Joint Conference of 1996 International Computer Symposium
December 19~21, Kaohsiung, Taiwan, R.O.C.

A Hierarchical Pyramid-Based PACS at Taichung Veterans General Hospital in Taiwan

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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 features and advantages that the second generation PACS can be improved, 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 successful pilot system ever implemented in a large-scale hospital in Taiwan. The experiences have shown a great promise of the HPACS in the future.

Key words: Picture Archiving and Communication Systems (PACS). Digital imaging. Hierarchical pyramid. Networks. Fiber Distributed Data Interface (FDDI). Resource Management

1. INTRODUCTION

Over the past years, there have been many reports on PACS published in the literature. Most of them are based on the framework of the second generation PACS model to improve PACS implementation [1-6], increase the resolution of 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 of installing 2k x 2k display stations in all departments, but only those places which require to view CR (computed radiology) images. It is our belief that a good large-scale PACS should effectively take advantage of various resources; reenforce administration of user security; distribute 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 are hinged 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]. Comparing with the first generation PACS which is a closed system and requires its own dedicated software and network, the second generation PACS has following advantages: open architecture, connectivity, standardization, and portability of software. The open architecture and connectivity make the system integrate different components easily. However, it also results in a 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 data base 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 1,260 beds and about 3,000 out patients per day. A total of more than 250,000 examinations is done 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 under way 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 outpatient 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.

2. Hierarchical Pyramid-Based PACS

According to past experiences, several issues of implementing a PACS in a large-scale hospital are (i) no systematic integration of different systems, (ii) poor resource management, (iii) inefficient distribution of system workload, (iv) low cost-effective and (v) lack of user security control. In order to resolve these problems, a hierarchical pyramid-based PACS (HP-PACS) is proposed which not only accomplishes the goals described above, but also provides great flexibility and adaptability. The architecture of the HP-PACS is made up of 2 components.

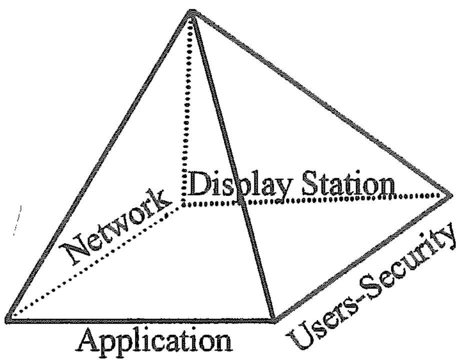

Figure 1(a): System resources management pyramid with four facets denoted by users-security, application, display station and networks

The first component can be described by a system resource management pyramid illustrated in Figure 1(a-c) 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 database storage hierarchy and a servers hierarchy.

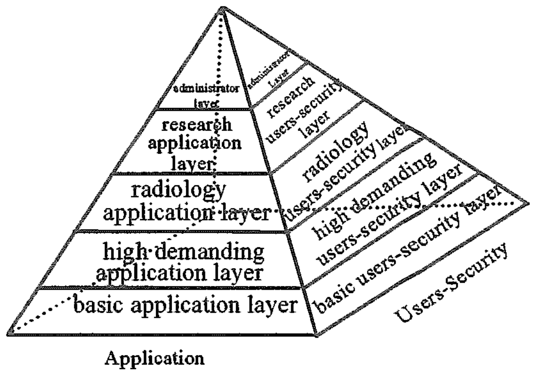

Figure 1(b): Layers in users-security and application facets of system resource management hierarchy

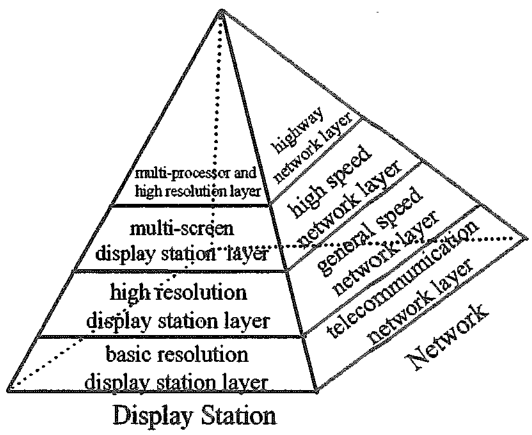

Figure 1(c): Layers in display station and network facets of system resource management hierarchy.

2.1 Component 1: System Resource Management Pyramid

The first major component of the HP-PACS is the system resource management pyramid which integrates users-security, application, display-station and network hierarchy into one pyramid as shown in Figure 1(a-c). It effectively distributes the available resources among users and optimize the utilization of the resources to avoid unnecessary waste.

2.1.1 Hierarchical Users-Security Hierarchy

There are many users in a large-scale hospital ranging from new coming trainees to researchers, doctors, nurses, technicians and staff. 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 hierarchical users-security hierarchy where the top-level is the highest-level hospital administrators and the bottom base layer corresponds to basic users such as entry-level personnel. The priority of data access is authorized from top to bottom. A diagram of a 5-layer hierarchical users-security hierarchy is depicted in Figures 1(b).

2.1.2 Hierarchical Application Hierarchy

The hierarchical applications hierarchy is established based on needs from different layers in the hierarchical users-security hierarchy. Different users-security layers require different applications and software implementations. In particular, the last two bottom layers can be further divided into three categories, inpatient unit, outpatient unit and emergency unit as shown in Figure 2, each of which has its own needs and requires separate applications. The reason for such division is to implement flexible adjustment of practical needs in these three units. This application layer hierarchy along with the users-security layer hierarchy constitute a key element in the design of a large-scale PACS. The advantage of this hierarchical application hierarchical structure offers a clear guideline for software design [18] and simple implementation in a predetermined manner in accordance with the application software and layer mapping table and can be also adjusted based on hospital's practical needs.

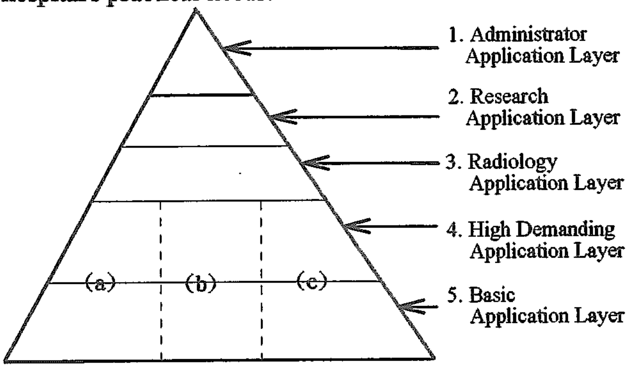

Figure 2: Structure diagram of hierarchical applications hierarchy

2.1.3 Hierarchical Display Station Hierarchy

In general, different medical imaging modalities require different resolutions. For example; CT and MR images require resolution of $512 \times 512 \times 12 - \text{bit}$ [10], whereas, the resolution for CR (computed radiography) ranges from $\text{k} \times 1\text{k} \times 8 - \text{bit}$ to $4\text{k} \times 4\text{k} \times 12 - \text{bit}$ [11] depending upon the types of disease and images taken from different locations. So, the capability of display stations determines the quality of images. The proposed display station hierarchy depicted in Figure 1(c) classifies display stations into 4 categories with different required purposes.

(i) the top layer is the multi-processor and high resolution display stations;
(ii) the second layer is the multi-screen display stations;
(iii) the third layer is the high resolution display stations;
(iv) the bottom layer is the basic resolution display stations.

2.1.4 Hierarchical Network Hierarchy

Network is a major issue when one comes to design a PACS. It determines the speed of data transmission. The previous PACS can only offer the high speed network when it is small, but cannot when the size is large. In the proposed hierarchical network structure, four layers are suggested to meet different cost and applications requirements. The top layer is called the highway network layer, the second is the high speed network layer, the third is the general speed network layer and the bottom layer is the telecommunication network layer. This is suggested based on the network systems presently available in the current market and can be modified whenever new networks are introduced in the future.

2.2 Component 2: Hierarchical Storage Management System

The concept of using a hierarchical architecture for a storage system in a PACS is to integrate data base, storage and servers all together in hierarchy as a hierarchical storage management system. Figure 3(a) shows a server hierarchical diagram where the data processing starts with the local operation of display stations, then goes up to departments' servers and finally reach the main server.

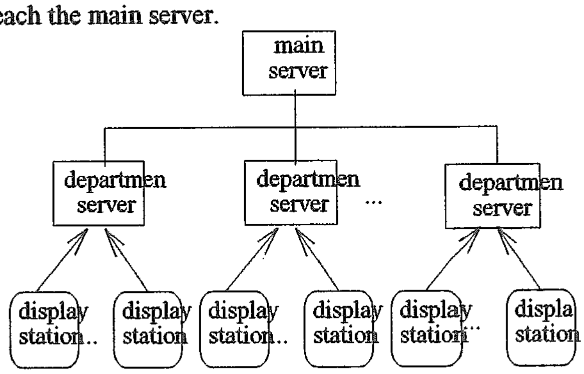

Figure 3 (a): Server hierarchy

Figure 3(b) is a hierarchical architecture for data base search where the data base (DB) search between two layers is carried out by SQL (sequential query language). It begins with the local DB of view stations, then uses SQL to go one layer up to access departments' server DB.

If the search is not successful, it will continue to use SQL to access the top layer, the main server DB.

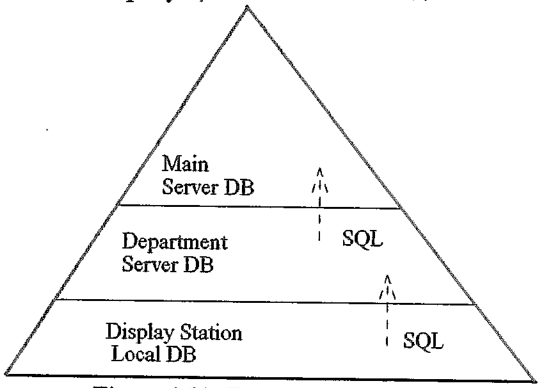

Figure 3(b): DB search hierarchy

Figures 3(c) illustrate two hierarchical sturctures designed for storage location and storage space in a storage system respectively (19).

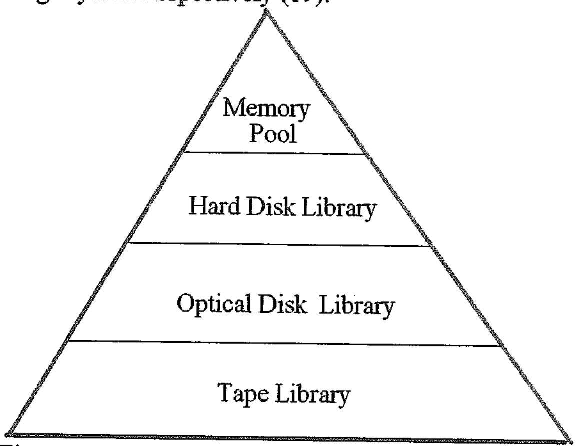

Figure 3(c): Storage space hierarchy in storage system

The top layer in Figure 3(c) is the memory pool which utilizes the ECC (error correcting code) memory to enhance the stability of a server. Since the hard disk in the second layer has very large capacity, redundant arrays of inexpensive disks (RAID) can be used to strengthen the fault tolerance capability. The optical disk in the third layer requires a juke-box to automatically control data storage and retrieval. In addition, a prefetch strategy can be further implemented in accordance with the specifications of image data to improve the performance of PACS.

3. PACS IN TCVGH

TCVGH began its interest in PACS in 1992. After a careful review and examination, the hierarchical pyramid-based PACS (HP-PACS) in the last section was adopted for implementation. The current planning consists of four phases with the first two phases already implemented.

3.1 Phase 1: System Configuration

In the first phase, a mini PACS was developed and installed in the emergency unit, computer center and the department of radiology in TCVGH as shown in Figure 4.

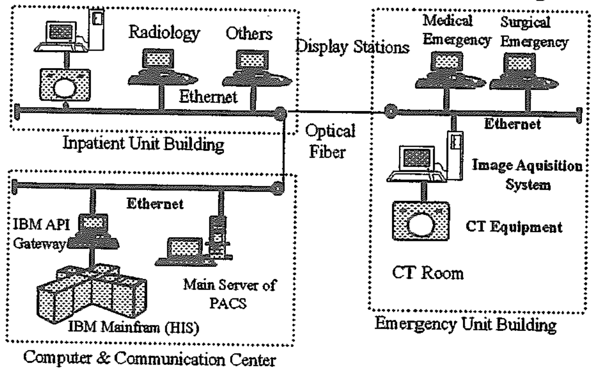

Figure 4: Infrastructure of emergency computed tomography PACS in the TCVGH

The system proposed in the first phase is a mini-PACS consisting of five components which are one main server, one Gateway system, one image acquisition system, one network system and several display station. Through this mini-PACS, it can help us figure out 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 consensus to evaluate 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 disks to store all patient image data and relevant information. It requires 100 MB storage per day on the average 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 one 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 install two SCSIs(small computer system interface) and two Ethernets to share the work load and speed up the system.

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 data base of the PACS with IMS data base 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 10MBPS 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 10MBPS, we have found the network system proposed in the first phase have achieved desirable performance and produced acceptable results. Before PACS being implemented, it generally took 30 minutes 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 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 seconds. 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 x 768 x 8-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 x 768 x 8-bit is acceptable for diagnosis. Only few cases require CT film for further diagnosis.

Image Acquisition System:

The main components of the proposed image acquisition system are a 486 PC and an image capture board 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 x 720 x 8 bit to match the CT video signal.

3.2 Phase 1: Software Configuration

The software configuration comprises a display station software, a data base 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 programming library.

Data Base System

Through the data base provided by the code base programming library we can create the desired data base for the proposed mini-PACS in the file server. This data base can be used for software development for the image acquisition system, gateway system and display station system.

Application Software

As mentioned in Section 2, the users-security hierarchy in the HP-PACS was categorized by 5 layers. In the mini-PACS of the first phase, the users-security hierarchy consists of only three layers, administration layer, radiology users-security layer and basic users-security layer. Using Figure 4 we can also identify the correspondent application software layers.

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 is integrated with the corresponding patient text data to create the patient's file. With code base the patient file is then stored in the data base of the file server for future retrieval by image display stations.

The above described mini PACS was completed in 1993 and received considerable interests and supports from the doctors and physicians in the emergency unit. The implementation of layers in seven hierarchys for phase one is detailed in Figure 5.

Hierarchy Name	Implementation Layer in HP-PACS
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

Figure 5: Layer implementation of the HP-PACS in the TCVGH with first phase.

3.3 Phase 2: System and Software Configurations

In the second phase, the mini-PACS developed in Phase 1 (i.e., the emergency unit 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), 3 ultrasounds, 3 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,

1. the storage of file servers was increased to store image data acquired from new added modalities;
2. 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;
3. the capability of the fault tolerance was improved by redundant hardware so as to increase the reliability and availability of the system;
4. many more display stations and image modalities were installed to extend the applications of PACS;
5. the bandwidth of the network was increased to accommodate vast amount of image data transmission.
6. the security and resource management were reenforced to achieve more cost-effective.

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 180GB hard disk is installed in the file server. In the mean time, RAID (redundant arrays of inexpensive disks) is used to prevent the file server from data loss resulting from unexpected or accidental damage. The capacity of the file server allows TCVGH store image data up to two 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 prevent the whole system from being shut down in case one server is out of work.

(c) It also uses 4 SCSIs to connect RAID of the main servers to increase the access speed. In addition, two FDDI networks and one Ethernet are used to defuse the network traffic resulting from the workload of the main servers.

Network

In the second phase, an extra layer, called high speed network layer is added to the network hierarchy 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 be interacted. 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.

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 delicated image processing and shorten the response time. In order to support high quality research on 3-D image reconstruction, 3-D visualization and virtual reality of surgical simulation, display stations with dual CPU are used to carry out sophisticated scientific computing. In the mean time, 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 hierarchy. 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.

Data Base

In the second phase, the Fox pro data base is used in conjunction with pre-fetch strategy for data base 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 data base layer is added to the Phase 1-data base hierarchy. Similarly, a new display station local hard disk layer is also created for Phase 1-storage location hierarchy. In order to execute pre-fetch rule, a dispatch server is employed with a predefined dispatch table to dispatch image data. The way the dispatch works is done by placing the image data in most likely accessible local hard disks of display stations. These display stations are determined in accordance with the types of examination, radiologists and physicians.

The second phase of HP-PACS was completed in June, 1995. Figure 6 shows the implementation of the first two phases with the second phase indicated by "*".

Hierarchy Name	Implementation Layer in HP-PACS
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

Figure 6: Layer implementation of the HP-PACS in the TCVGH with
the first two phases where second phase is indicated by *

Up to now, the first and second phases of PACS have been implemented in TCVGH on the basis of the proposed HP-PACS model. Many advantages have been found and can be summaried 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 HP-PACS is now in progress. The goal is (i) 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 $3k \times 4k \times 12\text{-bit}$; (iv) to install a new main server which includes tape libraries to complete the hierarchical structure for storage space system. When this phase is accomplished, telemedicine becomes possible. Departments' servers will be delayed until the fourth phase to implement. In addition, new technology and development will be also included in this phase. As soon as the fourth phase is completed, a full-scale HP-PACS is established. Since the HP-PACS 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 HP-PACS.

4.Discussion

As discussed previously, the users-security, applications, display stations and networks hierarchies actually function all together as a system resource management while the data base, servers and storage hierarchies are integrated to optimally manage data storage capacity and access time. Besides, shown in Figure 7 there exist correspondences and relationship 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 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, research application layer needs the high performance network because it generally requires a large volume of data for analysis and processing such as 3-D reconstruction and virtual reality. While Figure 7 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 Figures 1-3.

It is often the case that a large-scale hospital hesitates to install a PACS because of too expensive initial investment. 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 equipments can be moved to lower layers.

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

Figure 7: Users-security hierarchy versus applications, display stations and networks hierarchies

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 wastes or redundant purchase of the same equipments. Although a small hospital may not need a full scale system like HPACS at TCVGH, a large hospital can certainly take advantages of the its hierarchical structure to integrate a wide variety of equipments to eliminate possible incompatible equipments purchased from different vendors and various systems with requirement of different access levels and needs. Thus far, the HPACS at TCVGH has shown a great promise in the future and demonstrated its cost-effective and efficacy in performance.

5. Concluion

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

(i) It can integrate different types of systems and interact 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 HP-PACS 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 HP-PACS at TCVGH achieves the expectation and standard initially set by the TCVGH.

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