to design our system. Applying this system, the radiologist can provide consultation at home in emergency. In addition, this system can assist a rural hospital without a full-time radiologist with radiology reporting and remote consultation. All users can retrieve and manipulate images and hold remote consultation. To reduce the network transmission time, the command-passing and local command execution strategy was utilized to achieve the screen synchronization. In addition, to maintain the cursor consistency during consultation in a more efficient way, i.e. when a detail indication of the examined image is needed, a pointer function was developed. A dialog window was also designed for an alternative on-line conversation. Since Java programs can run on distinct platforms, the need for system maintenance and user training can be substantially reduced.

Acknowledgements

This report was partly supported by a grant from the Joint research program of Veterans General Hospital and National Tsing-Hua University in Taipei (VGHTH 85-024-3), sponsored by the Medical Research Advancement Foundation in memory of Dr. Chi-Shuen Tsou.

References

[1] A. Sykes, M. Symods, D. Van Doren, Collaboration in the Information Age, Business Communications Review, BCR Enterprises, Hinsdale, IL, May 1997, pp. 3—5.

[2] W.K. Wong, H.K. Huang, R.L. Arenson, J.K. Lee, Digital Archive System for Radiologic Images, InfoRAD 14, 1991 pp. 1119—1125.

[3] G. Irie, K. Miyasaka, HU-PACS. 10 months experience, Comput. Methods Programs Biomed. 36 (1991) 71—75.

[4] H. Mosser, M. Urban, W. Hruby, Filmless digital radiology-feasibility and 20 months experience in clinical routine, Med. Inform. 19 (1994) 149—159.

[5] G. Svahn, S. Holtas, E.M. Larsson, E. Bengtsson, PACS for radiology conference—improvement of application software, Comput. Methods Programs Biomed. 43 (1994) 81—84.

[6] M. Hosono, Y. Nakano, S. Urayama, J. Konishi, K. Uokawa, Y. Tanaka, Three-dimensional display of cardiac structures using reconstructed magnetic resonance imaging, J. Digital Imaging 8 (1995) 105—115.

[7] C.R. Guiado, P. Matinez, R. Roig, F. Mirosa, J. Salmeron, F. Florensa, M. Roger, Y. Barragan, Three-dimensional MR of the inner ear with steady-state free precession, Am. J. Neuroradiol. 16 (1995) 1909—1913.

[8] W.D. Bidgood, E.V. Staab, Understanding and using teleradiology, Semen Ultrasound CT MR 13 (1992) 102—112.

[9] C.W. Yang, P.C. Chung, S.K. Lee, et al., An image capture and communication system for emergency computed tomography, Comput. Methods Programs Biomed. 52 (1996) 139—145.

[10] T.C. Wu, S.K. Lee, C.H. Wen, et al., An economical PC-based picture archiving and communication system, Radiology 205 (1997) 746.

[11] J.S. Gage, An introduction to Java, MD Comput. 13 (1996) 476—480.

[12] H.K. Huang, Picture Archiving and Communication Systems in Biomedical Imaging, VCH, New York, 1996, pp. 329—332.

[13] G.T. Barnes, R.L. Morin, E.V. Staab, Teleradiology: fundamental considerations and clinical applications, in: J.C. Honeyman, E.V. Staab (Eds.), Syllabus: A Special Course in Computers for Clinical Practice and Education in Radiology, RSNA, Oak Brook, 1992, pp. 139—146.