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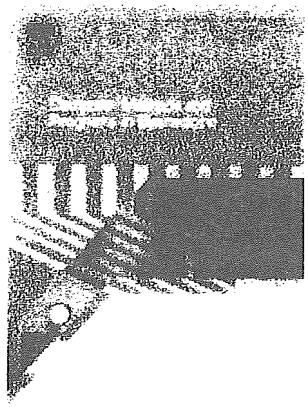

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Dear Mr. Hidenobu Tachibana

It is my honor and pleasure to inform you that the above paper has been accepted for publication in the Computer Methods and Programs in Biomedicine.

Further information will be provided as soon as possible.

Best regards,

Hiroshi Takeda,

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Design and development of a secure DICOM-Network Attached Server

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ABSTRACT

It is not easy to connect a web-based server with an existing DICOM server, and using a web-based server on the INTERNET has risks. In this study, we designed and developed the Secure DICOM-Network Attached Server (DICOM-NAS) through which the DICOM server in a hospital-LAN was connected to the INTERNET. After receiving a Client's image export request, the DICOM-NAS sent it to the DICOM server with DICOM protocol. The server then provided DICOM images to the DICOM-NAS, which transferred them to the Client using HTTP. The DICOM-NAS plays an important role between DICOM protocol and HTTP, and only temporarily stores the requested images. The DICOM server keeps all of the original DICOM images. When unwanted outsiders attempt to get into the DICOM-NAS, they cannot access any medical images because these images are not stored in the DICOM-NAS. Therefore, the DICOM-NAS does not require large storage, but can greatly improve information security.

Introduction

In recent years, many hospitals have installed high-tech medical equipment, including Computed Radiology (CR), Computed Tomography (CT), and Magnetic Resonance Imaging (MRI) [1]. Researchers and developers have attempted to combine this equipment with information technology (IT) to improve the quality of medical care. Web-based servers, which have enabled us to display patients' medical images on computers using Internet Explorer, have been especially developed. This allows medical physicians and other researchers to easily share and view these medical images anywhere when needed. However, the use of web-based servers also brings many problems [2-13].

Since most servers were originally designed for vender-customized DICOM servers, their versatilities are not very good. Therefore, users must install a web-based server combined with a particular DICOM server for medical use. This is sometimes not feasible because of technical and financial reasons. On the other hand, in order to distribute the medical images, patients' information must be stored in the servers at all times. Therefore, the misusage risk of patients' information becomes higher.

The present study developed a web-based server called the DICOM-Network Attached Server (DICOM-NAS), which can be easily installed and adjusted to DICOM protocol and HTTP. The DICOM servers in a hospital-LAN are connected to the INTERNET through the DICOM-NAS, and the patients' medical images and information are only kept temporarily in the DICOM-NAS when eligible clients need them. Since the patients' medical images are not stored there at all times, it greatly improves information security.

1. DICOM-Network Attached Server

1.1 Scheme of DICOM-NAS

The DICOM-NAS scheme is illustrated in Fig. 1. It communicates with the DICOM server by using the DICOM protocol when it is attached to the Local Area Network (LAN). An IP address, AE title, host name, and port number were assigned to the DICOM-NAS. In order to view the DICOM images, the Client can use the browser in any computer to connect to the LAN, the INTERNET, and then to the DICOM-NAS.

1.2 System configuration of DICOM-NAS and data flow

Figure 2 demonstrates the system configuration of the DICOM-NAS and the data flow. The DICOM-NAS can work with Internet Information Server (IIS) 5.0 on Microsoft Windows 2000 or XP and consists of Java Applets, Java Servlets, and DCMTK. The Java Servlets work with application servers Tomcat 4.0.1 and IIS 5.0 to provide a highly reliable, manageable, and scalable web application infrastructure for all versions of Windows 2000 and XP. The IIS can increase website and application availability and lower the system administration costs. Java Servlets provide a component-based and platform-independent method for building web-based applications without CGI program performance limitations. Java Servlets can access the entire Java API family, including JDBC API, to access enterprise databases and a library of HTTP-specific calls. They have all of the benefits of mature Java language, including portability, performance, reusability, and crash protection. Tomcat 4.0.1 is the servlet container that can improve performance and memory efficiency. DCMTK [14] is a collection of libraries and applications that implement large parts of the DICOM standard. It includes software for examining, constructing, and converting DICOM image files, as well as sending and receiving images over a network connection.

In this DICOM-NAS system, the Java Applets are the interfaces between the Client and the Java Servlets. The Java Servlets communicate with the DCMTK and the Diagnosis report database based on the information obtained from the Java Applets. The DICOM-NAS communicates with the DICOM servers using two applications, including DCMTK, which has the C-FIND and C-MOVE functions.

When a Client wishes to access the medical images of a patient, the Client should first connect to the DICOM-NAS using Internet Explorer and request a patient name or a patient name list, which is stored in the DICOM server. After receiving the request, the DICOM-NAS generates query keys related to the request and sends them to the DICOM server (C-FIND request). The DICOM server then responds by sending the patients' information list to the DICOM-NAS (C-FIND response). The DICOM-NAS extracts information from the responses and sends the related patient's information to the Client's computer. After selecting a particular patient from the list, the Client can obtain the patient's study information list through a data flow similar to the patient's information. The Client can then select a study from the list to obtain the images. The DICOM-NAS generates and sends the request-related query keys to the DICOM server (C-MOVE request). After the DICOM server accepts the request for the patient's images, the images will be copied into the DICOM-NAS, and then sent to the Client's computer. Once all of the images have been sent, they are immediately deleted from the DICOM-NAS.

1.3 Graphical User Interface (GUI) of the DICOM-NAS

The GUI of the DICOM-NAS for Query/Retrieve is displayed in Fig. 3. When the DICOM-NAS receives a particular patient's information or all of the information based on a Client's request, the information will be displayed in the patient list space. When the

Client clicks on a particular patient's ID or name, the patient's study information will be displayed in the study list space. When the Client clicks on a study date, modality, or study ID, the DICOM images of the study will be displayed on the browser.

The GUI of the DICOM-NAS for the DICOM web viewer is shown in Fig. 4. Since this viewer is an HTML document, it embeds a Java Applet that can perform a dynamic process, which a static HTML document cannot do. The Client can view the images using image-processing functions, such as WL/WW, Zoom, and cine mode.

The DICOM-NAS can be used to manage, create, and view diagnosis reports [15-17]. When the Client clicks the "Report" button on the viewer, the report window will be displayed (Fig. 5). After the necessary input, the diagnosis report will be sent back to the DICOM-NAS. The information will then be stored in the Diagnosis report database. In order to read the diagnosis information stored in the DICOM-NAS, the client needs to input the URL of the page that contains the information. When the Client accesses the page, the DICOM-NAS will extract the particular diagnosis information from the Diagnosis report database and transfer it to the Client's computer.

2. Materials and Methods

The DICOM-NAS is a PC with a PentiumIII 1 GHz CPU having a 512 MB memory and a 60 GB hard disk. The DICOM server has a Pentium II 400 MHz with a 384 MB memory and a 10 GB hard disk. The Client computer has a Pentium IV 2.8 GHz CPU with a 1 GB memory and a 120 GB hard disk. The LAN connections are either a 10 Mbps cable line or 100 Mbps cable line. The INTERNET connection used was the ADSL (Asymmetric Digital Subscriber Line, Max: 24 Mbps, Average: 7.216 Mbps).

In order to evaluate its performance, the DICOM-NAS was connected to two kinds

of standard DICOM servers and a Client's computer with LAN and the INTERNET. The DICOM-NAS was able to communicate with both the DICOM servers and the Client's computer. After transferring the images from the DICOM servers to the Client's computer, it will immediately delete all of the images. The downloading time, defined as the time needed for downloading 45 slices (12.8 MB) of CT images (abdomen, 512 × 512, 8 bit, 292 kB/slice) from the DICOM servers to the Client's computer, is measured in four kinds of network configurations (Fig. 6). This time period is 10 times.

3. Result

3.1 Performance

The DICOM-NAS was connected to two different DICOM servers, the Image Central Test Node (distributed by Kuratorium OFFIS e. V., University of Oldenburg) and DgS Image server (provided by DgS Computer Co., Ltd.). The Client was connected to the DICOM-NAS through the LAN or the INTERNET. After receiving a request for images from the Client's computer, the DICOM-NAS was able to download the DICOM images from each of the servers, and then sent the images to the Client's computer. When the Image Central Test Node and DgS Image server were both used, the DICOM-NAS was still able to download and transfer the DICOM images. Furthermore, the DICOM-NAS would immediately delete all of the images downloaded from the DICOM servers after the transfer was completed.

3.2 Measurements

The time required to download 45 CT image slices from the DICOM servers to the Client was measured in this study. The average and standard deviation of the

downloading times are listed in Fig. 7. These images were transferred from the DICOM servers to the DICOM-NAS using DICOM protocol, and were then transferred to the Client using HTTP, excluding the LAN1 that the Client was directly connected to DICOM servers and was used for downloading the images with HTTP. When the Client was directly connected to the DICOM servers with a 10 Mbps line (LAN1), the downloading time was 16.92 sec (SD: 0.3438 sec). When the Client was connected to the DICOM servers through the DICOM-NAS using cable lines of 10 Mbps (LAN2) or 100 Mbps (LAN3), the downloading times for these images were 32.86 sec (SD: 0.3298 sec) in LAN2 and 23.45 sec (SD: 0.2119 sec) in LAN3, respectively. When the DICOM-NAS was connected to the Client through a 24 Mbps (max) ADSL line and connected to the DICOM servers through a 10 Mbps lines (INTERNET), the downloading time was 46.82 sec (SD: 3.250 sec). The standard deviation of the INTERNET was the largest in four network configurations. A comparison of the connecting methods LAN1 and LAN2 revealed that the downloading time increased by 94.2%. However, a comparison between LAN2 and LAN3 revealed that the downloading time decreased by 28.6% when a faster network was used. A comparison between LAN3 and the INTERNET showed that the standard deviation of the INTERNET was larger than that of LAN3, and that the downloading time increased by 42.5% when the INTERNET was used.

4. Discussion

Today, many web-based DICOM servers and viewers can share images from anywhere using Internet Technology (IT) and browsers; some of the images are distributed for free. However, many of them only have the function to display the DICOM images and do not have the Query/Retrieve function [3-7]. Others may have both

functions, but the Query/Retrieve function depends on particular image databases [8-13]. In general, a patient's original images generated by CTs or MRs in hospitals are stored in DICOM servers. Therefore, extra servers that have large storage devices for image storage must be installed anywhere inside or outside a hospital, and this (using IT, but that) would cost a large amount of money. As an alternative method, a web-based server could be used to store the patients' original images to reduce the installation cost; however, the threatening risks of invading the patient's privacy are higher because an attacker can steal and modify the images via the INTERNET. We therefore designed and developed the DICOM-Network Attached Server to solve the cost and security problems. The DICOM-NAS can communicate with two different DICOM servers, and it enables the Client to obtain medical information and images from the DICOM servers. The DICOM-NAS plays an important bridge role between the DICOM protocol and HTTP and can immediately delete all information and images downloaded from the DICOM server after transferring them to the Client's computer. Since the DICOM-NAS only temporarily stores the requested images, and the DICOM servers keep all of the original DICOM images, unwanted outsiders attempting to access the DICOM-NAS cannot access any patients' medical information.

Figure 7 illustrates that the downloading time increases when the DICOM-NAS is used. After the Client requests to download the images, all of the images are temporarily stored in the DICOM-NAS. This extra information transfer and temporary downloading time increases the total working time. However, using faster cable lines can reduce this increase. According to our experience, the increased time by DICOM-NAS could be very small when the FTTH (Fiber To The Home), a faster ADSL, or a faster PC is used.

5. Conclusion

The DICOM-NAS developed in the present study has the following features: (a) It plays a bridge role between the DICOM protocol and HTTP. (b) It does not require a large amount of storage and can improve information security to better protect patients' privacy. (c) It can easily install, transfer, and distribute information and images stored in the DICOM servers. When medical images are transferred from the DICOM-NAS to the Client, image confidentiality can be improved on the INTERNET using VPN (Virtual Private Network) technology [18].

The DICOM-NAS program can be downloaded for free from the website http://umeken3.ahs.kitasato-u.ac.jp, and can be easily installed. In conclusion, the DICOM-NAS is useful because of the above-mentioned advantages, and it does not generate much cost.

6. Acknowledgement

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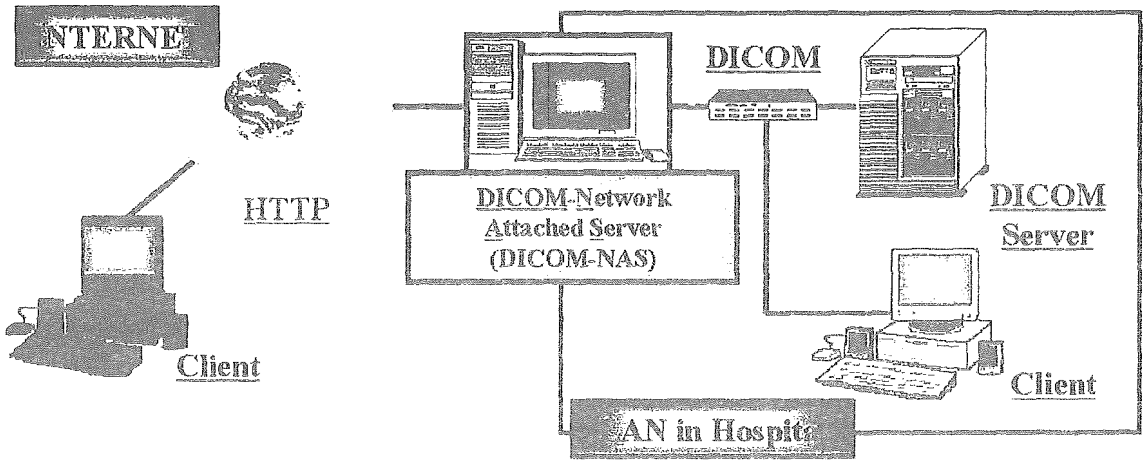

Fig.1 Scheme of DICOM-Network Attached Server

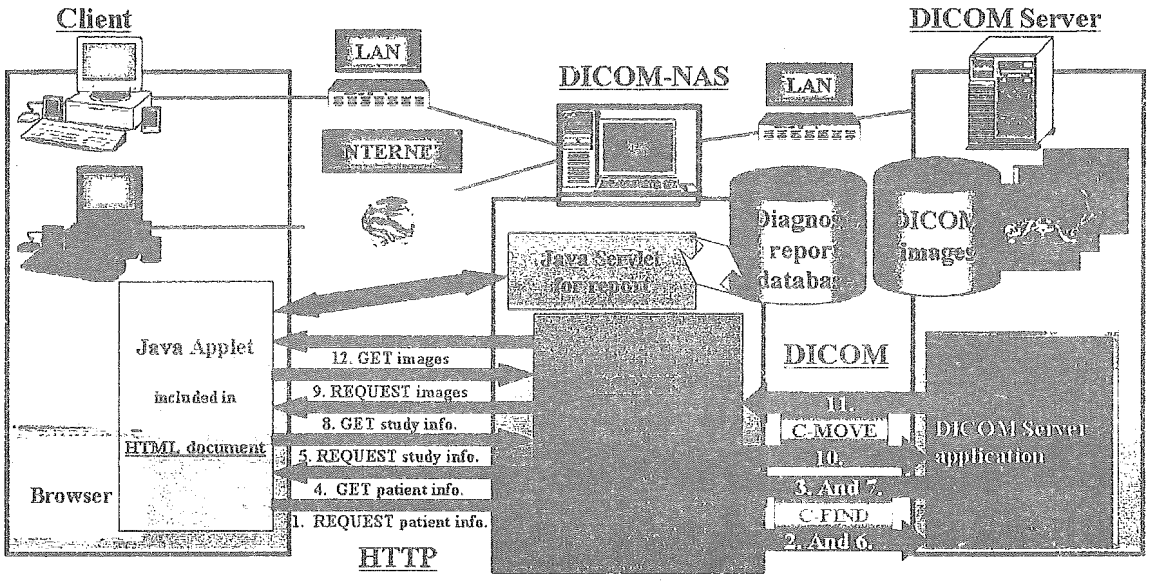

Fig.2 System configuration of DICOM-NAS, and data flow after downloading Java Applet that have the functions of Query / Retrieve and display of DICOM images from DICOM-NAS

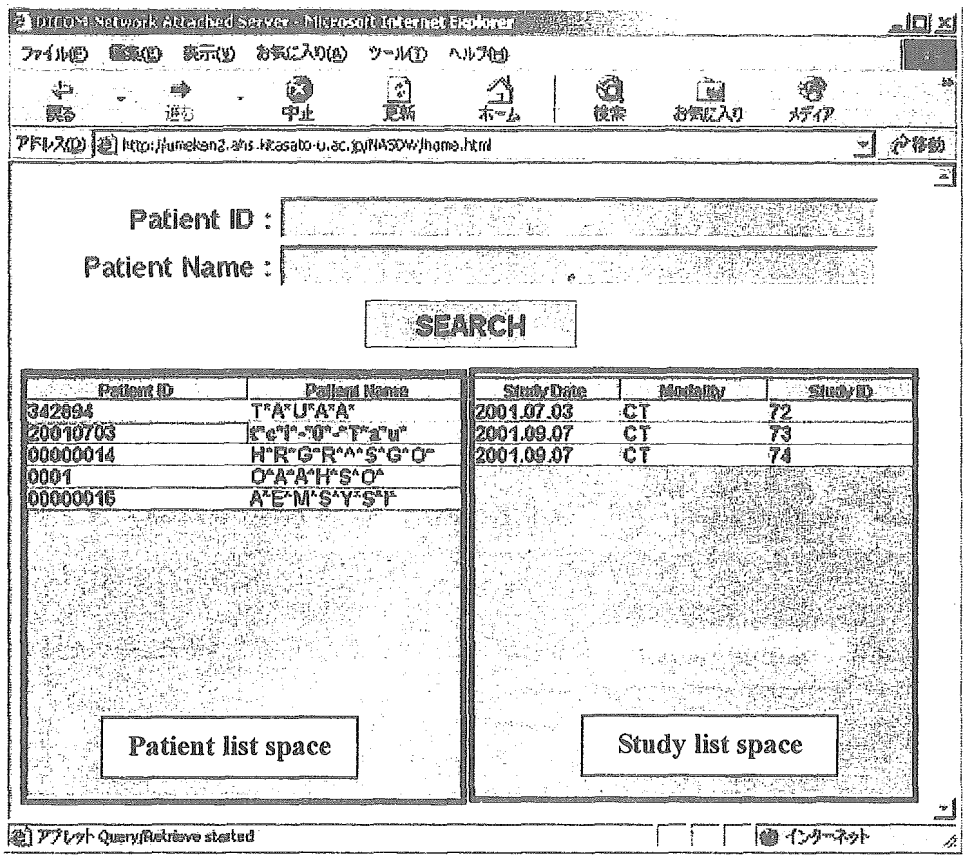

Fig.3 GUI of DICOM-NAS (Query/Retrieve)

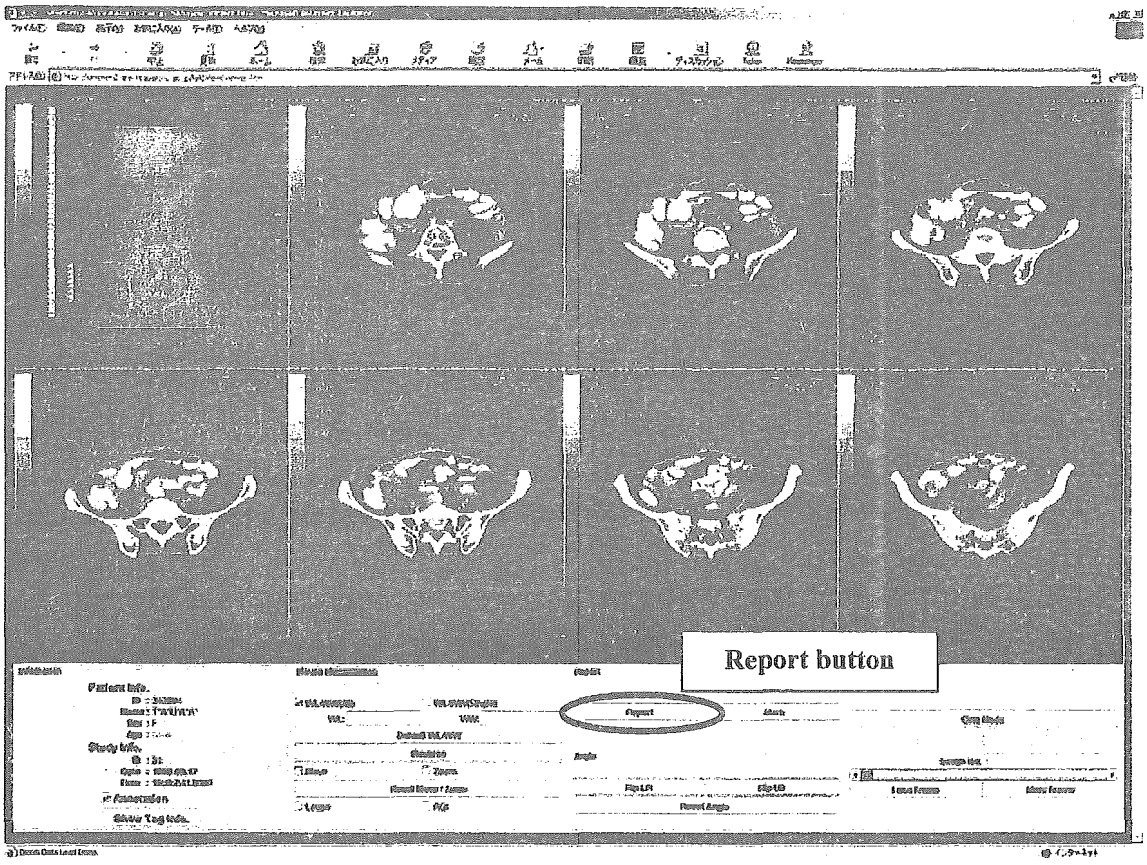

Fig.4 GUI of DICOM-NAS (DICOM web viewer)

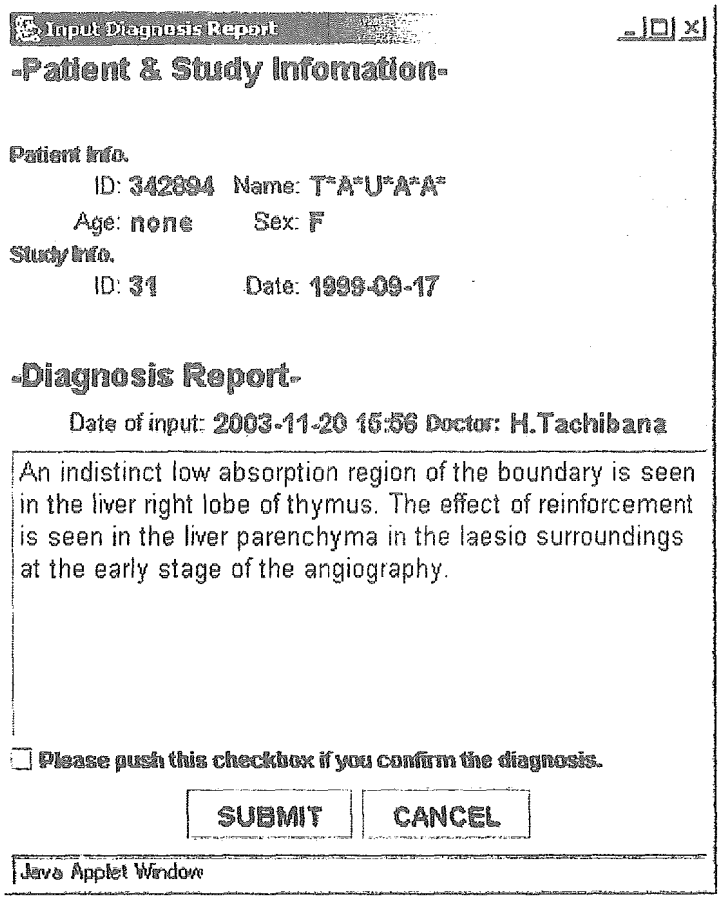

Fig.5 Screenshot of a window for inputting diagnosis report