Yonsei Medical Journal
Vol. 38, No. 4, pp. 193~201, 1997

□ Original Article □

Design of a Medical Image Processing Software for Clinical-PACS

Sun Kook Yoo[1], Kwang Min Kim[1], Nam Hyun Kim[1], Jae Man Huh[2], Byung Chul Chang[3], and Bum Koo Cho[3]

Software modules for interactive display, manipulation and retrieval of medical images have been designed for a Picture Archiving and Communications System (PACS). The target of these modules is not for a high-end diagnostic workstation for radiologists, but for a PC-based low cost clinical workstation for a referring physician. This software is constructed based on a concept of an object-oriented language which is designed to be modular and expandable. It consists of several functional modules: (a) a communication module for image retrieval, (b) a standard module for the interpretation of the DICOM images, (c) a user interface module for the non-computer oriented clinicians and (d) a tool module for viewing and manipulating images as well as editing the annotation.

Key Words: Software modules, clinical workstation, PACS, DICOM

Recent advancement of computer, communication and data processing technologies in the clinical environment has enabled physicians to access medical images at any location within a few seconds (Duchêne *et al.* 1993; Inamura and Takahashi, 1995). Additionally, as the demand for medical images acquired from diverse imaging modalities is increasing, it has become essential to develop an appropriate workstation for viewing, manipulating and editing medical images (Ehricke *et al.* 1994; Lemke *et al.* 1994; Ligier *et al.* 1994). There are two kinds of workstations, depending on their specific usage in the PACS environment (Horii *et al.* 1994). The diagnostic workstation is dedicated for primary diagnosis and usually consists of several high resolution monitors. The clinical workstation is intended for clinical review and is used in different kinds of medical areas such as the intensive care unit (ICU), conference room, outpatient ward, etc.

There has been a tremendous amount of effort put into the design of diagnostic workstations in radiology. However, few workstations have been clinically approved and the demand for a cost-effective system remains high (Hohman *et al.* 1994; Horii *et al.* 1994). Recent advances in personal computer technology tend to lower the cost of workstations, particularly in the case where high performance is not critical (Andriole *et al.* 1994; Ramaswamy *et al.* 1994).

The successful implementation of a clinical review workstation mainly relies on the performance of software modules (Ho *et al.* 1991; Ligier *et al.* 1994). The critical factors among the requirements for software modules are a well-designed user interface, accessibility to all related images and an elabo-

Received April 22, 1997
Accepted July 28, 1997
Department of Medical Engineering[1], Yonsei Cardiovascular Research Institute[2], Department of Thoracic and Cardiovascular Surgery[3], Yonsei University College of Medicine
This study was supported in part by a faculty research grant of Yonsei University College of Medicine for 1996.
Address reprint request to Dr. S.K. Yoo, Department of Medical Engineering, Yonsei University College of Medicine, C.P.O. Box 8044, Seoul 120-752, Korea

rate software structure for easy customization and extension of image manipulation, display and retrieval tools while maintaining a standard interface through the DICOM (Digital Imaging and Communications in Medicine).

MATERIALS AND METHODS

The software modules, presently implemented as a prototype, are based on a DICOM standard and object-oriented paradigm to meet the requirements for accessibility, expansion, and modularity. The objective of these modules is to provide a useful tool for referring physicians to display, manipulate and retrieve the medical images in a clinical PACS environment.

Hardware

Given a low-cost, end-user graphical interface and accessibility, it is desirable to implement these modules on a personal computer (PC) rather than on a workstation platform. The hardware components (Fig. 1) required for our software modules include a 166 MH_2 Pentium PC with a high density 3.5 inch disk drive, keyboard, mouse, a minimum 32 Mbyte RAM and 1 Gbyte hard drive, and a 650 Mbyte auxiliary optical drive or 1 Gbyte Jazz driver. A landscape 19 inch color monitor with a spatial resolution of 1280 X 1024, a brightness resolution of 256 color and grayscale capability is recommended. An optical scanner sized 14" X 17" is optionally required to capture printed film such as plain X-ray, CT, MR and angiogram, etc. Current PC platforms contain Ethernet and fast Ethernet, which can handle a throughput of 10-to-100 Mbit/sec, respectively. Also, a high-speed backbone network such as ATM (Asynchronous Transfer Mode) or FDDI (Fiber Distributed Data Interface) can be connected to the PC through the distribution of HUB (backbone to Ethernet).

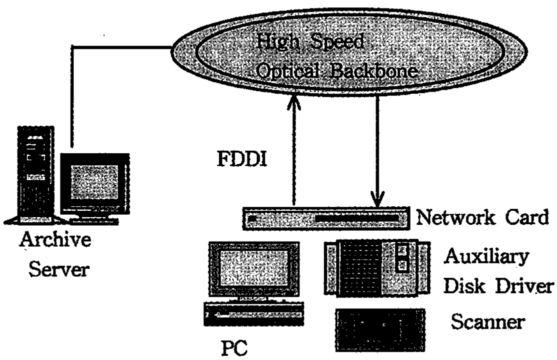

Fig. 1. Hardware configuration for medical image processing software.

Software

The software modules are designed to allow unified customization of diverse image processing functions, systematic extension of hardware components and easy graphical interface for non-computer oriented medical personnel. An object-oriented approach is employed by using the object-oriented programming language Visual C++ 4.2 (Kruglinski, 1995) under the WINDOWS 95 environment. The program structure is defined by a set of classes, organized in different layers. As shown in Fig. 2, the lowest layer classes are used as the device driver, which is specific to individual hardware interface components. The scanner, network and database interfaces are mainly based on such device drivers. The medium and highest layer are functionally divided into four separate modules: a communication module, a standard module, a user interface module and a tool module.

The communication module performs as the database connection to a remotely-located database server through the local area network. Transmission services are based on the TCP/IP (Transmission Control Protocol/Internet Protocol) suite of protocols, which is the "de facto" standard (Orphanos *et al.* 1993) and is implemented by using a Winsock version 1.1 API (Application Program Interface) library (Sinha, 1996).

The standard module is able to make the system as flexible as possible for image exchange. It is implemented as object-oriented classes, which are based on the data dictionary and unique identifiers, i. e., the DICOM standard. It is flexible according to whatever the image generator should be to organize and standardize the image outputs from the dif-

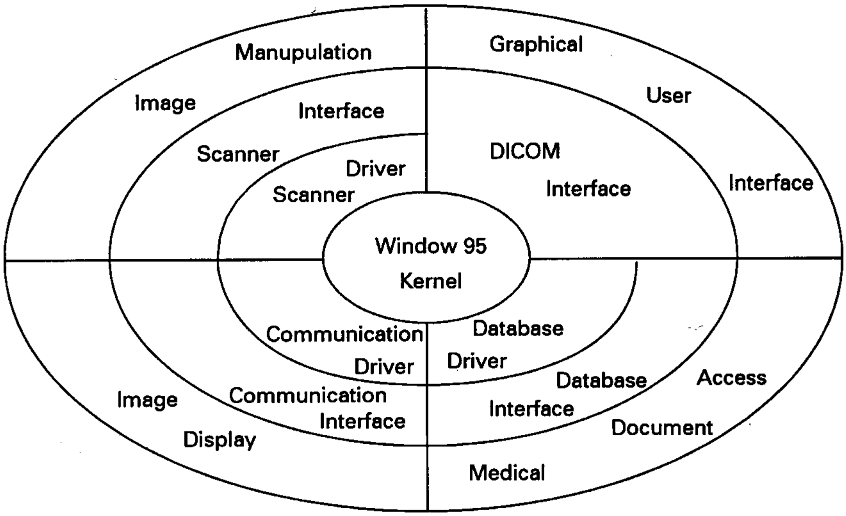

Fig. 2. Layered shoftware configuration of object-oriented medical image processing software package.

ferent imaging modalities, allowing easy communication and storage.

The graphical user interface module, based on Windows, icons, buttons, and menus, satisfies the need of referring physicians and does not require extensive computer skills. As the Windows 95 kernel provides a rich set of graphical user interface functions, user interface control classes are composed of those API functions. These classes provide methods for accessing and manipulating the diverse set of image processing functions supplied by the tool module.

The tool module provides a variety of generic image processing tools applicable to different image types. It is implemented as a modular fashion according to the function categories: image manipulation, image display and annotation tools.

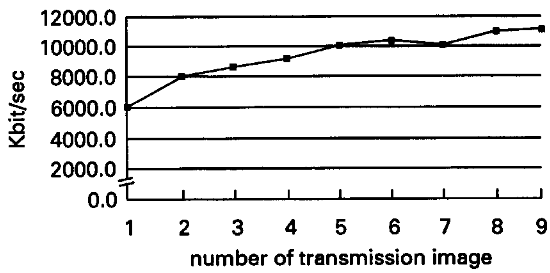

Fig. 3. The experimental throughput rate for repeated transmissions of a 1-Mbyte file.

RESULTS

Communication module

The TCP/IP protocol and API database services have been written by Dynamic Link Libraries (DLL), which contains the socket library logic and the C++ run-time library logic. The implementation of the diverse communication module, such as binding, connection, sending and requesting, has led to an object-oriented set of function classes. These functions have been used to support image retrieval operations through the structured database query language (SQL). The throughput measurement of the communication module was performed between the local computer and database server, connected locally via 100 Mbit/sec Fast Ethernet LAN. As the number of transmission images is increased, the throughput rate is increased, as in Fig. 3. This is due to the fact that the connection can be required only once during the first image transmission. The average transmission time of 8 Mbyte for typical CR (Computed Radiography) data is about 8 sec. The

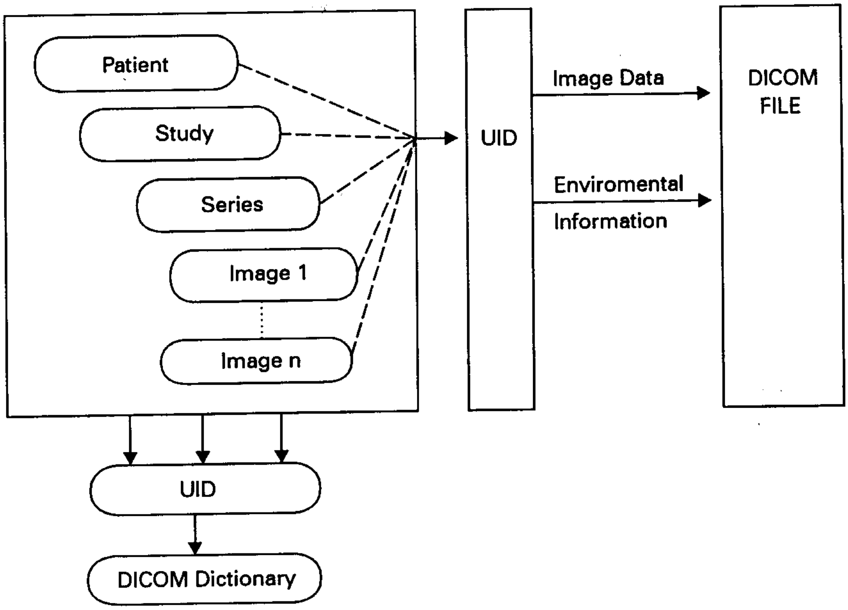

Fig. 4. Conceptual standard module architecture for DICOM file interpretation.

difference between the network bandwidth and the actual transmission is the result of the layered structure (Sinha, 1996) of the TCP/IP protocol. Although experimental results are not adequate for real-time interactions, the standardized TCP/IP interface enables the easy connection to a high-speed network regardless of the physical underlying network media.

Standard module

Most digital imaging modalities such as CR, CT, and MR generate patient images that comply with a DICOM V. 3.0 standard. However, the image header format acquired from the film scanner varies according to the individual manufacturer's specification. To acquire images from different modalities, the image file format must be uniform and consistent. Therefore, all the non-DICOM 3.0 file formats must be converted to a DICOM 3.0 format, and then the effective information such as image data and its additional environmental information (identification, patient, acquisition, relation, image presentation, and overlay) must be extracted from the DICOM 3.0 file.

The standard module is composed of various classes with several hierarchy levels, as in Fig. 4. Since the classes are implemented with several hierarchy levels, the highest level represents the patient, the next level studies, etc. The image data and environmental information at each level are recognized by the unique identifiers (UID). The DICOM dictionary is stored in a static data member within a class associated with a UID. The class function refers the DICOM dictionary, and then extracts the image data and environmental information according to a DICOM encoding rule (Moore, 1996). Since the software architecture of the standard module is designed based on a top-down hierarchy and modular principle, the designed classes can support the multiple images of one patient and the portability in various PACS workstations.

User interface module

The user interface is a backbone of the image tool module. In designing a graphical user interface module for a clinical workstation, the functions are activated through graphic icons, buttons and toolboxes, and are triggered through the mouse, as shown in Fig. 5. This module provides unified and interactive tools for display and manipulation of image data and allows the user to archive complex tasks with a

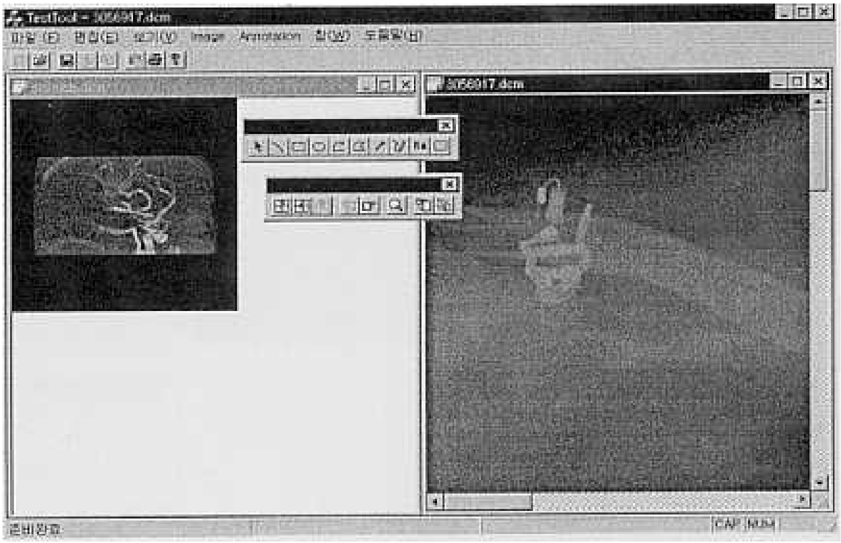

Fig. 5. Graphical User Interface based on graphic icons, buttons and toolboxes.

minimum amount of technical training. Each application typically has a window in which users carry on their primary interaction with the application. Additionally, graphic-based tools provide an easy way of handling multiple images at one time for both sequential images and filed images for a given patient.

Tool module

The tool module displays and manipulates images on the computer screen and edits the annotations by adding a short text and a mark to a given point in the image. It consists of image manipulation, image display and annotation tools as shown in Table 1. The image manipulation tools perform many image processing functions and provide a way of handling an image by means of a graphical user interface. The most important tool in image manipulation is the adjustment of contrast and intensity. While medical images have a dynamic range of up to 12 or 16 bits deep (4096 or 65536 intensity levels), most of the common display systems support an 8-bit display that allows only 256 levels of display at one time. The dynamic range can be adjusted in two ways. First, displayed maximum and minimum pixel values are set by two cursors on a regional or global histogram box. Second, the adjustment is performed in real time by using an interactive control box, as shown in Fig. 6. A button on the control box allows the user to interactively adjust the window width and window level by moving the mouse. Horizontal displacement changes the window width, whereas vertical displacement changes the window

Table 1. Image manipulation, image display and annotation tools

Image manipulation tools
▶ Contrast and intensity adjustment
▶ Rotation and flipping
▶ Filters (Smoothing and edge enhancement filters)
▶ Display of regional and global histograms
Image display tools
▶ Multiple image display(Tiled and stacked mode display)
▶ Zooming and panning
▶ Magnifying glasses
Annotation tools
▶ Annotations
▶ Arrow and lines

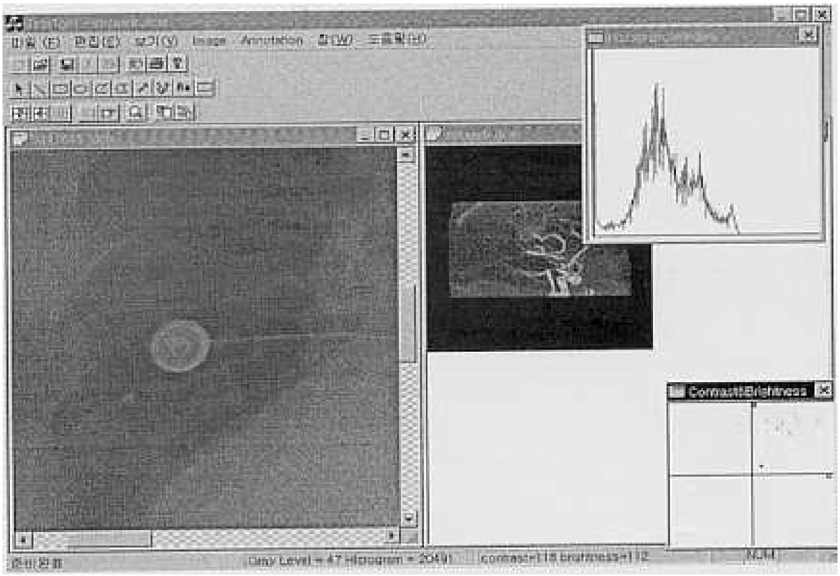

Fig. 6. Contrast and intensity adjustment of CR image.

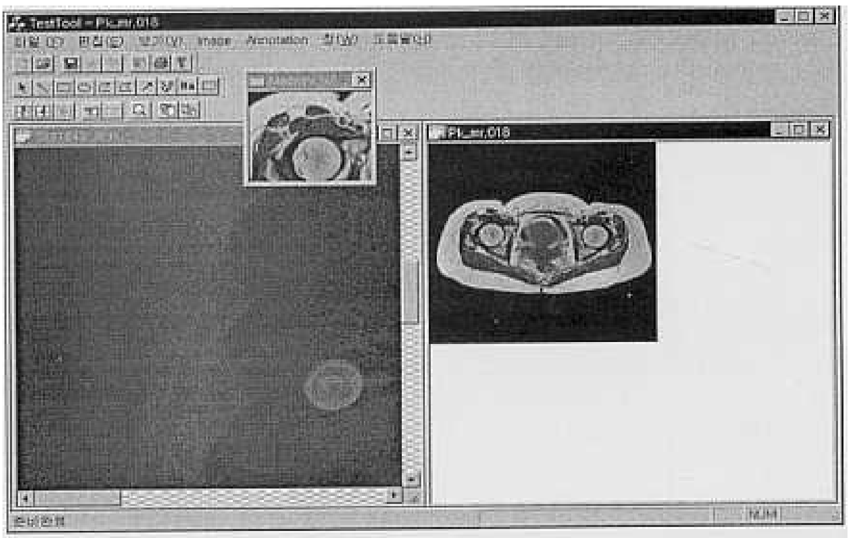

Fig. 7. Tile mode display with magnifying glass of MR images.

level.

Since medical images often consist of sequential images or a set of different views or sections, image display tools provide two different modes of image presentation: stack mode and tile mode. In the tile mode, the images are displayed side-by-side in a grid that is optimized to be rectangular based on the number and size of images to be displayed, as shown in Fig. 7. This mode exhibits an overview of the whole set and allows the user to zoom and pan the individual images and to change the order of the images in the set. In the stack mode, the images are vertically stacked on the display screen. It permits browsing through the images sequentially and dis-

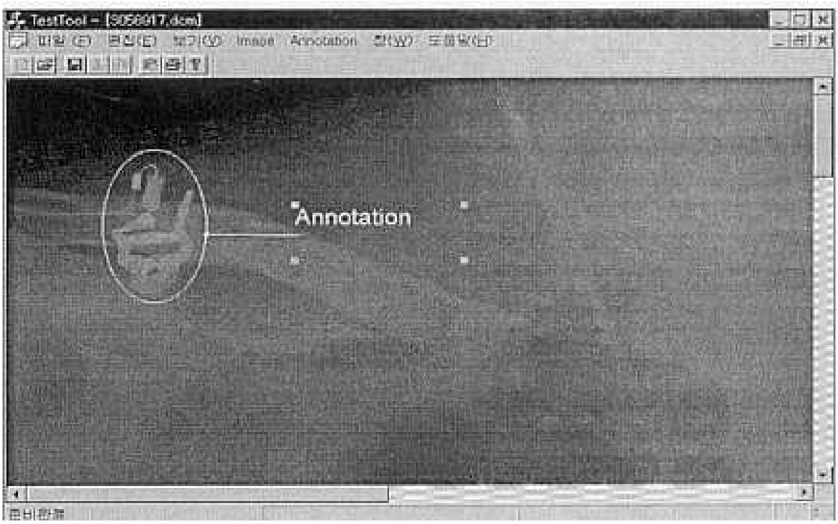

Fig. 8. Annotations for image interpretation and clinical information related to CR image.

playing only one at a time by activating or deactivating the images. It has proved to be very useful in obtaining the appropriate slice with sufficient resolution from the whole tomographic sections.

Annotation as shown in Fig. 8 allows the user to emphasize certain areas and features of an image by adding a short text to a given portion of the image. Annotation consists of an anchor point and an added message. The anchor point, with an arrow and line, indicates the significant area of the image. The attached message contains the image interpretation text as well as clinical information related to the image. Annotation should be added to the image in the form of a short text at any location in the image. All the annotations are handled as objects separate from the image itself, which can be moved, altered, and deleted at will.

DISCUSSION

All efforts to develop a PACS system for image transmission and archive will be useless unless appropriate image-handling software modules are provided. The requirements for image-processing software modules in clinical PACS depend heavily on performance, portability, standardization and cost-effectiveness. (Ho *et al.* 1991; Lou *et al.* 1993; Stewart *et al.* 1993; Ligier *et al.* 1994; Lun, 1995)

As for performance, these software modules for a clinical workstation have the capability to review multiple images simultaneously by tile and stack mode operation and to display and manipulate the images interactively. Honeyman *et al.* suggested that the most important function of the workstation is the ability to view multiple images for a single patient at one time (Honeyman *et al.* 1993). The advantage of digital display over analog display of the viewbox is that many powerful image-processing and manipulation tools can be used for better clinical applications. (Yang and Ivey, 1993)

In order to improve the overall visibility of an image, it is essential to reveal the detailed image and help referring physicians to visualize from a poorly-recorded image, many image processing functions have been implemented as the most frequently used parameters (Horii *et al.* 1994). These functions provide some generic tools such as zooming, panning, rotation, flipping, filtering and histograms, as well as contrast and intensity adjustments necessary to basic display and manipulation of images. Additionally, annotation is a set of computer-controlled graphic functions (Andriole *et al.* 1994). The annotation function allows the user to highlight the area of interest on the screen by drawing lines and arrows of variable size. Also, it can insert text strings as comments on the screen.

For portability, special care has been taken to provide a very consistent approach with different image processing tools. The different ways a task is performed are always very similar, allowing the user to become quickly familiar with the operation of all the features of the program. Most operating functions are based on graphical tools used for display and referred to graphical user interfaces. As for the initial experimental phase, none of the users seemed to be confused by the variety of graphical tools that the program offers. Also, all the function operations are written by C++ as an object-oriented language. The implementation is specific to the object and inaccessible to the other objects (Ligier *et al.* 1993; Lindley, 1995). Complex functions can be easily implemented by grouping relevant objects. Due to the object-oriented structure, it has been easy to integrate them into software modules.

Standardization has been a key issue. Standardization must cover the image transmission protocol for the network interface and image exchange for archiving and acquisition from different imaging modalities. The DICOM V 3.0 is the latest version of a series of ACR-NEMA (American College of Radiology and the National Electrical Manufactures Association) standards. DICOM covers the digital image communication standard and media storage standard. (Kevin *et al.* 1990; Moore, 1996) Since DICOM supports the TCP/IP protocol, a network program is implemented on top of the TCP/IP. Although a commercially-supplied DICOM development toolkit, such as ANAPI from DeJarnette Systems, provides the fastest method of producing a DICOM compliant (Frost *et al.* 1994), it can not be operated well in an object-oriented C++ environment. We took an object-oriented approach for accessing the DICOM dictionary and making DICOM formatted messages systematically. Also, the major benefit of using standards is that as the system becomes more open, so does it become easier to add new components or replace existing ones.

From the point of cost-effectiveness, image-display workstations are still expensive, so that the total cost of PACS installation becomes much more expensive (Ramaswamy *et al.* 1994). Therefore, the software platform based on the personal computer was selected. It is expected that PC performance will increase and hardware costs will decrease over the next few years with the advancement in technology and increasing market demand.

In conclusion, we have implemented a PC-based, low-cost clinical workstation for referring physicians. These software modules are designed as modular and expandable. They are based on a DICOM standard and object-oriented paradigm to meet the requirements for accessibility, expansion and modularity. They provide a useful tool for referring physicians to display, manipulate and retrieve the medical images in a clinical PACS environment.

REFERENCES

Andriole KP, Ratib O, Huang HK: Picture archiving and communication system(PACS)-to-personal computer (PC) radiologist workstation. *SPIE PACS Design and Evaluation 1899: 90-94, 1994*

Duchêne J, Lerallut JF, Gong N, Kanz R: MicroPACS: a PC-based small PACS implementation. *Med Biol Eng Comput 31: 268-276, 1993*

Ehricke HH, Grunert T, Buck T, Kolb R, Skalej M: Medical workstations for applied imaging and graphics research. *Comput Med Imaging Graph 18: 403-411, 1994*

Frost MM, Honey J, Staab E: A DICOM server for CT and MR acquisition to an archive. *SPIE PACS Design and Evaluation 2165: 70-77, 1994*

Ho BKT, Ratib O, Horii S: PACS workstation design. *Comput Med Imaging Graph 15: 147-155, 1991*

Hohman SA, Johnson SL, Valentino D, Taira RK, Manzo WA: Radiologists' requirements for primary diagnosis workstations: preliminary results of task-based design surveys. *SPIE PACS Design and Evaluation 2165: 2-8, 1994*

Honeyman JC, Arenson RL, Frost MM, Bidgood D, Staab E: Functional requirements for diagnostic workstation. *SPIE PACS Design and Evaluation 1899: 103-109, 1993*

Horii S, Feingold E, Kundel H, Nordin C, Langlotz C, Redfern R, Grevera G, Brikman I, Muck J: PACS workstation functions: usage differences between radiologists and MICU physicians. *SPIE PACS Design and Evaluation 2165: 266-271, 1994*

Inamura K, Takahashi T: Storage and presentation of images. *Int J Biomed Comput 39: 157-162, 1995*

Kevin MM, Masakazu O, Ralph M, Tawara K, Kris M, Rick V, Takeshi O, Kenichi K, William D, Yuki F, Akihiro T: Evaluation of the ACR-NEMA standard for communications in digital radiology. *IEEE Medical Imag 9: 281-289, 1990*

Kruglinski DJ: *Inside visual C++*, 4th eds. Microsoft Washington, Press, *209-242, 383-436, 1995*

Lemke HU, Faulkner G, Krauss M: Development towards multimedia medical workstations. *Comput Med Imaging Graph 18: 67-71, 1994*

Ligier Y, Ratib O, Logeon M, Girard C, Perrier R, Scherrer J: Object-oriented design of medical imaging software. *Comput Med Imaging Graph 18: 125-135, 1994*

Ligier Y, Ratib O, Rejmer M, Moricz R: Interactive software for cooperative medicine and remote consultation. *SPIE PACS Design and Evaluation 1899: 318-323, 1993*

Lindley CA: *Photographic imaging techniques in C++*, 1st eds. New York, Addison-Wesley, *1995, 280-352*

Lou SL, Huang HK, Taira R, Breant C: A 2K radiological image display station. *SPIE PACS Design and Evaluation 1899: 95-102, 1993*

Lun KC: New user interfaces. *Int J Biomed Comput 39: 147-150, 1995*

Moore SM: Observations on DICOM demonstrations at the RSNA annual meetings. *SPIE PACS Design and Evaluation 2711: 89-97, 1996*

Orphanos G, Kanellopoulos D, Koubias S: Communication software for physicians' workstations supporting medical imaging services. *SPIE PACS Design and Evaluation 1899: 476-485, 1993*

Ramaswamy MR, Avrin DE, Andriole KP, Wong AWK, Bazill TM, Arenson RL: Use of personal computer technology in supporting a radiological review workstation. *SPIE PACS Design and Evaluation 2165: 27-37, 1994*

Sinha AK: *Network programming in Windows NT*, 1st eds. New York, Addison-Wesley, *1996, 199-300*

Stewart BK, Aberle DR, Boechat MI, Taira RK, Sayre JW, Dwyer III SJ: Clinical utilization of grayscale workstations. *IEEE Eng Med Biol: 86-100, 1993*

Yang NY, Ivey J: Hybrid image archive systems. *SPIE PACS Design and Evaluation 1899: 165-171, 1993*