

Internet Based Medical Image Processing System Using Java Technologies

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ABSTRACT

This paper presents development and application of an Internet based integrated medical image processing system for display, registration, visualization, and analysis of tomographic images. This software system is developed using hybrid Java technologies to construct a client/server networking architecture on the Internet. The system has connected an system administrative workstation at System Cybernetics Laboratory at Chung Yuan University, and two distributed image database workstations at National PET/Cyclotron Center and National Cheng Kung University Hospital in Taiwan. Project-oriented servers, called project servers, can be mounted onto the system as needed to provide the project-related image data and function services; clients from different computer platforms connecting to the project server can interactively require various information or functions with a consistent graphical user interface. Discussions on some aspects of the system also are presented.

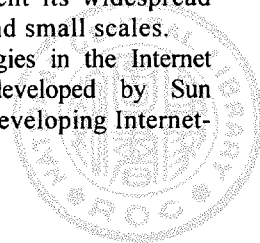
Key words: *Internet, tomographic image, image registration, Java, client/server.*

I. INTRODUCTION

As the exponentially growth of the Internet since the early 1990s, the potential resources have been attracting a wide range of commercial market explorers as well as research communities. The continuously growing Internet technologies have provided standard services like email, news, file transfer, Gopher, World Wide Web (WWW); simultaneously, various concepts and applications using the Internet as backbone, like teleconferencing, telemedicine, and so forth, also have been explored [1]. On the other hand, a variation of the Internet, the Intranet, was born in around 1995, which fully utilizes the well-developed protocols and tools for the Internet but within local areas or buildings [2].

Because of many advantages for establishing Internet or Intranet based computing environment, more and more early concepts of close private networking environment have been shifted toward the open, sharing, expandable, and even cheaper architecture. One example occurred in health care community is the hospital picture archiving and communication system (PACS). The strong need for specific technologies and specific computer platforms and thus high expanses in operating and maintaining the software and hardware are the main disadvantages of PACS, and prevent its widespread implementation [3] both in large and small scales.

One of the important technologies in the Internet world is the Java technology developed by Sun Microsystems for its suitability for developing Internet-



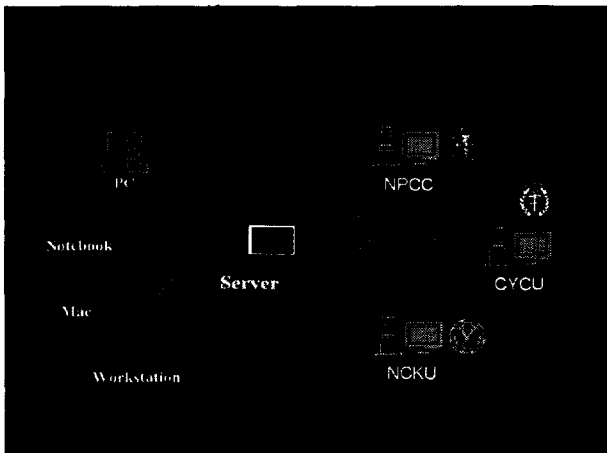


Figure 1. The implemented system architecture and components based on Internet technologies.

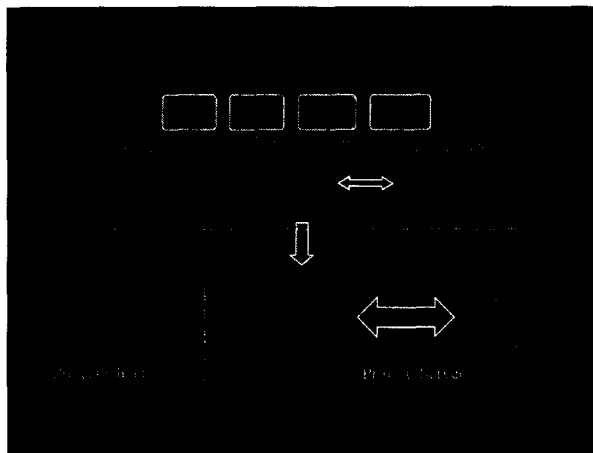


Figure 3. Hospital PACS is firewalled from the online client-server operations.

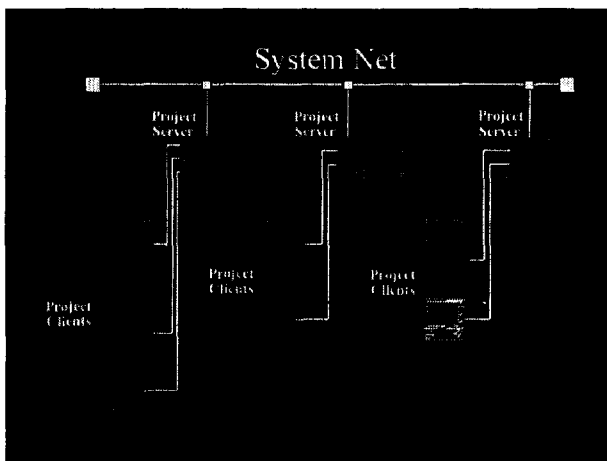


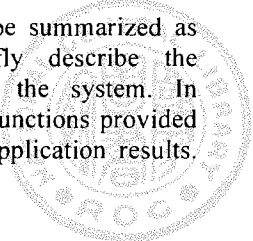
Figure 2. Several project servers can be mounted onto the system, allowing multiple project client connections.

related applications. The Java language is an object-oriented programming language designed to be small, simple, and portable across platforms and operating systems, which means that Java programs can run on any machine that has the Java virtual machine installed and shows a consistent graphical user interface (GUI) on each machine. In addition, various new software technologies are being integrated into the core Java Application Programming Interface (API), including Java Database Connectivity (JDBC), which allows interacting with a wide range of databases; Media API, which includes video, audio, 2D and 3D graphics, and telephony; Security API,

which provides cryptography, digital signatures, and authentication to meet the security needs; Java Beans API, which makes the truly reusable software components possible. These altogether can fully support the needs for constructing most of robust, secure, multimedia, distributed computing environment on the Internet [4]. The more important and attractive is that most of these resources as well as other Internet tools can be obtained in low expense, or even for free.

With the PACS experiences and having the mature Java technologies at hand, we have developed an integrated medical image processing system, which provides the displaying, registration, visualization, and analysis of multi-modality tomographic images in nuclear medicine department for clinical use and off-line research. The system is designed to work in a distributed computing environment, in which two medical image database server workstations at National PET/Cyclotron Center and Nuclear Medicine Department of National Cheng Kung University Hospital, and one system administrative server workstation at System Cybernetics Laboratory at Chung Yuan University are bridged over the Internet. Any number of project-oriented server, called project server, can be mounted onto the system to provides the project-related data and computing services, while the authenticated clients from different computer platforms connecting to the project server can interactively require various information or functions provided with a consistent user-friendly GUI.

The content of this paper can be summarized as follows. In Section 2, we briefly describe the infrastructure and development of the system. In Section 3, we describe in detail the functions provided by the system with some of their application results.



Finally, we conclude this paper in Section 4 with a discussion on the system and an outline of future work.

II. METHOD

A. System Architecture and Components

The Internet based image processing system is organized as shown in Fig.1. The two-layer system connects the two image database server workstations, which collect image data from image acquisition computers, located at the National PET/Cyclotron Center, Taipei and the Nuclear Medicine Department of the National Cheng Kung University Hospital, Taiwan, and the system administrative workstation located at System Cybernetics Laboratory of Chung Yuan University, Chung Li, Taiwan over the existing Internet backbone. The image data collected and stored in the two image database server workstations are mirrored in the jukebox of the system administrative workstation.

Project server can be mounted onto the system by connecting to the system administrative workstation to provide the project-related data and computing services to the authenticated clients from different computer platforms, such as PC, Macintosh, and workstation, while the clients connecting to the project server can interactively require various information or functions provided with a consistent user-friendly GUI. As shown in Fig. 2, more than one project sever can mount onto the system at the same time as needed for different study project purposes without conflicting to others.

In Fig. 3, the client asks for image data from the server, and can retrieve or store the region of interest (ROI) information to the server. The image data are one-way pushed from the image source, which would not be interfered by the communication between the server and the client.

B. Technical Aspects

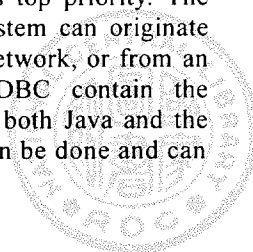
The Java programming language with the Java standard extension APIs is selected to be the main tool for implementation of the system, for it can fully satisfy the requirements of cross-platform, secure, and ease of implement, which are not provided by other technologies, like Microsoft's ActiveX technology. The programming environment primarily are Sun's Java Workshop 2.0 based on Java Development Kit (JDK) 1.1.3 running on Windows 95/NT 4.0 for PCs and Solaris 2.5 for Sun workstations. The code-generation tools as well as the project-management facilities included in these visual development tools

can help save the precious development time, like for GUI design.

There already have been many well-written classes and functions in the C/C++ programming languages developed for preceding projects, most of which can be reused in the present system. Therefore, they, such as image file format conversion, are directly translated from their original languages to Java, which borrows much of the syntax of C/C++ making the translation particularly straightforward and easy. When the computation efficiency of the functions is crucial, they are linked to Java by using Java's native method technique, that is, access through their compiled DLL or shared libraries form [5]. For example, the elastic image registration function of the system, originally written in C, is a novel iterative split-and-merge image manipulation process, but computation intensive, so it was left in its native form to keep its performance [6]. In addition, the tracer dynamic modeling technique, which involves solving coupled high-order differential equation systems, is also the case.

From the experiences learned in the preceding similar projects, developing the whole system or any sub-system from scratch is not a good idea, but reusing existing source codes is no better. In the present system, the emerging Java Bean component technology underlying the visual development tool -- Java Studio 1.0, which provides solution for easy visual integration of reusable software components, was widely and extensively utilized making the development of the system quicker, more flexible, and more reliable [7]. Also the system thus built is much easy to be maintained even when the whole project is shifted to next research and development group or personnel. The total system cost in time and energy is greatly decreased with the correct selection of this development strategy.

As with anything related to networks and the applications and databases that populated them, use of the JDBC and Structured Query Language (SQL) must address security. Whether the network is a small local area network (LAN), a wide area network (WAN), and intranet, or the Internet itself, security must be considered. The problem is that the more connected the system is to the environment, the more potential there is for illegitimate access to data contained on the system. Obviously, if the system is an isolated system, security is of little concern. However, if the system is exposed to the Internet, security is top priority. The potential for attack through the system can originate from someone else in the system network, or from an outside hacker. Java and the JDBC contain the following security measures. First, both Java and the JDBC have restrictions on what can be done and can



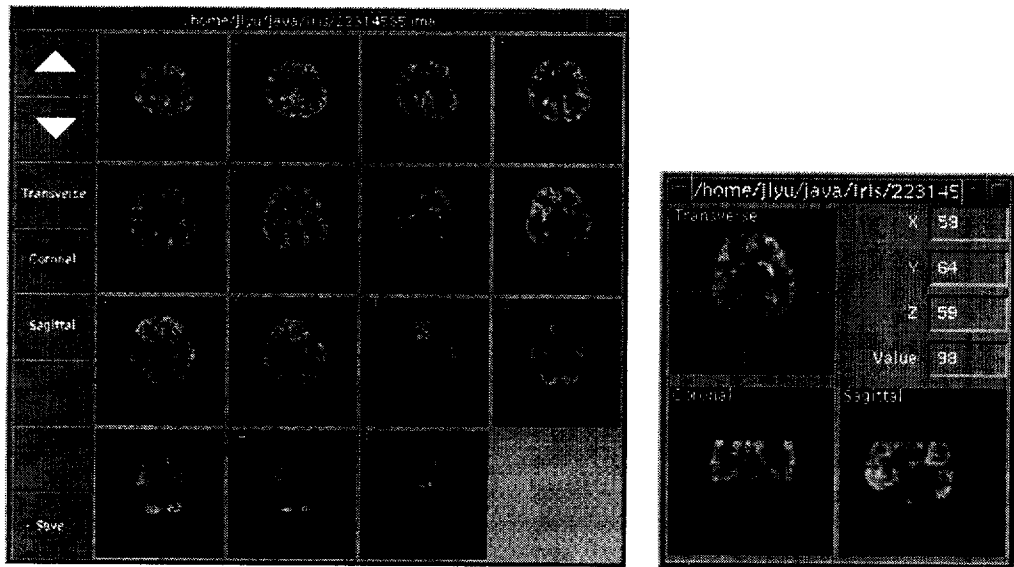


Figure 4. A typical PET image display in (left) multiple slice mode, and (right) three orthogonal plane mode.

not be done, helping to protect against attacks at the program level. Second, Java allows encrypted connections, Only the sender and receiver can decrypt messages. Someone listening in can not understand anything heard. This makes the actual connection more secure. Third, the database itself can act as a shield against unwarranted access with its built-in security model. Usually user should have an account with a database, and this account is created and delegated by the administrator of the database [8].

III. RESULTS

A. User Interfaces

In this subsection, we describe the user interfaces of image manipulation and analysis tools provided in the system.

(A) Image display

As shown in Fig. 4, a series of PET images is displayed in cine mode window and in orthogonal mode window. In cine mode window, the displayed images can be resliced to show the corresponding transverse, coronal or sagittal views. At one time, 16 slices can be shown, and up to 256 slices can be stacked in the buffer memory, which can be scrolled to be viewed by pressing up/down buttons. To obtain convenient image file format for paper publish,

Windows-compatible BMP file can be saved. In orthogonal mode window, the position of cutplanes can be selected by direct click on any of the windows; meanwhile, the x-, y-, and z-coordinates corresponding to the cutplanes, as well as the pixel value at the point, are shown in the window to provide numerical references.

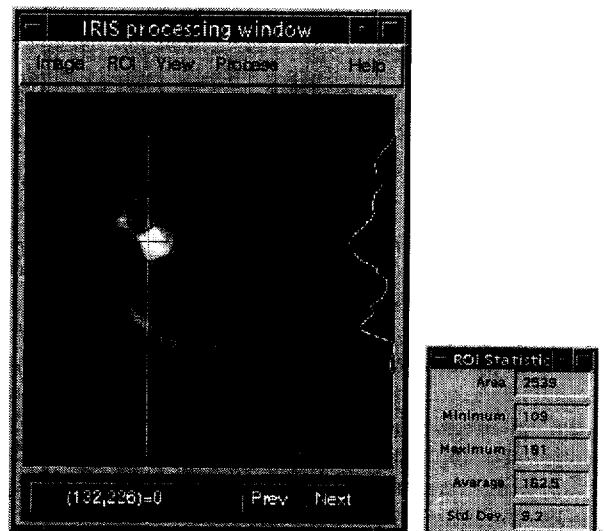


Figure 5. An example of regional analysis tool for ROI statistics.

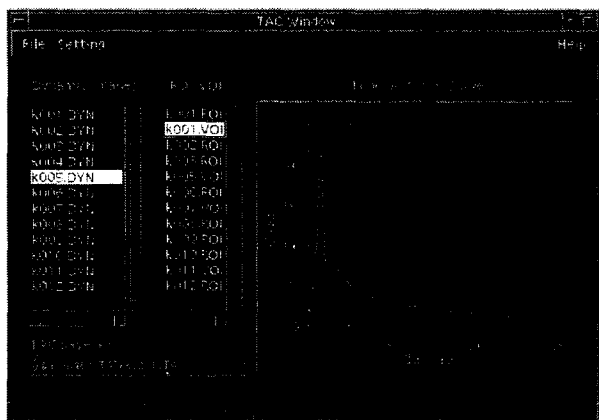


Figure 6. For dynamic functional image study, time-activity curve display can be generated.

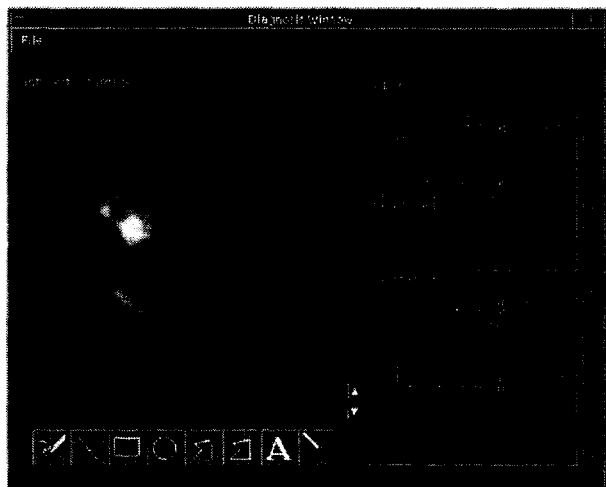


Figure 7. User interface for accessing image diagnosis, report, and annotation information from system database.

(B) ROI analysis

As shown in Fig. 5, an image file is loaded into memory; one of its slices is magnified and shown. User's mouse can be placed at any position on the displayed slice to examine the position and pixel value. All the slices can be browsed by click on Prev/Next buttons. The pixel value profiles corresponding to the x- and y-planes through the position of the mouse are superimposed at the right and bottom edges of the image, with calibration levels set at 100 and 200 for references. ROI can be drawn manually or automatically according to the pixel value variation. The drawn ROI is locally editable to correct unwanted

local shapes. The ROI statistics, such as area, maximum, minimum, mean, standard deviation, is immediately calculated after ROI is determined. The drawn ROI can be saved as file for later retrieval in order to compare the statistics of the same ROI but on other images, which is the essential tool for PET dynamic studies. This operation window can be magnified up to 4 times for easy identification of image details. Basic image processing tools, like thresholding, edge detection, thinning, and pruning functions, are also provided in this window.

(C) Time-activity curve

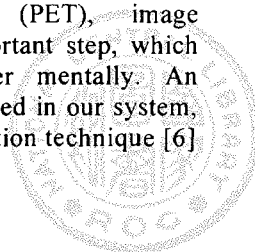
The dynamic image is composed of a series of image recorded at different time frames. For example, in PET dynamic studies, the distribution of the labeled pharmaceutical tracer is changed with time. Therefore, the images at a series of time can reflect the biological and biochemical processes of organs of interest providing important metabolic function information. In Fig. 6, the dynamic image file is selected, so is the ROI/VOI file, and the corresponding time-activity curve is thus generated on the right. The curve information can be saved into file for further curve modeling to get the insight of the region of interest.

(D) Image annotation

In the window shown in Fig. 7, image in the database can be retrieved to do diagnostic report and annotation, and then saved back with the textual information. Basic drawing tools, like free-hand, line, rectangular, circle, polygon, alphabet, eraser, are provided for image annotation. In report area, physician's general descriptions, notifications, and comments can be typed; in annotation area, the explanations of the annotations recorded on the image to provide quick understanding about the annotated image. This window also serves as a file teaching tool or as a communication platform between distant reviewers.

(E) Image registration

To combine information from different imaging modalities, such as anatomical images given by computed tomography (CT) and magnetic resonance imaging (MRI), and functional images given by single photon emission computed tomography (SPECT) and positron emission tomography (PET), image registration or matching is an important step, which has been done by image viewer mentally. An automated registration tool is provided in our system, which uses the elastic image registration technique [6]



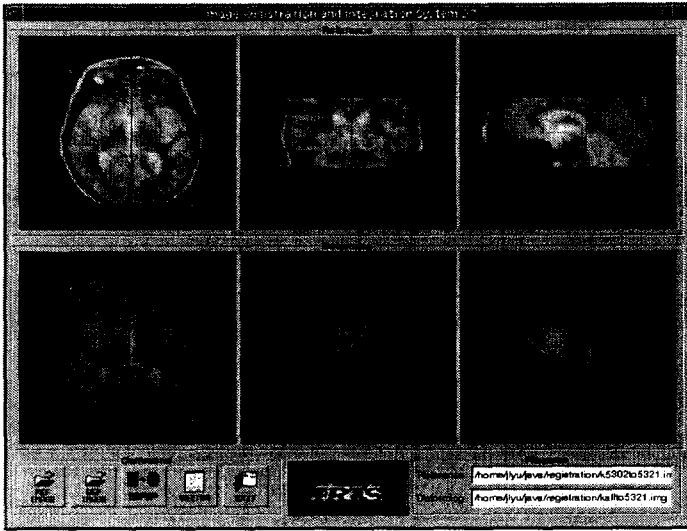


Figure 8. Easy-to-use user interface for inter/intra-subject image registration.



Figure 9. An example of true-color 3D image surface rendering and 2D image fusion.

for inter-subject studies. For intra-subject studies, the rigid image registration mode can be selected for the matching process. The operation is especially easy. The reference image and deforming image are input by click of buttons for loading image; rough frames for linearly matching of the two image as a preprocess of image registration are decided by mouse drag of the frame handles. The registration process starts after the map button is pressed, as shown in Fig. 8. As far as the elastic image registration is concerned, on average, 20-30 minutes are needed for one study on a Sun Sparc 20 workstation.

(F) Image visualization

In addition to 2D image display to simulate the conventional review of films, the system provides also 3D image visualization to add value to image interpretation. The registered images can be 3D surface or volume rendered to present accurate spatial relation between tissues, or the concept of the size of the tissue of interest. For 2D images, the true-color image fusion technique also provides the proportional overlay function to combine image information from different modalities, as shown in Fig. 9.

B. Applications

In this subsection, we present the results of inter-subject image registration among six normal subjects, and intra-subject image registration of abnormal

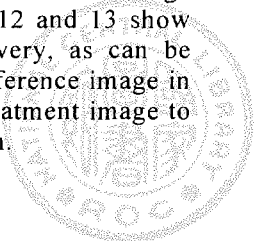
subject between two time frames.

(A) Inter-subject image registration

The registration accuracy of the elastic image registration technique is validated using MRI and FDG-PET images of six subjects. One subject's MRI and PET images are taken as reference images, to which other five subjects' MRI-PET registered MRI images are mapped elastically, and therefore the PET images are also registered to the reference according to the mapping vectors generated in the MRI-MRI mapping. As can be seen in Fig. 10, the result presents a satisfactory image matching.

(B) AVM study

The patient had been suffering AVM, a kind of brain tumor, when the patient received gamma ray treatment. Due to the image mis-alignment between pre- and post-treatment, the image difference reflecting blood flow recovery can not be possibly observed with naked eyes. However, after image registration, the comparison can be made with either eyes or computer. Fig. 11 shows the selected pre- and post-treatment image slices before and after registration, as well as the difference image calculated on a pixel basis. Slices 12 and 13 show the most evident blood flow recovery, as can be seen in Fig. 12. The thresholded difference image in color is superimposed on the pre-treatment image to show the blood flow recovery region.



IV. DISCUSSION AND CONCLUSION

The architecture and functions of the Internet based medical image processing system have been described in the preceding sections. However, the system, as in its first development phase, still has much space to improve. In this section we discuss some aspects of the present system, which also are the key topics in the future development of the system.

In the image source part, the mechanism of pushing image data from medical imaging facilities to the image database server workstation has yet been fully automatic. A few personnel should be responsible for the data transfer into the SQL-based image database system, so that the system administrative workstation can query the newly generated data records. The automation of the data transfer requires the design and implementation of the interface between the image acquisition computer in the imaging facility and the database system. Therefore, before this has been done, the queried image database record set would not be the newest until the routine or special required update and also additional human resource or expanse should be paid for the task.

With the present version of JDK 1.1.3, the Java bytecode speed is indeed very much slow--as much as 25 times slower than native executable code. In the cases of very processor-intensive operations, like the elastic image registration, kinetic modeling, and 3D visualization programs, the Java-based system starts to come up short in comparison to native codes. However, that does not necessarily make the Java-based system unbearable to use, if the multi-threading technique is properly used, which distracts user to other operations and runs the original tasks in background. Nevertheless, we still expect JavaSoft to continue making effort on Java virtual machine efficiency promotion. On the other hand, although the user-friendliness has been one of the emphasized concerns in the development of the system, the present system still lack of use of the convenient image record folder management facility. This makes the search of data sets under specific query conditions inconvenient, and somewhat lowers the physician's willing to use. To improve this, the better and consistent solution is to include the well-established Java Bean components for folder management.

The multimedia, and the Digital Imaging and Communication in Medicine (DICOM) standards have not been incorporated in the present system. For future versatility and connectivity of the system to industrial standard equipments, these two issues should be studied seriously [9]. In addition, the Web-station of the present system, which allows users to download

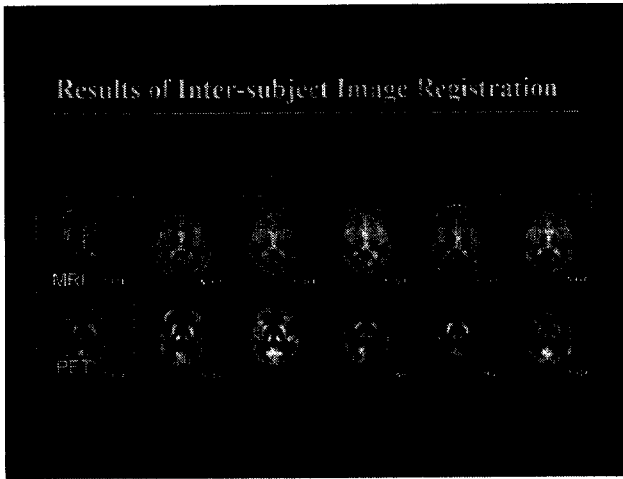


Figure 10. Results of MRI-PET inter-subject image registration among six normal subjects.

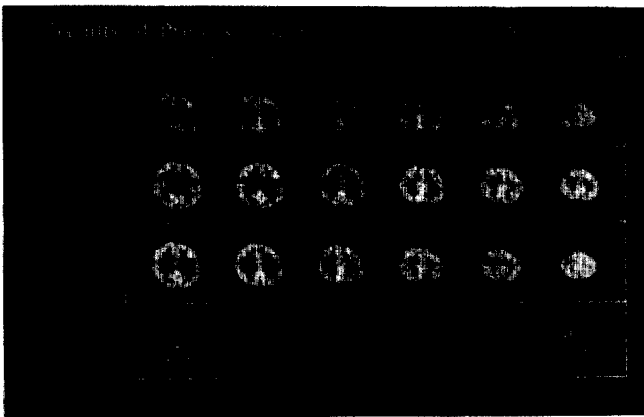


Figure 11. Results of pre- and post-treatment image registration of an AVM patient.

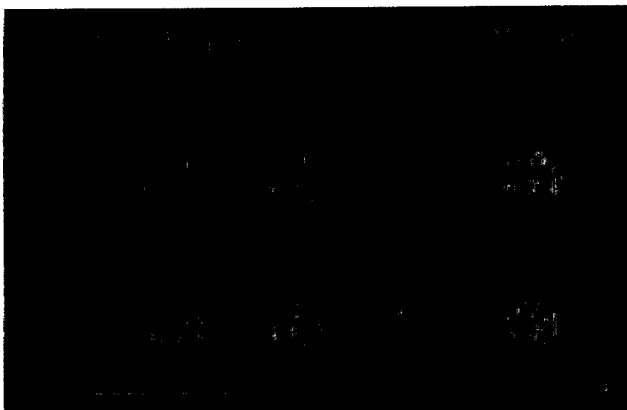


Figure 12. Results of image fusion of blood flow recovery region for clinical comparison.

the system programs from WWW by a Java-enabled Web browser and run inside an HTML Web page, is an unavoidable future trend.

In conclusion, we have implemented the first-generation Internet based medical image processing system connecting two major medical centers and one university laboratory in Taiwan. The client/server design of the system can provides clinical and research users with the interactive displaying, registration, visualization, and analysis of tomographic images. The whole system has been implemented with Java technologies to ensure the highest cross-platform ability and network security. For the present system fully relies on the existing Internet technologies and protocols, the physical limitation of the Internet also is the networking limitation of the system, and the emerging Java technologies, however, make the unlimited parts outstanding.

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以爪哇技術開發之醫學影像處理系統

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摘要

本文提出一以網際網路為基礎之醫學影像處理整合系統, 以提供電腦斷層影像之顯示、對位、視覺及分析為目的。本軟體系統係使用數種爪哇技術, 發展一於網際網路上運作之用戶/伺服器網路架構。本系統已連接位於中原大學系統研究室之系統管理工作站, 和分別位於國家多目標醫用迴旋加速器中心與成功大學附設醫院之分散式影像資料庫工作站。專案導向式的伺服器可依需要連接至本系統, 提供與專案相關之影像資料和功能, 而用戶可透過不同的電腦平台連接至伺服器, 以一致之使用者介面靈活操作本系統。文後並針對系統諸方面提出討論。

關鍵字：網際網路, 電腦斷層影像, 對位, 爪哇, 用戶/伺服器。

