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An image capture and communication system for emergency computed tomography

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Abstract

An image capture and communication system for emergency computed tomography (CT) is presented. The system, named ICCS, integrates CT scanners, personal computers (PC), network systems, an IBM API gateway and an IBM mainframe platform. The ICCS was implemented in the emergency unit in the Taichung Veterans General Hospital (TCVGH) and has received considerable support from the doctors, nurses and staff of the TCVGH emergency unit who have shown great interest in ICCS. This is because ICCS allows physicians in the emergency unit to examine patients' images on image viewing stations immediately after the patients are CT scanned. It also makes remote consultation possible for doctors who can stay where they are and consult with radiologists through the system and a hot line without leaving the emergency unit. This advantage greatly reduces the consultation time and saves many unnecessary trips between the emergency unit and the Department of Radiology. Copyright © 1997 Elsevier Science Ireland Ltd

Keywords: Emergency computed tomography; Image capture and communication system (ICCS); Picture archiving and communication system (PACS); Computed tomography (CT)

1. Introduction

Over the past years, digital medical images have shown great advantages over conventional analog film-based medical images in image data retrieval and storage. It has also become a major trend for doctors to use various digital imaging modalities such as computed tomography (CT), magnetic resonance imaging (MRI), and digital subtraction angiography (DSA) as computer-assisted diag-

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nostic tools to improve their diagnosis. However, the image data acquired by different medical vendors vary. As a result, how to retrieve and manipulate these incompatible images with the same platform in a computer environment is a challenging issue. Another issue is that the Department of Radiology must invest tremendous manpower and filing space to manage the vast amount of image data. Therefore, using a picture archiving and communication system (PACS) seems a promising solution for management of medical images [1,2].

The Taichung Veterans General Hospital (TCVGH) located in central Taiwan is the second largest among three veterans general hospitals in Taiwan and the only medical center in the central part of Taiwan. By realizing the importance and pressing need of PACS, it initiated a pilot project to implement PACS in May, 1993 [3]. Several problems were encountered and needed to be overcome when the PACS was installed: (a) too many medical images were digitized at one time, (b) the network connection interface is not available for old models of digital imaging equipment and the vendors generally decline to provide users with their image formats, (c) the limited budget limits the use of workstations, (d) ethernet was too slow to transmit mass medical images, (e) insufficient manpower was devoted to developing the software of PACS and (f) no successful examples in Taiwan could be used for reference.

In order to overcome these problems, a pilot PACS program was evaluated incorporating and adopting several suggestions. These were: (a) an emergency CT was selected to be the candidate for implementing PACS, (b) due to various image formats of computed tomography resulting from different vendors, an image board was used to solve problems of file format incompatibility and lack of network connection interface, (c) instead of using expensive workstations, personal computers were employed for image capture and viewing stations to meet tight budget requirements, (d) a preload process was used to reduce the traffic of ethernet as well as speeding up the transmission of CT images, (e) since no example in Taiwan can be followed to develop PACS, the knowledge of implementing this project is collected from the experiences reported in the open literature. Based on these guidelines, an image capture and communication system, named ICCS was developed for emergency computed tomography. The system has been functioning well since its inception. One of the accomplishments of this pilot project offers good experience and reference for hospitals in Taiwan wishing to install PACS. Another is to provide a good example of using PACS in the emergency unit of a hospital.

2. Architecture of ICCS hardware

ICCS integrates a mainframe computer, a file server, two optical fiber networks, three ethernet segments, an IBM API gateway, two image capture stations and many image viewing stations. The ICCS architecture is shown in Fig. 1.

2.1. Image capture station (ICS)

A 486-33 personal computer (PC) is used to serve as the ICS. It has 32 MB memory (RAM) used as a buffer for prompt image access and a 300 MB hard disk driver to store the captured images and image processing software. Images are captured from CT by connecting an image capture board to the CT video line. The CT operators are responsible for image acquisition. The captured images are then stored in the file server and displayed on a 19" NEC 5D multifrequency high resolution monitor and the CT monitor synchronously. An additional 14" multifrequency color monitor is also used to display some text data outputs, such as patient's demographic data, and control procedure data.

2.2. Image viewing station (IVS)

For IVS, we also used 486-33 personal computers each with 32 MB RAM and a 300 MB hard disk driver to view the images. Images and text mode outputs are integrated on the same screen (i.e. on 14" high resolution color monitor).

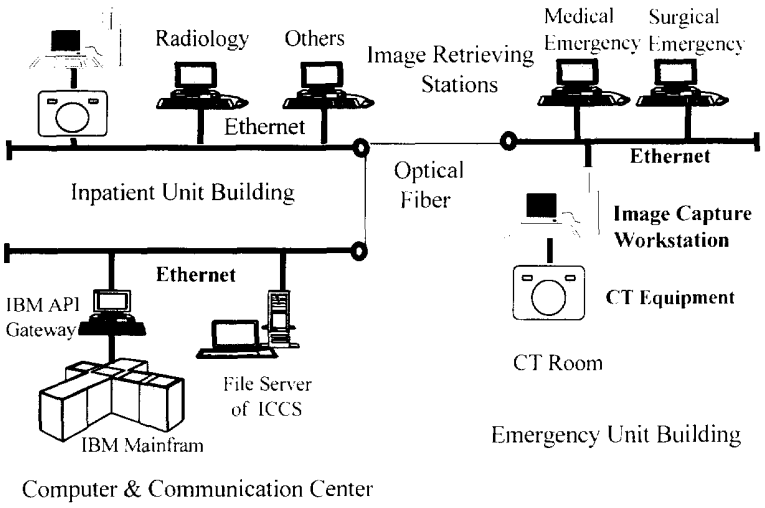

Fig. 1. Infrastructure of emergency computed tomography ICCS in TCVGH.

2.3. Network and storage devices

ICCS is connected by ethernet segments and optical fibers to transmit digital images and an ethernet architecture for image transmission between ICS, IVS and a file server. ICCS is integrated with the hospital information system (HIS) [4]. ICS and IVS are connected to a file server through ethernet by the IPX protocol which provides 10 MB transmission rate and can transmit one CT image every 2 s on average. Images are stored in a file server in the computer and communication center of the hospital which has a 3 GB hard disk and can store up to 7500 CT images. The file server generally supports 300 ICS and IVS simultaneously. In the emergency unit of the TCVGH, 15 CT examinations are done per day on average. Therefore, the CT image data acquired for emergency can be kept on-line in the server for about 1 month.

2.4. IBM API gateway

The HIS of the TCVGH is developed based on using an IBM mainframe machine as a platform with the IBM application interface (API) set up for the gateway between HIS and PACS [5]. By means of API the data base of HIS can be integrated with the data base of a PACS to achieve data sharing and consistency. Demographic data of patients and CT request orders of physicians on the IBM mainframe can be transferred to the PACS through this gateway which is fully automated.

3. System operations

3.1. Data record build-up of CT orders

As soon as the API gateway is connected to the HIS, all the information of CT requests ordered by the emergency doctors (including order number, patient's demographic data, examination item) will be automatically transferred from the IBM hierarchical database to the relational database of the PACS file server. The CT operators will pull out all the relevant image data records associated with order numbers and transfer them to the PACS server. Each image file name is then assigned by a text string coded by the patient's order number and the date of image acquisition. This data record build-up avoids unnecessary duplicate key-in and data inconsistency.

3.2. Image capture

The digital CT images are captured from a CT monitor by an image capture board with spatial resolution 740 × 580 and 256 gray levels. All of the images are stored in the standard bit-map (BMP) format. Two image capture stations are currently installed in ICCS which can capture images from two CT scanners, a Siemens Somatom DR3 and a Picker 1200 SX. It takes about 2 s to capture one CT image and store it in the hard disk of the file server through the ethernet system. It should be noted that no data compression is done in ICCS [1] because (1) it is expected that the acquired digital images do not suffer from too much distortion, thereby there is no need of compression and decompression for the sake of time saving; (2) there is enough storage space on the file server to store the data for the emergency unit.

The required memory space for each captured image (in standard BMP format) is:

740(pixels) × 580(lines) × 8(bit)/8(bit)

$= 429\,200$ bytes $\cong 0.43$ MB

3.3. Image transmission, storage and retrieval

The captured patient's CT images are transmitted via ethernet and stored in the file server installed in the computer and communication center of the hospital. Once a physician in the emergency unit has selected a patient's order data listed on the IVS, the image files of the selected patient will be downloaded from the file server or the local hard disk of IVS if the image data are already preloaded and displayed in the IVS automatically. In order to save retrieval time, the set of CT images is stored in the extension memory specification (EMS) instead of the hard disk of the IVS. Since both ICS and IVS have 32 MB RAM, they can store up to 60 images. The image data in EMS will be erased as soon as the next patient's image data are selected.

Image processing functions provided by ICCS are listed in Table 1. For the purpose of easy image data collection for clinical research, a software program is provided for users by simply copying image files onto floppy diskettes.

The TCVGH has installed approximate 40 image viewing stations, three are in nursing stations of medical and surgical emergency units, two are in the Department of Radiology and the remaining image viewing stations are installed in wards and offices of other departments as well as in the intensive care unit (ICU).

3.4. Storage of digital images

Digital images are stored in the PACS server with a three GB hard disk. The capacity of the hard disk is enough to store emergency CT images for about a month. Storage of image files for ICCS is generated by 3 rules: (1) all blank records are deleted, (2) records over one-month old are backed up and deleted, (3) a minimum free storage space of the PACS server is reserved. The default minimal free available space of hard disk is 50 MB. Whenever the storage space of the PACS server is less than 50 MB, the oldest records will be deleted automatically until 200 MB free space of the PACS server is available.

3.5. Consultation and report

Doctors may consult with radiologists and/or other specialists through ICCS and telephones. They can simultaneously retrieve patients' CT images at different locations for diagnosis. This saves doctors the need to travel between the emergency unit and the Department of Radiology.

As soon as the CT examination is completed, an identification sheet of application form including patient's personal data, case history and examination items is automatically printed in the

Table 1
Image processing functions of ICS and IVS

IVS	ICS
Patient record selection	Image capture
Image browsing	CT without order
Image size changing	Retake process
Image enhancement	Parameter setting
Image filtering	
Image measurement	
Auxiliary functions	

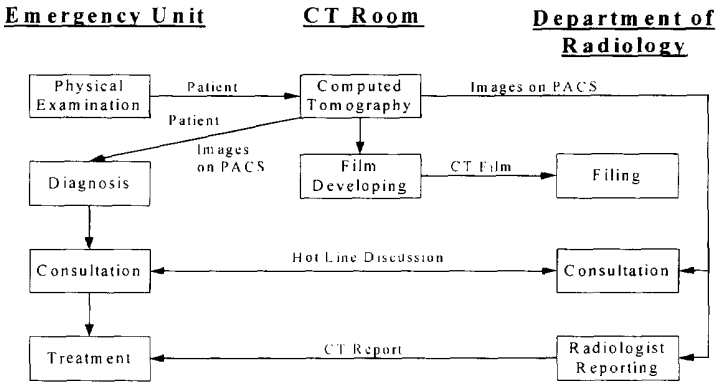

Fig. 2. The flow diagram of ICCS of the emergency computed tomography in the TCVGH.

Department of Radiology to inform the radiologist that the CT examination has been completed. By taking advantage of ICCS, the radiologist can prepare their reports of emergency examination and immediately print them out in the nursing stations of the emergency unit for clinical references.

4. Results

The flow diagram of the emergency CT image processing currently being used in the TCVGH is shown in Fig. 2. After 1 years experience of implementing the PACS of emergency computed tomography, some conclusions are listed as follows:

(1) The quality of digital images which are supported by the 740 × 580 spatial resolution and tone display (256 gray scale) of the 8-bit standard BMP image format are acceptable by doctors in the Department of Radiology and emergency unit.
(2) The image capture board in ICCS can be used to connect to not only CT scanners, but also other medical image equipment.
(3) Clinical physicians can directly retrieve any patient's CT images on image viewing stations in the emergency unit. They no longer have to wait for film-checkout and processing. Table 2 shows the comparison of the processing time between traditional CT and ICCS.
(4) Image capturing is performed by the CT operators without interrupting the regular CT process.
(5) Downloading images into the EMS of the IVS and preloading image data into the local hard disk of IVS can speed up image processing as well as reduce the access time of the hard disk.
(6) On consultation with radiologists, ICCS saves doctors' trips between the emergency unit and the Department of Radiology.
(7) It is found that the doctors in the emergency unit are more interested in ICCS than the doctors in the Department of Radiology because ICCS allow them to read CT images on IVS in the emergency unit and consult with radiologists without leaving their work.

Table 2
A comparison of processing time (in min) between traditional CT and ICCS

Activities	Traditional CT	ICCS
CT examination and image capture	3	3
CT film development	6	0
Film lending	8	0
Consultation	5	1
Diagnosis	3	3
Filing	3	0
Total	28	7

5. Discussions

When the CT images are digitized, some information can be lost during image capture since original CT images are coded by 12 bits while images displayed on the image viewing stations use only 8 bits. Therefore, some images which require more than 8-bit resolution, such as bone and lung windows, cannot be optionally displayed on the image viewing stations. This problem can be resolved by the CT operators by manually adjusting different window settings when these images are captured.

In addition to PACS installed in the Department of Radiology, ICCS also proposes to implement PACS in the emergency unit for the following reasons:

(1) Since PACS offers the advantage of hospital-wide access to medical images, it makes sense to install PACS in departments other than the Department of Radiology as this allows PACS to access medical images hospital-wide without checking out original images from the Department of Radiology. Taking all things considered, it seems the emergency unit is the best location to implement PACS.
(2) Installing PACS in a department which requires rapid image retrieval and processing may be a good solution. One such department is the emergency unit which should have top priority to install PACS since timing is very important and critical in saving human lives.
(3) Another advantage is that image data in the Department of Radiology can be shared with other departments to increase the data utilization.
(4) Since the emergency unit runs 24 h a day, doctors in the unit can access image data at all times even when the Department of Radiology is closed.

After a 1 year trial of ICCS, it was found that the performance of ICCS exceeded the early expectations. ICCS was immediately accepted by the doctors in the emergency unit who gave it tremendous support. This result has encouraged the communication and computer center and the Department of Radiology in the TCVGH to further to modify and improve the system to make it more convenient and cost effective.

Two major improvements on ICCS can be done: (1) developing an environment under Chinese Microsoft Windows to make user interface more friendly and (2) integrating separate terminals of HIS, RIS and PACS into a multifunctional kernel.

When compared with the traditional CT image processing systems, ICCS has the following advantages:

(1) The image capture board solves the problem of image compatibility resulting from using equipment from different vendors, so it is not necessary to establish different connection interfaces for different equipment.
(2) The waiting time of CT image acquisition is reduced while the image quality is improved.
(3) Physicians and radiologists can discuss the CT images simultaneously by retrieving these image on image viewing stations at different locations. This is different from the traditional consultation.
(4) The checkout and missing rates of CT films are significantly reduced.
(5) ICCS provides tools for research, case study, and collection of teaching files.
(6) The image processing software used in ICCS are developed by a local computer company which provides software support and upgrade, particularly custom designed software, an advantage most computer software companies cannot support.
(7) Despite the fact that personal computers are used to replace workstations for image capture and viewing, ICCS still meets the general requirements of CT image processing.

ICCS is the first successful PACS to be implemented in Taiwan. However, some improvements are still needed to make it more cost-effective and user friendly. A basic structure and test environment for future development of PACS is currently under review and will be implemented soon. The ultimate goal is to retrieve all CT and MR images directly in DICOM 3.0 standard, integrate all the digital image modalities, install image viewing stations in the entire hospital [6–8] and set up a hospital-wide PACS so that all image data management and communications can be done within the designed system.

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