Remote Access to Radiotherapy Treatment Planning Information: Demand Analysis and Prototype Implementation

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Digital data from radiotherapy treatment planning systems (RTPS) is generally used for patient planning only, but it also contains enormous quantities of valuable information regarding patient anatomic geometries, tissue outlining, treatment approaches and dose distribution. Attempts on implementing a Web-based digital archiving system (DAS) in order to provide immediate access to the treatment planning information were described in this article. The DAS served as a universally virtual printer for diverse RTPS, and it could transparently intercept print job and archive them into its database automatically. These treatment planning images such as dose distribution images, dose volume histograms (DVHs), and digitally reconstructed radiographs (DRRs) in the DAS were registered to the Apache Web server by Coppermine photo gallery, and were made available for authorized users to search and browse using a simple Web browser. This prototype allowed for rapid review and remote comparison of treatment plans efficiently and conveniently.

Key words: Radiotherapy; Radiotherapy treatment planning system; Telemedicine

Dose distribution images and dose volume histograms (DVHs) generated by radiotherapy treatment planning systems (RTPS) play important roles in radiotherapy [1-4], because clear documentation of dose prescription, specification, and reporting are paramount for tissue toxicity and treatment outcome evaluation [5, 6]. Hard copies of these images are stored and made available for referral by radiation oncologists as needed [7-9]. In most cases, these images are not readily available to medical personnel outside the radiation oncology department [9-13].

Paper printing has many limitations: Vast quantities of paper are involved; each copy must be updated when any change is made; there are a limited number of copies confined to specific locations; and only one person can access a copy at a time [14]. In order to view such images directly, multiple visits may be required to different locations and offices for each patient. Therefore, many hospitals have struggled to change a paper-based archiving system into a digital archiving system (DAS). However, most commercially available RTPS do not support electronic treatment chart or computer-based patient record (CPR) natively. The facility of exporting images and reports generated by RTPS to a picture archiving and communication system (PACS) or hospital information system (HIS) directly is still limited.

Nearly every member of staffs in the radiation oncology department has access to a networked personal computer (PC), and it is therefore both possible and desirable to provide access to the printout of RTPS on-line [15]. Commercially available radiation oncology information systems, supporting both Web-based review of treatment planning information and a wide range of RTPS from different manufacturers using various operating systems, are not well-established [16]. This article described a preliminary implementation of a Web-based
review system which was capable of auto-archiving and electronic distribution of treatment planning information within a radiation oncology department.

MATERIALS AND METHODS

Design considerations

In the field of radiation oncology, many attempts are made to store medical information electrically and promote the efficacy and quality of radiotherapy [8, 17, 18]. Most radiation oncology departments have already taken steps in developing a networking infrastructure to meet the increasing demand for connectivity and higher bandwidth to the desktop workstations [19, 20]. Although the Digital Imaging and Communications in Medicine (DICOM) implementation has provided an efficient method of transferring cross sectional images from diagnostic radiology to radiation oncology department, elegant archiving systems for radiotherapy treatment planning reports and images are not well established [18, 21, 22]. Consequently, we developed an in-house system that enabled our treatment planning process to be managed better.

Like most radiation oncology departments, our equipment is heterogeneous with respect to manufacturers and computer operating systems (OS). In order to retrieve the printer-ready data from heterogeneous RTPS in a multi-OS and multivendor environment, we used a client-server architecture which was able to provide a central printer queue service for direct connection to a variety of remote Line Printer Daemon (LPD) clients such as RTPS. The prototype system had been constructed such that automatic data transfer could occur between disparate systems.

System description

This DAS served as a virtual PostScript printer for RTPS. It transparently intercepted print jobs and archived these PostScript printout files into its database automatically. A diagram of the flowchart using the DAS was shown in Fig. 1. A captured PostScript file consisted of a text header portion which contained demographic information from RTPS and an image bitmap portion. Therefore, medical chart number could be found in these PostScript files independent of its position by using the pattern matching method to look for the format of the medical chart number. A shell script was constructed to extract the medical chart number from these PostScript files and convert them into image files in Joint Photographic Experts Group (JPEG) format for viewing via a Web browser. All the images of each patient which were organized into an individual album and named by the unique medical chart number were eventually stored into the image database based on Coppermine Photo Gallery, which was an open source software. Users could view these images in thumbnails, which were created swift with a Web browser. The administrator who was the medical physicist in charge of RTPS could manage the albums and images in the image database via the Web interface, too. He had the authority to delete the uploaded images in the presence of error or to remove the misprinted images of unapproved plans. The built-in print accounting function in LPD service would log the entire processing history of every PostScript file. (The shell script along with the source code can be freely supplied upon request to the author by e-mail.)

This DAS used the GNU/Linux operating system (Red Hat 9.0 Linux distribution) and Apache Web server on an AMD XP 2500+ Processor with 1 GB of RAM. Short-term storage capacity was more than one year with routine usage of an 80-GB hard drive. The long-term mass storage media consisted of a DVD burner, which could be used to backup the image database periodically, or to restore it on demand.

RESULTS

We had implemented a prototype system consisting of a central printer queue and an image database server providing a Web-based interface of a collection of radiotherapy reports and images. It automatically archived printout from RTPS, and additional manpower to scan or transform paper documents into digital format was not required. These images in the image database were registered to the Apache Web server and were available for searching and browsing via the Web browser.

The only requirement for the RTPS to use the DAS was the functionality to support remote LPD printing, which was a built-in function of UNIX-based RTPS for printing of treatment parameters and relevant images. Windows-based RTPS supported TCP/IP-based printing which was compatible with LPD protocol, and therefore we could configure them to print a remote print server easily. When a user wanted to submit treatment planning data or images to the DAS, the user simply printed them to the virtual printer of the DAS. The procedure was exactly the
Remote access to radiotherapy treatment planning information

The DAS transformed the PostScript files to industry-standard JPEG images automatically, and stored them in the image database. The image quality was set to 184 dpi, while 1/5 data compression maintained image quality well. Converting the whole set of treatment planning data for one single case, including about 10 image-pages, spent less than 5 seconds, and cost only 5 Mbytes for storage.

We used the authentication feature of Apache Web server to protect patient information privacy. After entering the correct user name and password, the DAS provided a friendly Web browser-type interface of the output of RTPS in digital image format. The objective of the security implementation was to achieve at least the same level of security which existed with the paper system. These digital documents in the form of JPEG images could be printed later, using Web browser, on color or black-and-white printers. Additional software installation was not required for the client side. Not only PCs but also Personal Digital Assistants (PDA) could have access to this Web-based DAS as long as network connection and Web browser were ready. After entering the medical chart number to search, this system returned the search results as a Web page (Fig. 2). Thumbnails, which could be enlarged to the full-size images by clicking the icon, were created swiftly (Fig. 3). The full-size images display was especially useful for viewing isodose charts superimposed with CT images (Fig. 4). The dose distribution images produced by this system reveal isodose information as clearly as the original RTPS. Therefore, radiation oncologists did not have to be bound to the workstations of RTPS, which were usually occupied in a busy radiation oncology department, for review of treatment planning information.

This Web-based DAS was based on open source software packages, which is a cost-saving software.

Figure 1. A diagram demonstrating the flowchart using the Web-based digital archiving system is shown.

Figure 2. Search results can be viewed in lists of thumbnails.
Remote access to radiotherapy treatment planning information

solution for archiving and delivery of information to multiple digital destinations from any combination of host environments, such as UNIX or Windows-based RTPS. We did not need to purchase software packages from vendors of RTPS or the expensive frame grabber to support the transfer of treatment planning data to the DAS. The most elegant digital solution, easy for end users, was to capture the printer files as they were sent to the printer, and automatically transformed them to the file formats needed for the DAS. Even not DICOM-compliant RTPS could use the universally available LPD printing mechanism for auto-archiving of treatment planning reports and images. This system actualized an electronic archive of dose distribution images in a database available for quick and remote review, evaluation, and comparison of radiotherapy treatment plans. It could improve access to the treatment planning information using Web and internet technologies. Storing printout of RTPS in digital format also enabled both space saving and paperless environment.

DISCUSSION

The exchange of radiotherapy data between various RTPS and different institutions has become an important issue. Olsen et al. define three levels of exchange functionality from basic image display to advanced real-time remote operations [1]. Deasy et al. describe a computational environment for radiotherapy research (CERR) to facilitate reproducible research in radiation oncology treatment planning, which is a very powerful tool for sharing and reproducing treatment planning data from disparate RTPS using the DICOM or RTOG archiving mechanism [23]. However, archiving of treatment planning data in DICOM or RTOG format requires larger storage space. For example, storing treatment planning data of one single case in RTOG format requires about 50 Mbytes. Besides, not all commercially available RTPS support exporting treatment planning information to DICOM or RTOG format. Notwithstanding some RTPS can export the treatment planning data to DICOM format, it is still not as informative as the hard copy.

Although radiation oncology departments usually have a large, multi-platform client environment (such as mixed PCs and UNIX workstations), this DAS requires only a Linux OS on an ordinary PC and operates independently of the client OS and host platform. It converts printer files into high-quality images of the document pages automatically for storage, viewing and searching. The transferring of printouts from RTPS to the DAS is based on the LPD protocol. One of the reasons for this is that printing is such a universal, reliable and comfortable method to get documents out of an application or RTPS. The routine use of printing function in RTPS
can accomplish this task, and additional efforts of uploading treatment planning data to the DAS are not necessary. Therefore, the medical physicists can adapt themselves to the new system easily. In the clinical practice, this DAS requires no significant changes in the already established radiotherapy workflow and has been successfully configured in an acceptable time; on the other hand, the way the information are exchanged and shared dramatically changed towards a paperless and filmless format.

This prototype system was primitive and had several limitations. All the images of each patient were organized by the medical chart number irrespective of the treatment course, hence queries were limited to medical chart number. Radiotherapy treatment planning was such a dynamic process including changing field shape, rearranging beam angle, and recalculating dose distribution that statically printed images were unadvisable for approval of radiotherapy treatment plans. Therefore, the DAS was designed to archive images from approved plans only, and to provide at least the same quantity of treatment plan information which was retained in the paper system. To generically extract key information such as medical chart number from captured PostScript files was one of the most difficult tasks in the implementation of this prototype system. PostScript files from RTPS could provide more demographic information than other types of printer files attributed to their text header portions. The pattern matching method was used to look for the format of the medical chart number independent of its location in these PostScript files. However, we still could not differentiate DVHs from isodose charts in PostScript files, because their text header portions were the same. Consequently, categorization of output images was not implemented.

Seamless integration of all types of patient data is a critical feature for clinical software [24]. Digital archiving of treatment planning information enables smaller storage space, on-line image transfer, image manipulation, and a lower storage cost. This DAS also promised reliable storage and efficient management of treatment planning information. The online treatment planning images could present data in ways not possible with a paper chart or other physical media, because it could provide multiple users with instant access to the same treatment planning information simultaneously at independent work areas (patient examination room, physician’s office, simulation room, treatment planning room, or conference room).

The establishment of the World Wide Web (WWW) has added a new avenue for the delivery and access of medical images and clinical information system [15, 25, 26]. This Web-based DAS could enable telemedicine by allowing remote review of treatment planning and quality assurance of treatment delivery [10, 11, 27]. Patient care can be enhanced by the transmission of treatment planning information to other experts for consultation. It also enables the evaluation of consistency of three-dimensional planning target volumes across physicians and institutions [3, 28], and could be a reliable tool for education and a valuable tool for comparison of different treatment plans at clinical practice.

CONCLUSION

We had implemented an auto-archiving system for storing treatment planning data and images of patients who underwent radiotherapy. The DAS acted as a virtual printer enabling users to convert documents to graphics by simply "printing" them. The familiar procedure let anyone who ever printed documents from RTPS started using this system in no time. The Web-based interface enabled authorized users to view treatment planning images from any PC or handheld device remotely and easily.

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Remote access to radiotherapy treatment planning information

遠端存取放射治療計劃資訊：需求分析與雏型建置

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病患的治療計劃資料除了用於放射治療之外，其中亦包含許多寶貴的臨床研究資訊如解剖位置、組織輪廓、治療方向與劑量分布，本研究嘗試建置一套網頁式數位存取系統籍以提供實時的病患放射治療計劃資訊。本系統簡稱DAS可當作現今市面上不同廠家的放射治療計劃系統的虛擬印表機，自動擷取來自治療計劃電腦的列印資料，並將其轉換成數位圖像儲存於系統資料庫中，這些治療計劃相關圖像如劑量分布圖、劑量體積卡方圖（DVH）、數位重組影像等可經由Apache網頁伺服器與Coppermine圖像軟體加以呈現，唯有經授權的使用者可以在遠端透過網頁瀏覽器操作介面進行檢索與查看圖像，這雏型系統可使不同治療計劃間的檢閱與比較更加方便及更有效率。

關鍵詞：放射治療；放射治療計劃系統；遠距醫療