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A HIERARCHICAL MODEL FOR PACS

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Abstract—In this paper, a hierarchical model for Picture Archiving and Communication Systems (HPACS) is presented and implemented at Taichung Veterans General Hospital (TCVGH) in Taiwan. Despite the fact that the HPACS is built on the architecture of the second generation PACS, it offers many improved features and has advantages over the second generation PACS, such as the user security control, fast resource dispatch and efficient resource management. This HPACS can be used as a reference model for a hospital with any scale-size. The real implementation of HPACS is currently undertaken in the Taichung Veterans General Hospital (TCVGH), Taiwan, Republic of China and consists of four phases with the first two phases already completed. It is the first pilot system ever to be implemented successfully in a large-scale hospital in Taiwan. The experiences have illustrated the great promise of the HPACS in the future. © 1997 Elsevier Science Ltd. All rights reserved.

Key Words: Picture Archiving and Communication Systems (PACS), Digital imaging, Hierarchical pyramid, Networks, Fiber Distributed Data Interface (FDDI), Resource management

INTRODUCTION

In recent years, there have been many reports on PACS published in the literature. Most have been based on the framework of the second generation PACS model to improve PACS implementation (1–6), increase the resolution of the display station (7), to design faster network systems or to enhance the capacity of image management and operation on personal computers (8, 9), etc. Very few addressed the issue of optimal design for managing resources so as to reduce the cost of PACS. This is particularly important for a large-scale hospital with limited resources. For instance, there is no need to install 2k×2k display stations in all departments, but only those places which require one to view CR (computed radiology) images. It is our belief that a good large-scale PACS should effectively take advantage of various resources, reinforce administration of user security, distribute the system workload to display stations and increase the system fault tolerance capability. As a result, the burden of the main server and network system can be relieved, the system response time will be improved and the peak time system workload will be reduced.

It seems that all the problems mentioned above hinge on the architecture of PACS. The first generation PACS is an integrated network of digital devices used to electronically acquire, store, manage and display images obtained by any radiological technique, along with the corresponding diagnosis and text information about patients (10–17). When compared to the first generation PACS which is a closed system and requires its own dedicated software and network, the second generation PACS has the following advantages: open architecture; connectivity; standardization; and portability of software. The open architecture and connectivity make the system integrate different components easily. However, there is the problem of management difficulty if the number of components to be connected increases and no guideline of management strategy is provided. In order to resolve this problem, we propose a hierarchical PACS (HPACS), which offers a management reference model so that HPACS can be adapted to meet different scales of PACS.

The HPACS implemented in TCVGH consists of two major components. The first component is a system resource management pyramid which integrates users-security hierarchy, application hierarchy, display-station hierarchy and network hierarchy respectively. The second component is made up of a database hierarchy, a storage hierarchy and a server hierarchy which form a hierarchical storage management system. There are also layer-correspondences between different hierarchies and interfaces between layers in various hierarchies.

The HPACS at TCVGH has planned four phases with the first two phases already completed in 1995. The TCVGH is the only medical center located in the central part of Taiwan which has 1260 beds and about 4000 outpatients per day. More than 300,000 examinations are performed every year including digital imaging modalities, X-ray, CT, MRI, Ultrasound, etc. The first phase of HPACS was to install a mini-PACS in the emergency unit and the Department of Radiology, while the second phase is to extend the first phase PACS via networks to cover various digital imaging modalities including MRI, CT, ultrasound, video endoscopy and digital fundus images. The third phase is currently underway with the aim of using ISDN networks or Internet networks to connect other remote veteran hospitals in Taiwan. When this is accomplished, telemedicine becomes possible and the environments of high resolution display stations and multi-screen display stations can be set up along with pertinent softwares. The fourth phase, i.e. last phase will enhance software and hardware of HPACS to support inpatient applications. Thus far, the HPACS is the first successful pilot system ever installed in Taiwan. It will serve as a model for other hospitals which plan to install PACS in the future.

HIERARCHICAL MODEL FOR PACS

The first component of HPACS is a system resource management pyramid illustrated in Figs 1–3 with four facets representing: (i) users-security hierarchy; (ii) application hierarchy; (iii) display station hierarchy; and (iv) network hierarchy. The second component is a hierarchical storage management system which integrates a servers hierarchy shown in Fig. 4, a database hierarchy in Fig. 5 and a storage hierarchy in Fig. 6. A servers hierarchy starts with local operation of display stations, then goes up to the departments' server and finally reaches the main server. A database hierarchy begins with the local DB of view stations, then uses SQL (sequential query language) to go one layer up to access the departments' server DB. If the search is unsuccessful,

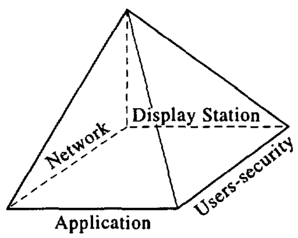

Fig. 1. System resources management pyramid with four facets denoted by users-security, application, display station and networks.

it will continue to use SQL to access the top layer, the main server DB. Figure 6 illustrates the storage space hierarchy which can be found in (18). In addition to the proposed hierarchical storage management system, a prefetch strategy can be further implemented in accordance with the specifications of image data to improve the performance of PACS.

PACS IN TCVGH

TCVGH began its interest in PACS in 1992. After a careful evaluation, the proposed HPACS was adopted for implementation based on the following advantages.

Users-security hierarchy

There are many users in a large-scale hospital. In order to achieve different levels of computer security, users must be classified and assigned by different authorized computer accesses to protect the data. An effective and efficient data management with user security control is built on a users-security hierarchy with high demanding users designated as doctors in ICU (intensive care unit), OR (operation rooms) and

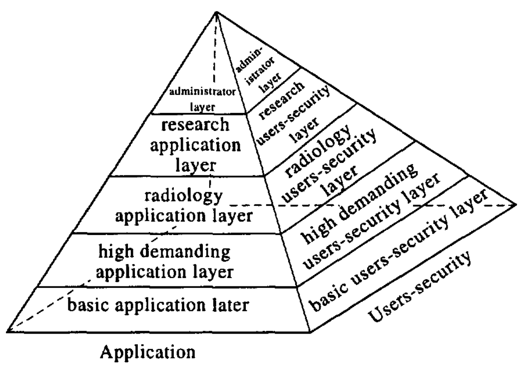

Fig. 2. Layers in users-security and application facets of system resource management pyramid.

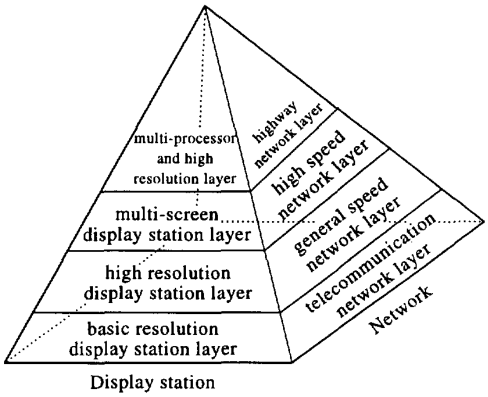

Fig. 3. Layers in display station and network facets of system resource management pyramid.

ER (emergency room) and basic users as doctors working in wards and technicians. The priority of data access is authorized from top to bottom as depicted in Fig. 2. We first define different groups of users and assign them different levels of access authorizations. Each user will have his own ID and password. We then use one mapping table to identify the user and his associated group and another mapping table to identify the group and its given level of access authorization to achieve various levels of security.

Application hierarchy

The applications hierarchy is established based on needs from different layers in the users-security hierarchy. In particular, the bottom two layers can be further divided into three categories, inpatient unit, outpatient unit and ER as shown in Fig. 7, each of which has its own needs and requires separate applications. The reason for such a division is to implement flexible adjustment of practical needs in these three units. This application layer pyramid, along with the users-security layer pyramid, constitutes a key element in the design of a large-scale

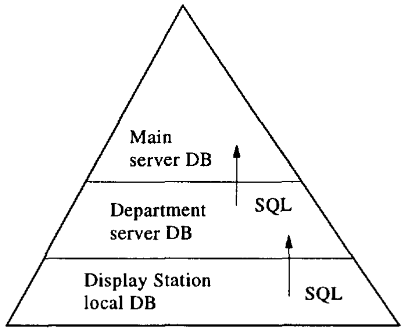

Fig. 5. DB search hierarchy.

PACS. The advantage of this application hierarchy offers a clear guideline for software design (19) and simple implementation in a predetermined manner in accordance with the application software and layer mapping table and can be also adjusted based on a hospital's practical needs.

Display station hierarchy

In general, different medical imaging modalities require different resolutions. The proposed display station hierarchy depicted in Fig. 3 classifies display stations into four categories: (i) the multi-processor and high resolution display stations; (ii) the multi-screen display stations; (iii) the high resolution display stations; and (iv) the basic resolution display stations.

Network hierarchy

Network determines the speed of data transmission. The previous PACS can only offer the high speed network when it is small, but cannot when it is large. In the proposed network hierarchy, four networks are suggested to meet different cost and

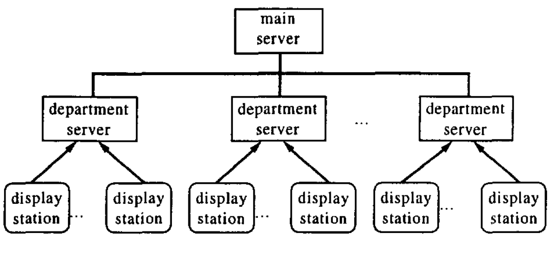

Fig. 4. Server hierarchy.

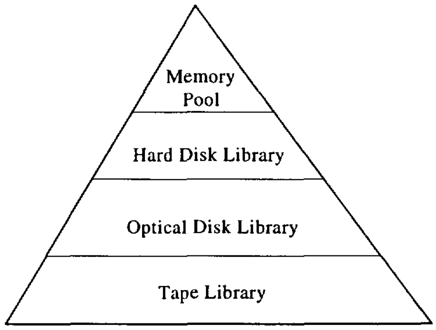

Fig. 6. Storage space hierarchy in storage system.

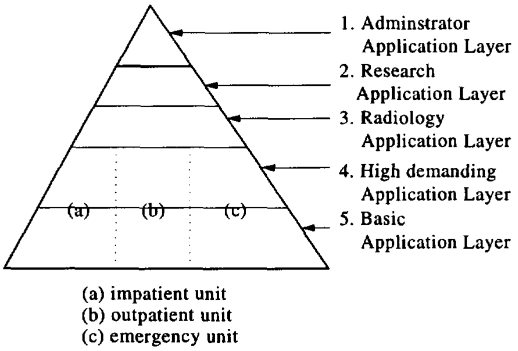

Fig. 7. Structure diagram of applications hierarchy.

applications requirements. They are the highway network, the high speed network layer, the general speed network and the telecommunications network layer.

The current planning HPACS consists of four phases with the first two phases already completed.

PHASE 1: SYSTEM CONFIGURATION

In the first phase, a mini- PACS was developed and installed in ER, computer center and the Department of Radiology in TCVGH as shown in Fig. 8.

The system proposed in the first phase is a mini-PACS comprising five components: one main server; one gateway system; one network system; several display stations; and one image acquisition system. Through this mini-PACS, it can help us calculate the cost and effectiveness for future development of a large-scale PACS system. In addition, it can also help to identify some potential issues which may arise in expansion of PACS so that these problems can be resolved in the second phase. More importantly, this mini-PACS can be used as a measure in evaluating the degree of doctor's acceptance of using the PACS.

Main server

The main server is primarily used for storage. It has one 3.6 GB and one 1 GB hard disk to store all patient image data and relevant information. It requires an average of 100 MB storage per day to accommodate CT image data produced by the emergency unit in TCVGH. The capacity of the main server allows us to store data up to 1 month. This is acceptable for the emergency unit and the Department of Radiology. In order to increase retrieval rate, the memory of the file server is expanded to 32 MB to create a memory pool to store those data which are frequently accessed. As a result, the storage space of the main server can be divided into two layers, memory pool and hard disk library. The main server installs two SCSIs (small computer system interface) and two Ethernets to share the work load and speed up the system.

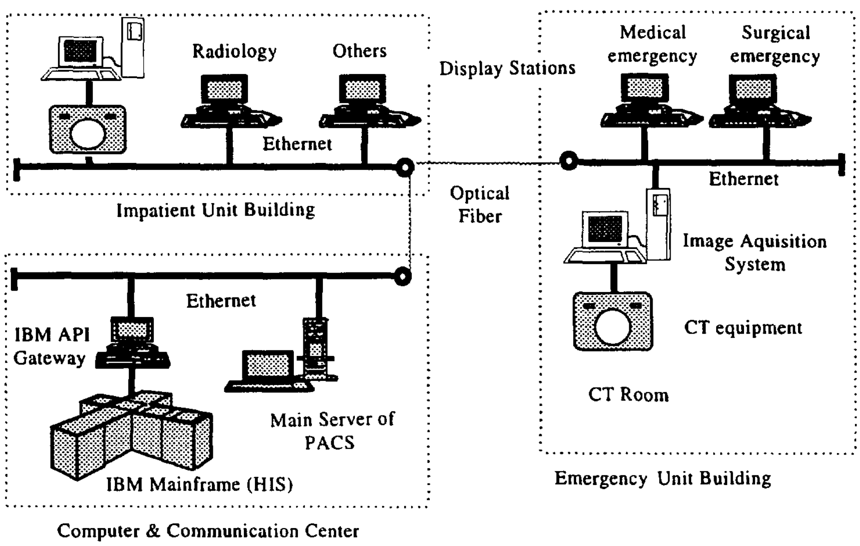

Fig. 8. Infrastructure of emergency computed tomography PACS in the TCVGH. Pyramid name implementation layer in HPACS.

Gateway system

Since the HIS in TCVGH is well-developed, the Gateway system in the first phase is designed to integrate the existing HIS, RIS and PACS. This integration system is built based on a 486-33 PC with Ethernet interface and IBM terminal emulation interface. It uses IBM API (application interface) to successfully integrate the database of the PACS with IMS database of HIS in the IBM 9121-511 mainframe computer.

Network system

The network system in the first phase is called the general speed network layer described in the hierarchical network pyramid which based on a 10 MBPS Ethernet. The network used by each mini-PACS in the first phase is connected by Ethernets. However, PACS's installed in different buildings are networked by optical fibers while the coaxial cables are used to connect the network between stories in the same building. Despite the fact that the transmission rate is only 10 MBPS, we have found the network system proposed in the first phase have achieved desirable performance and produced acceptable results. Before PACS was implemented, it generally took 30 min for doctors in ER to acquire one CT image. When time is urgent, the doctors in ER must run into the CT room to examine the image to make a timely diagnosis. Such a situation is drastically improved after the first phase of our PACS was completed. The doctors in ER can view CT images directly from their computers via network systems. The acquisition time for one CT image is about 2 s. As a result, TCVGH can provide patients with better quality service.

Display station

The proposed display station is built in a 486 PC-based environment. It installs an additional 32 MB memory to create a memory pool for storage of frequently used data so that these data can be promptly accessed for fast retrieval. Since the mini-PACS in the first phase targets CT modality, the basic resolution display station with the resolution $1024\times768\times8$-bit is sufficient and acceptable to doctors in ER. This is because in TCVGH most of ER patients who took CT images are brain injuries and the resolution $1024\times768\times8$-bit is acceptable for diagnosis. Only a few cases require CT film for further diagnosis. This display resolution is provided by an ET 4000 display card.

Image acquisition system

The main components of the proposed image acquisition system are a 486 PC and an image capture board (Precision 15 AT video capture board, ADI Audio Digital Image, Inc.) used to connect the video line of CT scanner. The CT images are transmitted via the video line and the image capture board to the PC and then stored in the file server. The resolution of the image capture board requires $580\times720\times8$ bit to match the CT video signal.

PHASE 1: SOFTWARE CONFIGURATION

The software configuration comprises a display station software, a database system and an image acquisition software, all of which are developed in the PC-DOS and Novell Netware environment and written in C language to be compatible with the Code Base V.5.0 programming library (Sequiter Software Inc, Canada). Since this configuration does not require high sophisticated techniques, it is very suitable for a hospital who wishes to install a PACS without experience.

Database system

Through the database provided by the code base programming library we can create the desired database for the proposed mini-PACS in the file server. This database can be used for software development for the image acquisition system, gateway system and display station system. The advantage is that the code base library can be called by direct use of C language and has a better access capability.

Application software

As has been mentioned, the users-security pyramid in the HPACS was categorized by five layers. In the mini-PACS of the first phase, the users-security pyramid consists of only three layers, administration layer, radiology users-security layer and basic users-security layer. In the first phase of PACS, the users are limited. So, the 5-layer users-security hierarchy is acceptable. However, the number of layers can be increased to accommodate more users when it is necessary. In addition, we also offer many image processing techniques to manage image data such as segmentation, zoom in, zoom out, low-pass and high-pass filtering, normalization and various techniques to measure the angles of bone fracture.

Image acquisition software

The image acquisition software is written in C to drive the image capture board to acquire the image data. Through the gateway system and HIS the image data are integrated with the corresponding patient text data to create the patient's file. With code base the patient file is then stored in the database of the file server for future retrieval by image display stations.

The above described mini-PACS was completed in 1993 and received considerable interest and support from the doctors and physicians in ER. The implementation of layers in seven hierarchies for phase one is detailed in Fig. 9.

PHASE 2: SYSTEM AND SOFTWARE CONFIGURATIONS

In the second phase, the mini-PACS developed in Phase 1 (i.e. ER and the Department of Radiology) was extended via network systems to link those places in TCVGH which need to view image data, such as operation rooms, ICU, NCU and wards, etc. During this phase, one MRI (Picker Vistar), three ultrasounds, three CT scanners (Picker 2000, Picker 1200 and Siemens Semato DR 3) and one video endoscopy and one digital fundus image were all network connected. In other words, in the second phase, the problems discovered in Phase 1 were resolved and the functions of PACS were improved and strengthened. In particular:

- the storage of file servers was increased to accommodate image data acquired from new added modalities;
- a prefetch strategy was implemented to reduce peak time workload of network systems and file servers so as to increase the access response time of display stations;
- the capability of the fault tolerance was improved by redundant hardware to increase the reliability and availability of the system;
- many more display stations and image modalities were installed to extend the applications of PACS;
- the bandwidth of the network was increased by connecting two FDDI networks to 40 Ethernet segments.
- the security and resource management were reinforced to achieve greater cost-effectiveness.

Pyramid Name	Implementation Layer in HPACS
Users-Security	Administrator Layer Radiology Users-Security Layer Basic Users-Security Layer
Applications	Administrator Application Layer Radiology Application Layer Basic Application Layer
Networks	General Speed Network Layer
Display Stations	Basic Resolution Display Station Layer
Servers	Main Server
Data Base	Main Server Data Base
Storage Space in Main Server	Memory Pool of Main Server Hard Disk of Main Server

Fig. 9. Layer implementation of the HPACS in the TCVGH with first phase.

More specifically, we discuss the second phase implementation in detail as follows.

Main server

(a) Since the demand of the digital image data grows rapidly in the second phase, an additional 180 GB hard disk is installed in the file server. In the meantime, RAID (redundant arrays of inexpensive disks) is used to prevent the file server from data loss resulting from unexpected or accidental damage. RAID is a new fault tolerance disk system. When five disks are used for storage, one of them will be used for parity check disk. If one of disks crashes, the parity check disk can detect it and automatically recover data after the crashed disk is replaced. The capacity of the file server allows TCVGH store image data up to 2 years and also allocates data storage for future development of CR.

(b) In this phase, an additional main server is also installed so that two main servers can back up each other to avoid the complete system shut down if one server is out of work. This will secure the availability of the main servers during 24 hr service.

(c) It also uses four SCSIs to connect RAID of the main servers to increase the access speed and each SCSI has 20 MB bandwidth per second. In addition, two FDDI networks and 40 Ethernet segments are used to defuse the network traffic resulting from the workload of the main servers.

Network

In the second phase, an extra layer, called a high speed network layer is added to the network pyramid developed in the first phase. Two FDDI dual rings are used to link five major buildings in TCVGH and two routers are used to connect 40 Ethernet segments in the original general speed network layer so that the data in two separate layers can interact. Besides, in the high speed network layer, 60 CDDI (copper distributed data interface) are also added to the FDDI network to support the high demanding application layer. Both CDDI and FDDI have the same 100 MBPS.

Display station

To improve the capability of display station, multi-processor and high resolution display stations are introduced in the second phase so that display station can handle more dedicated image processing and shorten the response time. In order to support high quality research on 3D image reconstruction, 3D visualization and virtual reality of surgical simulation, display stations with dual CPU are used to carry out sophisticated scientific computing. In the meantime, the application software creates special functions for research applications and offers researchers an independent access to different levels of security. As a result, a new research application layer is added to the phase 1-developed users-security pyramid. In addition, more display stations are installed in places which need to view images. A total of 200 display stations have been installed in the second phase.

Database

In the second phase, the Fox pro database is used in conjunction with pre-fetch strategy for database management where the aging criterion is adopted for optimality. This allows one to keep most recent image data in the local hard disks of display stations. As a consequence, a new display station local database layer is added to the Phase 1-database pyramid. Similarly, a new display station local hard disk layer is also created for Phase 1-storage location pyramid. In order to execute pre-fetch rule, a dispatch server is employed with a predefined dispatch table to dispatch image data. The dispatch works by placing the image data in the most likely accessible local hard disks of the display stations. These display stations are determined in accordance with the types of examination, radiologists and physicians.

The second phase of HPACS was completed in June 1995. Figure 10 shows the implementation of the first two phases with the second phase indicated by "*".

To date, the first and second phases of PACS have been implemented in TCVGH on the basis of the proposed HPACS model. Many advantages have been found and can be summarized as follows.

(i) The proposed PACS can be expanded step by step from a small-scale system to a large-scale system.
(ii) The security of data access can be implemented under safety control.
(iii) The resource management and utilization can be optimized at a desirable level.
(iv) The system can be built on the existing second generation PACS.

The third phase of HPACS is now in progress. The main goals are: (i) to use ISDN networks or Internet networks to connect other remote veteran hospitals in Taiwan; (ii) to set up environments of high resolution display stations and multi-screen display stations along with relevant and necessary softwares; (iii) to include a new modality, CR (computed radiology) since its resolution can be as high as $3k \times 4k \times 12$-bit; and (iv) to install a new main server which includes tape libraries to complete the hierarchical pyramid for storage space system. When this is accomplished, telemedicine becomes possible and the environments of high resolution display stations and multi-screen display stations can be set up along with pertinent softwares. Department servers will be delayed until the fourth phase to implement. The fourth phase, i.e. final phase will enhance software and hardware of HPACS to support inpatient applications. In addition, new technology and development will be also included

Pyramid Name	Implementation Layer in HPACS
Users-Security	Administrator Layer *Research Users-Security Layer Radiology Users-Security Layer Basic Users-Security Layer
Applications	Administrator Application Layer *Research Application Layer Radiology Application Layer Basic Application Layer
Networks	*High Speed Network Layer General Speed Network Layer
Display Stations	*Multi-Processor and High Resolution Display Station, Basic Resolution Display Station Layer
Servers	Main Server
Data Base	*Display Station Local Data Base Main Server Data Base
Storage Space in Main Server	Memory Pool of Main Server Hard Disk Library of Main Server

Fig. 10. Layer implementation of the HPACS in the TCVGH with the first two phases where second phase is indicated by *Hierarchies.

in this phase. As soon as the fourth phase is completed, a full-scale HPACS is established. Since the HPACS is developed based on the concept of object-oriented strategy, any new technology in the future can be very easily introduced and incorporated into the HPACS.

DISCUSSION

As discussed previously, the users-security, applications, display stations and networks hierarchies actually function all together as a system resource management while the database, servers and storage hierarchies are integrated to optimally manage data storage capacity and access time. Besides, as is shown in Fig. 11, correspondences and relationships exist in the system resource management between layers in the four resource hierarchies. The first column is designated as layers of the users-security hierarchy. The second, third and fourth columns correspond to applications, view stations and networks hierarchies. Each row across columns 2–4 represents how many layers a user in the users-security hierarchy can access under each particular hierarchy. For instance, the administrator layer in the users-security hierarchy has authorized access to all layers in applications, view stations and networks hierarchies. In other words, the users in this layer have top priority to use all applications, display stations and networks layers. For users in the radiology layer, they can only access layers 3–5 in the applications hierarchy, layers 2–4 in the display stations hierarchy and all layers in the networks hierarchy. For instance, the research application layer needs the high performance network because it generally requires a large volume of data for analysis and processing such as 3D reconstruction and virtual reality. While Fig. 11 is not rigid (it only provides an example implemented in the TCVGH), it can be modified and adjusted to meet different needs required by hospitals. In particular, a hospital can select any layer in the HP-PACS appropriate for its own size to implement a PACS and gradually expand the system by following the hierarchies of the system resources management pyramid in the HP-PACS as shown in Figs 1–6.

Hierarchies / Users-Security Hierarchy	Applications	Display Stations	Network Systems
Administrator	1, 2, 3, 4, 5	1, 2, 3, 4	1, 2, 3, 4
Research	2, 3, 4, 5	1, 2, 3, 4	1, 2, 3, 4
Radiology	3, 4, 5	2, 3, 4	1, 2, 3, 4
High Demanding	4, 5	3, 4	2, 3, 4
Basic	5	4	3,4

Fig. 11. Users-security hierarchy vs applications, display stations and networks hierarchies.

It is often the case that a large-scale hospital hesitates to install a PACS because the initial investment is too expensive. On the other hand, every hospital has its own needs and budget to determine what size of PACS it can afford to install. The proposed HPACS at TCVGH offers a good solution. A hospital of any size can choose an appropriate layer from the pyramidal architecture to install its desired PACS and then gradually expands it in the future if necessary. In addition, the hierarchical pyramid architecture allows the HPACS at TCVGH to adapt very easily to fast-growing computer technology. New softwares and hardwares can be included and implemented in the system without difficulty. New products and upgraded equipments can be also easily included in the higher layers, while the obsolete equipment can be moved to lower layers. The system resource management pyramid and the hierarchical storage management system in the HPACS at TCVGH are designed to best utilize the existing resources and facilities to avoid unnecessary waste or redundant purchase of the same equipment. Although a small hospital may not need a full scale system like HPACS at TCVGH, a large hospital can certainly take advantage of the hierarchical structure to integrate a wide variety of equipment to eliminate the possible incompatibility of equipment purchased from different vendors and various systems with different access level requirements and needs. Thus far, the HPACS at TCVGH has shown great promise for the future and demonstrated its cost-effectiveness and efficacy of performance. The Taipei Veterans General Hospital (TPVGH) has adopted the proposed HPACS model to implement its own PACS with the first phase completed in 1994.

CONCLUSION

In this paper, a hierarchical pyramid-based PACS at TCVGH is presented. The pyramidal architecture of HPACS at TCVGH can be adjusted easily and implemented based on different needs and requirements. It is very flexible and may be adjusted subject to request. The advantages of HPACS at TCVGH are summarized as follows.

(i) It can integrate different types of systems which may interact with one another.
(ii) It can best manage the resources and facilities.

(iii) New products or equipments can be included very easily and incorporated into the HPACS at TCVGH without causing any difficulty.
(iv) Since all resources and users are categorized and structured in a pyramidal architecture with predetermined criteria, the management is efficient and effective.
(v) Different levels of access security can be implemented based on the pyramidal structure to prevent illegal break-in or change of data.
(vi) The overall performance of HPACS at TCVGH achieves the expectations and standards initially set by the TCVGH.

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