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Pilot PACS with on-line communication between an image workstation and CT scanners in a clinical environment

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Abstract

A pilot PACS project named KIDS (Kyoto University Hospital Image Database and communication System) for actual radiological diagnosis in Kyoto University Hospital is reported.

The system consists of one X-ray CT scanner, a diagnostic image workstaion and a juke-box like optical disk system, and it is planned to be connected with an MRI(magnetic resonance imaging) scanner and a laser film printer. For the system design, fundamental data such as repetitive examinations for each patient were inquired from the hospital information system. Also, retrieval time of X-ray CT examination history from optical disks has simulated.

Software of the image workstation developed considering compatibility with a traditional viewbox is also described.

Introduction

Kyoto University Hospital (KUH) started a pilot PACS project in 1985. In the project, a small PACS called KIDS) has been developed in order to build a PACS that actually works in a clinical environment. Our opinion is "A PACS for an appropriate target within currently available technologies is to be examined before all-round PACS." In our hospital, X-ray CT and MRI-CT are grouped in one radiological section, therefore one X-ray CT scanner was firstly connected to the system and an MRI-CT is scheduled in the next step. A prototype image workstation is designed enough for diagnosing of CT images. And a juke-box styled optical disk system (called 'optical disk library') is prepared for archiving during long range. These devices are connected to an optical fiber network that communicates within the CT section.

Prior to a detail design, image generating rate and frequency of repetitive examinations for each patient were inquired from an X-ray CT examination history database (not including CT images) in our hospital information system. Analyzing those data, an expected retrieval time for images of past studies stored in the optical disk library was estimated.

The schedule of the project in each step is listed below :

1. Analyze the traditional system
2. Design and produce of an image workstation
3. Lay out a network and connect an X-ray CT scanner to it
4. Design and construct an image database system using optical disks
5. Evaluate the system in a clinical environment
6. Install a laser film printer
7. Connection an MRI scanner to the network

These steps are planned to be completed in 1987.

Analyzing and modeling of CT examinations

KUH is a typical old and large-scaled hospital in Japan and it has 1600 out-patients per day, 22 out-patient departments, 900 beds and 21 wards. There are many digital image equipment in KUH such as 2 X-ray CT scanners, 1 MRI scanner, 1 digital subtraction angiography (DSA), 1 computed radiography (FCR), 5 Gamma cameras and 1 positron emission CT (PET). Table 1 shows image size, number of examinations and number of generated images for each modality at KUH. For reference, the conventional X-ray film system including FCR is listed in "Plain Radiography".

Table 1. Image size and amount number of images for each modality at KUH

Modality	Matrix	Depth (bytes)	images/Exam.	images/year	Gbytes/year
X-ray CT	320 x 320	2	11	55000	11
MRI	256 x 256	2	20	24000	3
Nuclear Medicine(*)	64x64 - 256x256	2	8	40000	1.3
Ultrasound	256 x 256	1	45	32000	2
DSA	512 x 256	2	2	5000	1
Plain Radiography(**)	2510 x 2000	1	2	280000	1400

(*) Gamma cameras and PET are contained.
(**) FCR and conventional X-ray film system are contained.

We had chosen X-ray CT, and investigated tendency of its examination using a X-ray CT examination history database system. This database system is a component of Kyoto Univ. Hospital Information System, and stores history of entire examinations since 1976 when the CT scanner started to run. The database has patient's identification, examination date, run #, scanned location, diagnosis, comment and so on, but doesn't include CT image itself.

Counting records in the database, number of examinations in each month was obtained as shown in Figure 1. In the figure, number of RI imaging examination is also indicated in dotted line. There was one head CT scanner at first, and one more body CT scanner was added in 1979. The averaged number of examinations per month is 433, and it has been almost constant since 1980. According to Table 1, one CT image needs 200 Kbytes to store without data compression, and 11 images are generated per one examination on average. Therefore, the storage capacity required for archiving images during each month is 950 Mbytes.

The frequency of repetitive studies for each patient is also obtained. This information is important for design of an image workstaion and estimation of the retrieval response time when examination history is requested. The number of cases is plotted for each repetition of examinations during 60 months (from February 1981 to January 1985) in Figure 2. In these 5 years 21620 cases had been studied, and 27% of them had repetitive studies. This frequency curve fits well to an exponential distribution,

$$\log_{10} n = -0.157t + 3.29 \qquad (r = -0.965)$$

where n is number of cases and t is a repetition time. The dotted line also indicates for RI imaging examinations.

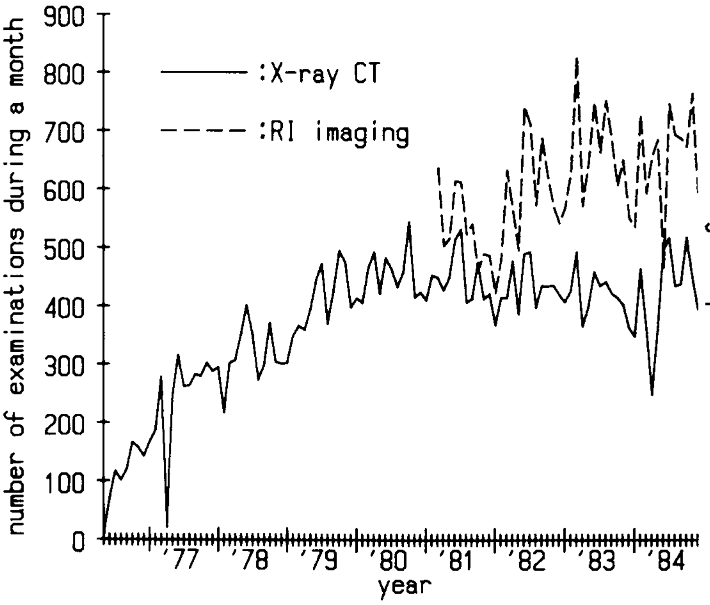

Figure 1. Number of Examinations per Month

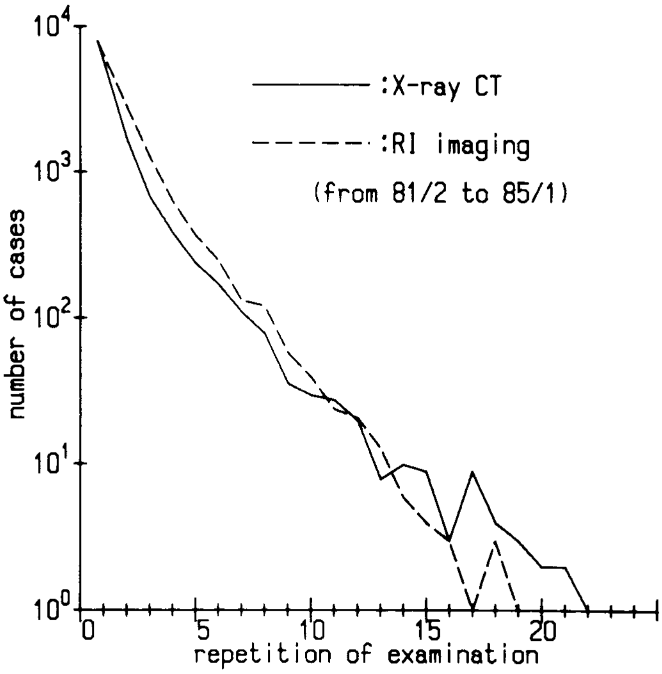

Figure 2. Frequency of Repetition of Examinations

Information Flow Analysis of CT Examination

Information flow concerned with a CT examination at KUH is a little different from a typical flow of American radiological section. A printed film is always returned to the department or the ward from which the examination was ordered. Figure 3(a) shows the conventional information flow at KUH. An order form and a patient are sent from a clinical department. After scanning, image data are recorded onto a magnetic tape and a film. A radiologist in CT section reads the film, makes a diagnosis and a comment on a report form. Then the film is duplicated, one is stored in a film library of radiology department and the other is returned to the ordered department with the report form. If necessary the radiologist makes a consultation with the physician who ordered the examination. The most important point is that image data must be returned to the ordered department. This fact requires satellite image workstaions in each department. It is too heavy specification for a pilot system, so we have designed a compact system shown in Figure 3(b).

```
+------------------------------------+
![out-patient departments or wards]  !
!    +-----------------!-------------+
!    !                 !
!    ! examination order!
!    !                 !
!    !   +-------------!-------------+
!    !   ![CT section] !             !
!    !   !             V             !
!    !   !          scanning         !
!    !   !             !             !
!    !   !    CT image !             !
!    !   !             !             !
!    !   !             V             !
!    !   !       data recording      !
!    !   !         !          !      !
!    !   ! (film)  ! (magtape)!      !
!    !   !         !          V      !
!    !   !         !      storing on !
!    !   !         !      MT shelf   !
!    !   !         V                 !
!    !   !   diagnosing              !
!    !   !         !                 !
!    !   !         ! diagnosis       !
!    !   !         !  comment        !
!    !   !         V                 !
!    !   !       duplicating         !
!    !   !         !       !         !
!    !   ! report  !       ! (film)  !
!    !   ! (form)  !       V         !
!    !   ! (film)  !    storing      !
!    !   !         !  in film library !
!    !   +---------!-----------------+
!    !             !
!    +-------------!-----------------+
!                  V                 !
!               return               !
+------------------------------------+
```

(a) flow in the conventional system

```
+------------------------------------+
![out-patient departments or wards]  !
!   +------------------!-------------+
!   !                  !
!   !  examination order !
!   !                  !
!   !   +--------------!-------------+
!   !   ![CT section]  !             !
!   !   !              V             !
!   !   !           scanning         !
!   !   !              !!            !
!   !   !    CT image  !+------+     !
!   !   !    (network) !       !     !
!   !   !              V       !     !
!   !   !         storing in   !     !
!   !   !         optical disks !    !
!   !   !              !       !     !
!   !   !              !       !     !
!   !   !              V       V     !
!   !   !           diagnosing       !
!   !   !   on an image workstation  !
!   !   !              !             !
!   !   !    diagnosis !             !
!   !   !     comment  !             !
!   !   !              V             !
!   !   !         auto-filming       !
!   !   !   by a laser film printer  !
!   !   !              !             !
!   !   !   report     !             !
!   !   !    (form)    !             !
!   !   !    (film)    !             !
!   !   !              !             !
!   !   +--------------!-------------+
!   !                  !
!   +------------------!-------------+
!                      V             !
!                    return          !
+------------------------------------+
```

(b) flow in the new system

Figure 3. Information Flow of CT examination

System Implementation

System design

Based on the fundamental design shown in Figure 3(b), following devices are developed :

- Image workstation suitable for CT images
- Network system expandable to connect another modalities or workstations
- Interface between a CT scanner and the network
- Image database system using optical disks

Each device is described below in detail.

Image Workstation

We have designed an image workstation considering CT diagnostic use. Fundamental specifications are listed below.

(a) Many images should be displayed simultaneously just like a conventional film to compare them between slices and also between studies.

(b) Both operations of retrieval and handling of images on a screen should be easy enough to comprehend its contents.

(c) Response of operations must be quick enough not to prevent diagnosing.

To realize those specifications, following hardware and software have been developed.

Hardware design

Our workstation was constructed based on a 68000 machine. The architecture is shown in Figure 4. The workstation has three CRT monitors of 1024 x 1024 pixels whose overview is shown in Figure 5. Each monitor displays contents of image memory which is mapped on 2 Mbytes width in the memory space of 68000 CPU and swapped by memory-bank switching. Each monitor has two 2-Mbyte planes to display image of 1024 x 1024 x 16 matrix size, 0.8-Mbyte plane for bit-map graphics and one A/D converter with a programmable look-up table.

Those memory planes can be quickly exchanged with each other by bank-switching. It is also possible to exchange display contents on any 2 of 3 monitors.

```
                         Versa-Bus (16bit width, 1 MWords/sec)
                                          __
   +-----------------------+       !!      +----------------------+
   !       68000 CPU       !       !!      !    System Memory     !
   !    OS : Versa-dos     +------++------+ for OS & application !
   !    console terminal   !       !!      !       4 MBytes       !
   +-----------------------+       !!      +----------------------+
                                   !!
   +-----------------------+       !!      +----------------------+
   !     Magnetic Disk     !       !!      !  Magnetic Tape Drive !
   ! for data and software +------++------+     for off-line     !
   !      132 MBytes       !       !!      !    data transfer     !
   +-----------------------+       !!      +----------------------+
                                   !+---------------------------------------+
   +-----------------------+       !!      +----------------------+          !
   !     Communication     !       !!      !  Image Processor(ALU)!          !
   !       Interface       +------++------+ with 5 Mbytes Memory !       +--+--+
   !     10 Mbits/sec      !       !!      !  and Internal Bus    !       !Mouse!
   +-----------+-----------+       !!      +----------+-----------+       +-----+
               !                   !!                 ! (8 MWords/sec)
   +-----------+-----------+       !!      +----------+-----------+
   !  Optical Fiber Link   !       !!      !12 Mbytes Image Memory!  +-----------------+
   +-----------+-----------+       !+------+ Bitmap Display Memory!  ! 3 CRT  monitors !
               !                   !!      !(2 Mbytes Memory Bank)+--+   monochrome    !
 to Network <--+                   !!      !     A/D converter    !  !   1280 X 1024   !
                                   --      +----------------------+  +-----------------+
```

Figure 4. The Architecture of the workstation

An image processor including ALU (arithmetic and logic unit) and 5-Mbytes working memory is used for image data handling such like positioning of image on a memory plane. Display exchange described above is performed by ALU's function through 8 MWords/sec internal bus between image memory and ALU. Those image memory and ALU are also connected the Versa-bus. The Versa-bus has 16-bit (1 Word) data width and 1 MWord/sec data transfer rate.

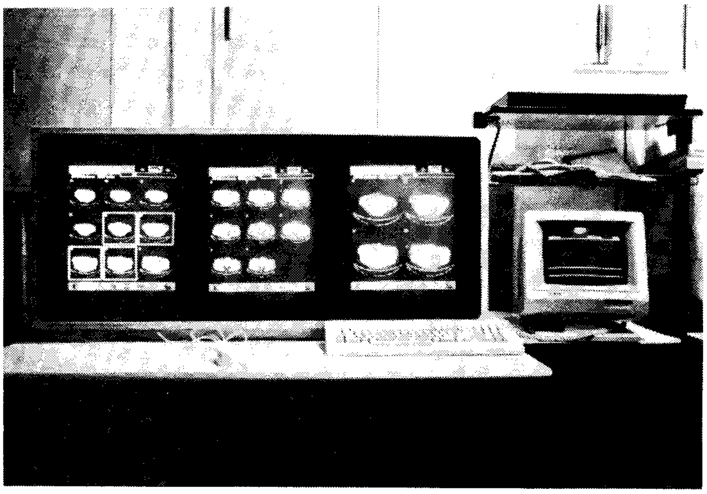

Figure 5. The Overview of the Workstation

Software and man-machine interface

User interface for image handling on the workstation and for retrieval of an image database has been developed. The image handling software is described in this section and the retrieval system in the section of the image database. These software are written in BIPOLA language (a BASIC-like compiler language) on Versa-dos operating system.

The image handling software is developed considering compatibility with a conventional film handling on a viewbox. The matrix size of an image generated by our CT scanner (GE, CT/T8800) is 320 x 320 x 12, and generated images were used to be printed on a conventional film (36 x 42 cm) in 3 x 4 slice format. We prepared two types of display format:

1) 3 x 3 slices on a screen in 320 x 320 pixel original resolution (shown in Figure 6)
2) 4 x 4 slices on a screen in 256 x 256 pixel reduced resolution (shown in Figure 7)

In type 2 format, 16 slices can be browsed where 9 slices in type 1 format.

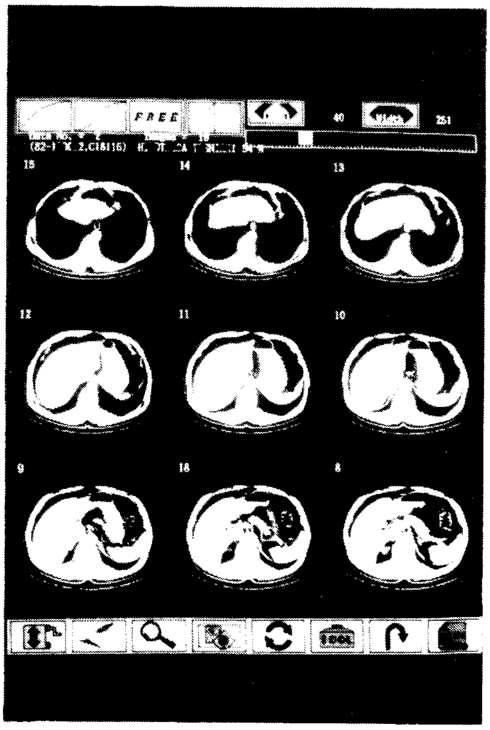

Figure 6. A Typical Display in 320 x 320 Format

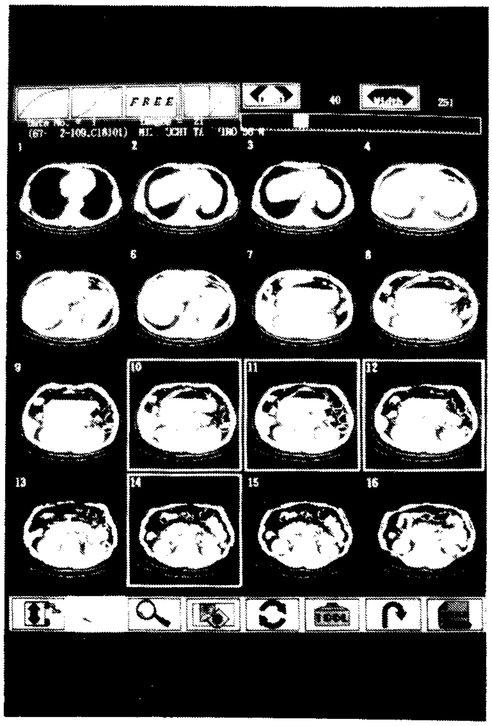

Figure 7. A Typical Display in 256 x 256 Format

All operations on image handling are done by pointing icons displayed on top and bottom of screen shown in Figure 6 and 7 with a mouse. Icons on bottom of screen mean as follows (left to right) :

1) Scroll

In one image memory bank, 18 slices can be stored in type 1 format and 32 slices in type 2 format. The displayed slices can be vertically scrolled out instead of slices outside of display region.

2) Pick-up

Images can be displayed in a zoomed format shown in Figure 8. This icon is for selection of slices to be zoomed. A selected slice will be framed shown in Figure 7.

3) Zoom

Pointing this icon an interpolated zooming will be done. Figure 8 shows a example of zoomed display in 512 x 512 format.

4) Change Study

This icon is for changing display to another study.

5) Swap

To exchange contents of screen with another monitor, this icon should be pointed.

6) Tool

This icon means special functions such as measurement of length of angle in an image, edge enhancement and so on.

7) Return to Previous Screen

This icon will be used when the previous screen should recalled in a zoomed display.

8) Return to Main Menu

When all works has done, this icon should be pointed to return to the main menu.

Images obtained from the network link are stored in a magnetic disk at first, and then transferred to image memory and displayed. To display them appropriately, image data are passed to A/D converter through a look-up table which has preset for some modalities and scanned locations (such as a look-up table for a head scanning by X-ray CT). Those preset look-up table are automatically chosen by identification of modality and location code in a file header of image data. Icons on top of screen are used for manual changing of the look-up table. Icons on left half have a function to change a look-up table shape, i.e. a gamma characteristics. And gray scale window modifying icons are displayed on right half with a window indicator.

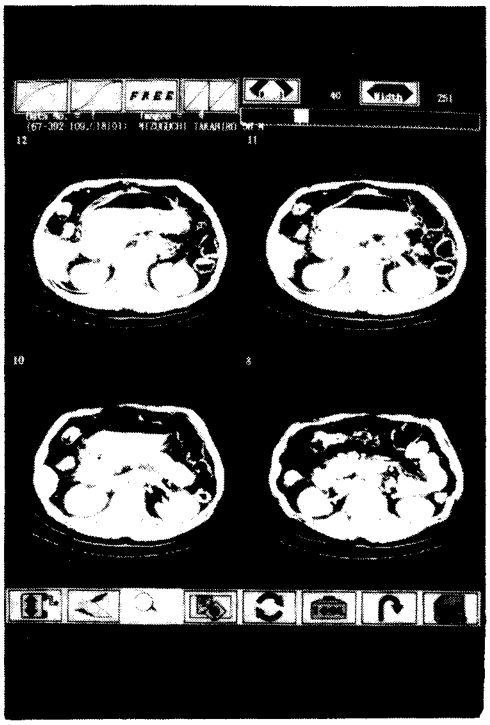

Figure 8. A typical Zoomed display

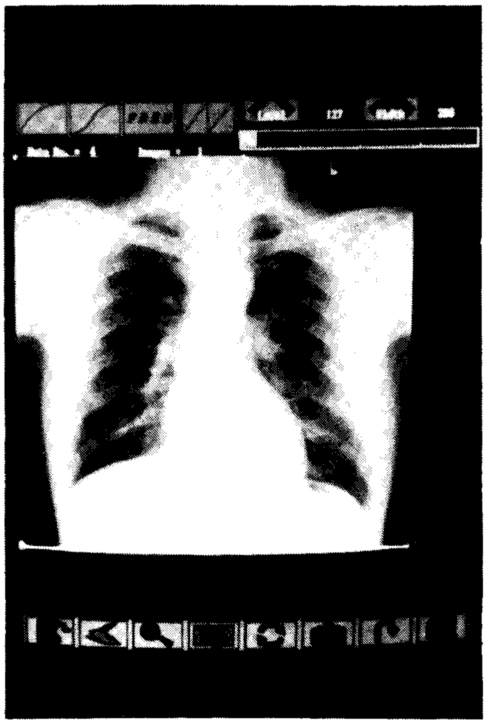

Figure 9. An Display Example of Radiography

Estimations

The image workstation is working in our CT section now. There are some estimations about the workstation at present.

On response time, a screen in type 1 format is displayed from the magnetic disk within 8 seconds, and 10 seconds in type 2 format. The scrolling is quick enough (it can't be measured). 5 seconds is required for zooming of one slice. The swapping of screens is done within a second.

After having experience of diagnosing with the workstation, some impressions of radiologists are summarized as follows :

1) It works enough for clinical use.
2) The screen is darker than a conventional viewbox.
3) It is a little long time till images are displayed.
4) Zooming must be done quickly.
5) It is very interesting that digital operation like a look-up table modification is possible in contrast with a conventional films.
6) The display is a little poor for a plain radiographic image (shown in Figure 9).

On-line Communication with X-ray CT

A CT scanner has connected to a network described in the next section. GPIB interface is used for the communication between the scanner and a network interface. This network interface (called 'converter') is consisted of a 68000 CPU, some memories, a magnetic disk, GPIB interface and optical fiber link. It performs format conversion of CT images and buffering between the scanner and network. Our GPIB interface was slow (15 Kbytes/sec) and requires 13.3 seconds for transmission a slice image to the converter. Therefore, Generated images are transmitted in a batch operation twice a day.

Network Implementation using optical fiber link

A network has implemented to connect the image workstation, scanners, optical disks and other components. Media of the network is 10 Mbits/sec optical fiber and HDLC with 64 Kbytes packet length is used. This optical fiber is used only for image data transmission. A realized data rate of the network is 350 Kbytes/sec in node-to-node transmission. A central minicomputer (micro VAX II) used for database management described in the next chapter, communicates control messages with each component by RS232-C lines connected in star-like shape. Although this network architecture is not sophisticated, it simplifies the network software. The network diagram is shown in Figure 10.

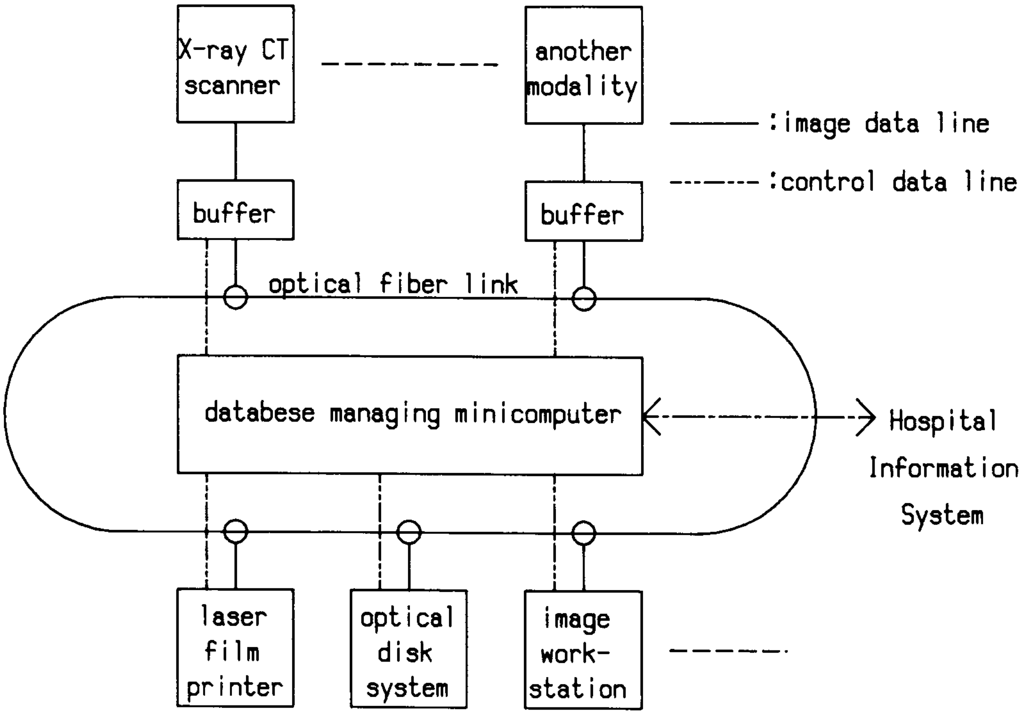

Figure 10. The Network Diagram of KIDS

Image Database using Optical Disks

Hardware Design

A juke-box styled optical disk system called optical disk library (ODL) is used for archiving of images. The ODL has 32 optical disk cartridges of 2.6 Gbytes per cartridge. Inside view of the ODL is shown in Figure 11. Images archived in the ODL are managed by a minicomputer in which a relational database management software (RDB) runs. The ODL is connected by high-speed GPIB (400 Kbytes/sec) to another 'converter' like the converter used in communication with the CT scanner. And the converter is linked to the network.

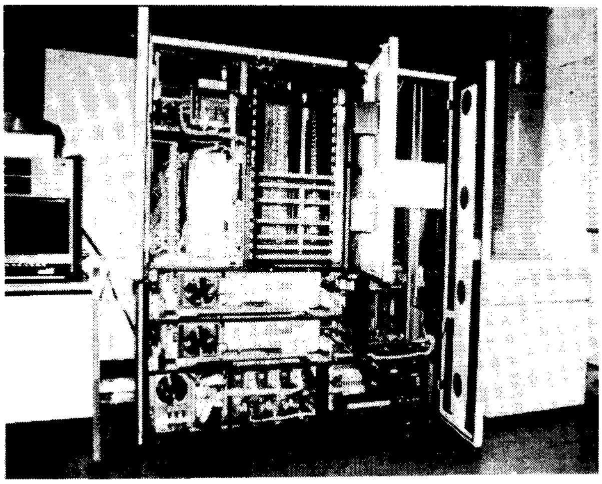

Figure 11. Inside View of ODL

Patient Relation field name	Examination Relation field name
Patient's ID Number	Sequential Number
Last Sequential Number	Date of Examination
Patient's Name	Mnemonic of Modality
Date of Birth	Diagnostic Codes
Sex	Plane or Contrast etc.
	Scanned Location
	Count of Past Access
	"In ODL" or "On Shelf"
	Allocation Address in ODL

Table 2. Design of Relational Database

Database Design

Archived images are managed by RDB under tables designed as Table 2.

Retrieval System

For the retrieval system, we prepared two types of user interface. Each of them can access to images with any combination of keys listed in the previous section.

The first type displays a list such as a study list of today or patient's examination history list according to a query to RDB. A user can select studies from them by pointing, then images are displayed.

The second type uses a shrinked images shown in Figure 12 instead of a list. This idea has shown in our experiment (Electronic Viewbox). Using this method, a user can browse contents of data selected from RDB.

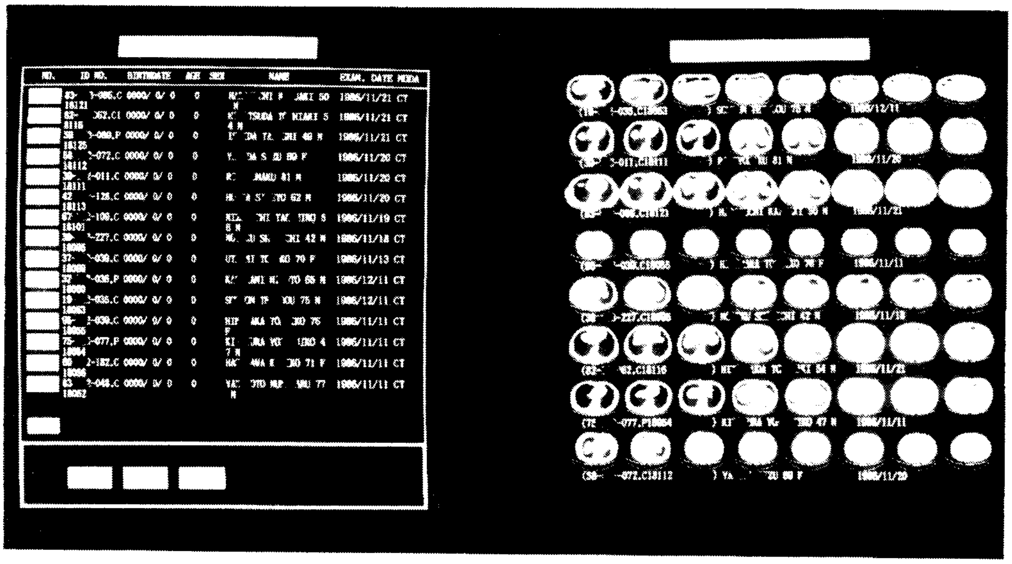

Figure 12. Retrieval User Interface Using Shrinked Images

Disk Access Simulation

An optical disk cartridge can store images of CT studies during 2.6 months. Therefore we can simulate an optical disk access when all past studies of each patient are retrieved. This simulation can be done using the CT examination history database that is described before. Specifications of ODL is listed below :

Time to mount a cartridge to disk drive	:	9.0 seconds
Time to dismount a cartridge	:	7.5 seconds
Seek time on a cartridge	:	0.2 seconds
Transfer rate to external port	:	300 Kbytes/sec
Sector length	:	512 bytes/sector

We assumed that one examination generates 11 slice images in average. If a cartridge which has required images, the response time to get those images will be 14.7 seconds. From the result of analysis by the history database, 1.34 exchanges of disk cartridge is expected when all past studies are retrieved. In this case, the response time will be 48.7 seconds.

Concluding Remarks and Future Plans

This system, KIDS works actually in the clinical environment in KUH. It has the alternative function of the conventional system. Though the advantage results from this system have not been estimated exactly yet, following advantages are clearly achieved :

1) There is no need to duplicate of films and dump image data on magtapes.
2) Images are archived in OLD automatically and retrieved on-line.
3) Radiologists can make diagnosis using various digital tools.

This system has various functions required in PACS, i.e. on-line data acquisition, long term archiving, display device for diagnosing, communication between devices and man-machine interface. It is enough for a pilot system and can work the CT section, but it still incomplete to expand this system to a hospital-wide PACS. To improve this system, following steps are scheduled in the next two years :

1) Speed up of on-line communication with the CT scanner
   The improvement will make the communication faster 10 times or more than present one.
2) Speed up of action inside the image workstation
   A large improvement of the workstation is required for quicker response.
3) Design and construction of a satellite image workstation

References

1. M.Komori, K.Minato, et al., "ELECTRONIC VIEWBOX : AN INTEGRATED DIAGNOSTIC WORKSTATION FOR PACS", Medical & Biological Engineering & Computing, Vol. 23, Supl. Part 1, pp. 231-232. 1985.