Development and Evaluation of a Low-Cost and High-Capacity DICOM Image Data Storage System for Research

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Thin-slice CT data, useful for clinical diagnosis and research, is now widely available but is typically discarded in many institutions, after a short period of time due to data storage capacity limitations. We designed and built a low-cost high-capacity Digital Imaging and COmmunication in Medicine (DICOM) storage system able to store thin-slice image data for years, using off-the-shelf consumer hardware components, such as a Macintosh computer, a Windows PC, and network-attached storage units. "Ordinary" hierarchical file systems, instead of a centralized data management system such as relational database, were adopted to manage patient DICOM files by arranging them in directories enabling quick and easy access to the DICOM files of each study by following the directory trees with Windows Explorer via study date and patient ID. Software used for this system was open-source OsiriX and additional programs we developed ourselves, both of which were freely available via the Internet. The initial cost of this system was about \$3,600 with an incremental storage cost of about \$900 per 1 terabyte (TB). This system has been running since 7th Feb 2008 with the data stored increasing at the rate of about 1.3 TB per month. Total data stored was 21.3 TB on 23rd June 2009. The maintenance workload was found to be about 30 to 60 min once every 2 weeks. In conclusion, this newly developed DICOM storage system is useful for research due to its cost-effectiveness, enormous capacity, high scalability, sufficient reliability, and easy data access.

KEY WORDS: Data storage, archive, computed tomography, PACS, thin-slice CT

INTRODUCTION

Multidetector CT (MDCT) scanners can now generate submillimeter isotropic volumetric images, providing a detailed view of normal and pathological anatomy. These thin-slice data are very useful for both clinical diagnosis and research, but are typically stored for only a short

period of time due to the storage capacity limitations of picture archiving and communication system (PACS) in many institutes.^{1,2} The cost of increasing the storage capacity sufficiently to save all thin-slice data of all MDCT studies for years is currently prohibitive for many institutions.³

At Kyoto University Hospital (KUH; Kyoto, Japan) thin-slice data are produced by five MDCT scanners: about 0.4 gigabyte (GB) per average study: about 50 GB per clinical day, 1.3 GB per month, and 15 GB per year. These data are transferred to a clinical DICOM server for temporary storage and are used to create maximum-intensity projection, multi-planner reconstruction, and/or volume-rendering images. The data are automatically discarded after about 6 months due to storage limitations, whereas the thick-slice data are transferred to the clinical PACS and stored for years. This clinical system is supposed to correspond with phase 2, which is centralization of thin-slice data with temporary storage, as proposed by Meenan et al.¹

We have built a massive low-cost high-capacity (LCHC) MDCT data storage system, independent of the clinical PACS system, to enable us to save and store all the KUH thin-slice data for years and to make these data available at any time for

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research purposes. If combined with this storage system, the clinical system can be used as a virtual phase 3 system,¹ which is thin-slice archive as part of the medical record, though limited to research purposes.

We found that there were a number of challenges to implement such an LCHC system, including cost, capacity, scalability, reliability, continuity, usability, and data management.

Clinical PACS is typically very expensive, prohibitively so in the case of research, especially if a very large storage capacity is required. Conversely, the cost of consumer hardware has been continuously decreasing roughly according to Moore's law.⁴ Thus, we chose to purchase low-cost consumer hardware and build a storage system by ourselves from readily available off-the-shelf hardware components.

Hard disk drives (HDD) are advantageous for use as storage media because all data are accessible at any time without loading disks or tapes—rapid random access. But, HDDs are usually disadvantageous for reliability with regards to long-term storage due to their failure rate. Thus, for our HDDs, we adopted RAID5 and saved each datum in two RAID5 systems (i.e., duplicated) in order to prevent data loss.

There are several kinds of interface with HDD or RAID HDD units such as SCSI, SATA, USB, IEEE1394, and Ethernet. We chose Ethernet, network-attached storage (NAS), for three reasons. First, NAS-enabled hardware can be added to the storage system as long as private IP addresses are available, the number of which is about 2^{24} , effectively infinite for our purposes. This is advantageous for capacity and scalability. Second, all data on NAS are available from client machines without any intermediary server machine. This is advantageous with regards to system robustness and response performance to multiple client queries. Third, Ethernet is generally considered to be the most long-lasting and mature interface. This is advantageous for continuity.

DICOM servers typically use relational databases (RDB) to respond to queries from clients. However, our LCHC storage system did not need to duplicate this RDB functionality, as it was already available in the installed clinical PACS system. Thus, we were able to simply implement an "ordinary" hierarchical file system instead of

an RDB, to manage a large number of DICOM data files by arranging them in directories so that DICOM files of each study were easily accessible by following the director hierarchy or shortcuts (.lnk) with Windows Explorer organized by study date and patient ID. The directory hierarchy of the LCHC storage system was designed so that each directory did not have too many sub-folders to enable quick and easy access to each file even if the amount of stored data increased substantially.

MATERIALS AND METHODS

Our LCHC storage system was composed of three programs: (1) a DICOM server to query and retrieve DICOM data from a DICOM server used for temporary storage; (2) a DICOM file arranger to move received DICOM files to NAS; (3) a DICOM file counter to count DICOM files on the NAS system (Fig. 1).

IRB approval was waived because the entire system was built within a dedicated and closed network. However, it is stipulated that any investigation using this accumulated data requires IRB approval.

1. In our institute, all thin-slice data produced by all MDCT scanners were transferred to a clinical DICOM server (TFS-7000, Toshiba Medical Systems, Japan) for temporary storage. The clinical server was set to forward all the data to our LCHC DICOM research server. The research server was configured with OsiriX,⁵ a Macintosh computer (Macmini1,1, Apple Computer Inc., USA), and a RAID HDD unit (RHD4-UXE2.0, I-O DATA DEVICE INC., Japan) with four 500 GB HDDs. The unit was attached to the Mac mini-through a USB interface, set to RAID 5 mode, used to save the thin-slice data as DICOM files by OsiriX,⁵ and shared on the local area network (LAN).
2. The DICOM files were moved from the unit to the NAS system (TS-H2.0TGL/R5 or TS-X4.0TL/R5, BUFFALO Inc., Japan) via the LAN by an arranger program running on a Windows PC. This program was started manually before the unit went full, about once in 2 weeks. This program was developed in-house and is now freely available for download and

Fig 1. Overview of the clinical network and the research network.

use via the Internet as “File Mover”, included in a free package, “YAKAMI DICOM Tools”.⁶ The NAS system in which each file was stored was organized by patient study date because a new NAS unit was added to this system every

Fig 2. Shortcut files to share root directories of NAS and directory hierarchy in each NAS. A shortcut file was named as “20080207-20080405”, for example, to show the range of study date of DICOM files in the NAS.

time a NAS unit became full. A shortcut file (.lnk) to the share root directory of each NAS was created to show the range of study date of the DICOM files in the NAS. Each file was arranged in the NAS by the program as is listed on Figure 2.

This rule prevented each directory from having too many sub-folders, ensured that a file would not be overwritten and enabled quick and easy access to each file. The DICOM files of each study were easily accessible by following directories or shortcuts with Windows Explorer. Once each NAS unit became full, backup copies of all files in the NAS unit were made and saved in another NAS unit to prevent data loss.

To facilitate access to each study folder, shortcuts to it were made and saved in the directory for every patient ID and for every study date. This can be automatically done using a freeware program, named “Shortcut Maker”, included in “YAKAMI DICOM Tools”.⁶ Each shortcut was arranged in a NAS by the program as is listed on Figure 3. These shortcuts substituted for search capability of clinical PACS.

3. All DICOM files in each NAS unit were counted via the LAN by a counter program

Shortcuts arranged by Patient ID

Shortcuts arranged by Study Date

Fig 3. Directory hierarchy of shortcut files to each study directory. One was arranged by its patient ID; another was arranged by its study date.

running on the same PC as the arranger program generating an updated list of studies in the NAS system. This program, which was started manually after the arranger program finished, was also developed in-house and is now similarly freely available for download and use via the Internet as “DICOM Counter”, included in “YAKAMI DICOM Tools”.⁶ Each line of the DICOM file inventory list was composed of patient name, patient ID, modality, number of slices, and study date and time. The list of studies on the clinical server was also generated by OsiriX.⁵ Both lists were sorted in the same order at the same time and visually compared with each other. Slice numbers of each study were also checked in this procedure. If some DICOM data were found to be missing in this LCHC storage system, they were retrieved manually via OsiriX⁵ from the clinical PACS and moved to their proper places in the NAS system by the arranger program, “File Mover”.

The LCHC storage system has now been in use since 7 Feb 2008 and was surveyed on 23 June 2009 according to the following criteria:

1. Amount of data stored
2. Cost
3. Maintenance workload
4. DICOM data integrity
5. Data retrieval speed

The time to load a study containing 496 MB of DICOM files with a DICOM file viewer was measured, “DICOM Viewer”, included in “YAKAMI DICOM Tools”.⁶

The time to copy the same DICOM files to the local HDD with Windows Explorer was also measured.

The machine used was a DELL PRECISION T7400, with two Intel Xeon CPUs running on 3.00 GHz and 16 GB of main memory, and the OS was Windows Vista Ultimate 64 bits.

Table 1. An Analysis of the Thin-Slice Data Stored in the LCHC System on 23 June 2009

Total data size	21.3 TB
The number of studies	38,342 cases
The data size per study (on average)	556.8 MB
The number of slices per study (on average)	1,083 slices

Table 2. The Detail of the Cost to Build the LCHC System, Excluding LAN Environment

Mac mini	\$800
RAID5 HDD unit with USB interface	\$800
Windows PC	\$500
Displays	\$300
NAS	\$1,200

RESULTS

The results of the surveys were as follows.

1. Amount of data stored

The LCHC system stores all thin-slice data of all studies scanned with all MDCT scanners in Kyoto University Hospital since 7 Feb 2008. The data amount stored was 21.3 TB in total on 23 June 2009. The details are shown on Table 1.

2. Cost

Initial cost was about \$3,600 in total, excluding LAN environment. The details are shown on Table 2.

Storage cost was about \$900 per 1 TB. A NAS unit costs about \$1,200, which has four 1-TB HDDs forming a RAID 5 unit with an effective 3-TB capacity. All the data were duplicated, and less than 90% of the capacity was used to preserve data safety. The cost was calculated to be about \$900 per 1 TB with the following expression:

$$\frac{1200 \times 2}{3 \times 0.89} \approx 900$$

3. Maintenance workload

Maintenance workload was mainly composed of occasional maintenance and troubleshooting. The occasional maintenance was found to be less than 1 min once in several days and about 30 to 60 min once every 2 weeks. The details are shown on Table 3.

Table 3. Summary of Maintenance Workloads

Task	Minutes	Interval
Checking OsiriX	1	Several days
Moving and verifying DICOM files	30 to 60	2 weeks
Setting up a new NAS	30	2 month

Troubleshooting was sometimes required due to software/hardware problems. For example, OsiriX⁵ was sometimes terminated due to a runtime error between once a week and once a month. Thus, it had to be monitored and restarted manually. When one of the 84 HDDs in 21 NAS units crashed, it was replaced and re-synchronized. DICOM data transfer was sometimes terminated due to these errors, and some data were missed. They had to be retrieved manually from the clinical server.

4. DICOM data integrity

The numbers of studies and slices had been periodically checked and verified since 7 Feb 2008.

The DICOM files of more than 200 studies now stored on this LCHC system have been used for research; but, to date, no corrupted DICOM files have been found.

5. Data retrieval speed

The loading time of 496 MB DICOM image data using the viewer was 68 s, and the copying time of the same data was 101 s.

DISCUSSION

A new storage system for DICOM image data was developed and used successfully for research for over 1 year. The evaluation results from long-term usage of this system showed that it has high cost-benefit and enough reliability and ease-of-use for research. The LCHC system promises to be a solution for research institutes requiring a data server for huge three-dimensional image data. Although commercially available PACS can be used for research, initial cost and maintenance fees prohibit such an option from being considered if very large image data sets are required to be saved. One of the major advantages of our system is cost per capacity, which is far lower than for a commercially available PACS.

A key feature of the LCHC system is the distributed design, which obviates the need for a centralized server and relational database. The simplified flat file organization and distributed storage provides ease of system scalability and robustness.

Compared with a commercial PACS, however, this LCHC system may be disadvantageous for reliability, response performance, searching stud-

ies, and maintenance workload. Reliability and performance can be improved by duplicating or multiplying NAS units—a trade-off between cost and reliability. Search capability is not required if a clinical PACS is available, but can be supplemented by making shortcuts to study folders in the directory for every patient ID and for every study date. This can be done automatically using a freeware program, named “Shortcut Maker”, included in “YAKAMI DICOM Tools”.⁶ Maintenance workload is another disadvantage; but, it was found to be acceptable in the experience of our research group. Manual comparison of DICOM data in the NAS system with those in the temporary DICOM data server was found to be a major time-consuming problem. We are currently working to develop new programs to automate this procedure.

This LCHC system is also suitable for backup storage, as it has been designed such that data stored on the NAS system should be readable for many years. All hardware and software items needed to read the data are Ethernet, TCP/IP, a file share/transfer protocol (SMB, AFP, or FTP), and DICOM file format. All of them are common and matured. No other devices, interfaces, protocols, or file formats are required to be supported, most of which tend to go obsolete in decades if not sooner.

CONCLUSION

A massive low-cost high-capacity DICOM file storage system for research was designed and successfully implemented using off-the-shelf consumer hardware components and free software including “YAKAMI DICOM Tools”.⁶ All thin-slice data of all studies scanned with all MDCT scanners in our institute have been successfully stored and verified for over 1 year.

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