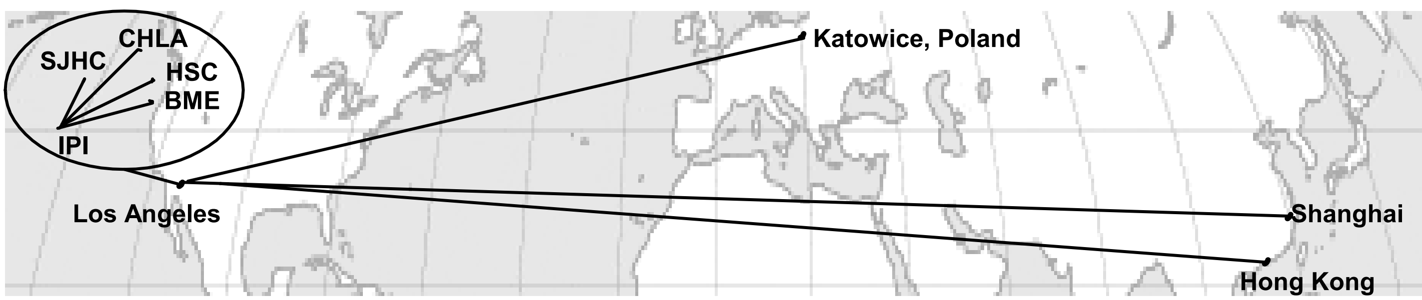
UNIVERSITY OF SOUTHERN CALIFORNIA

Image Processing and Informatics Laboratory (IPI)

Annual Progress Report

February 2004



RIS/PACS Simulator Demonstration at 89th Radiological Society of North America (RSNA) Annual Meeting, 2003

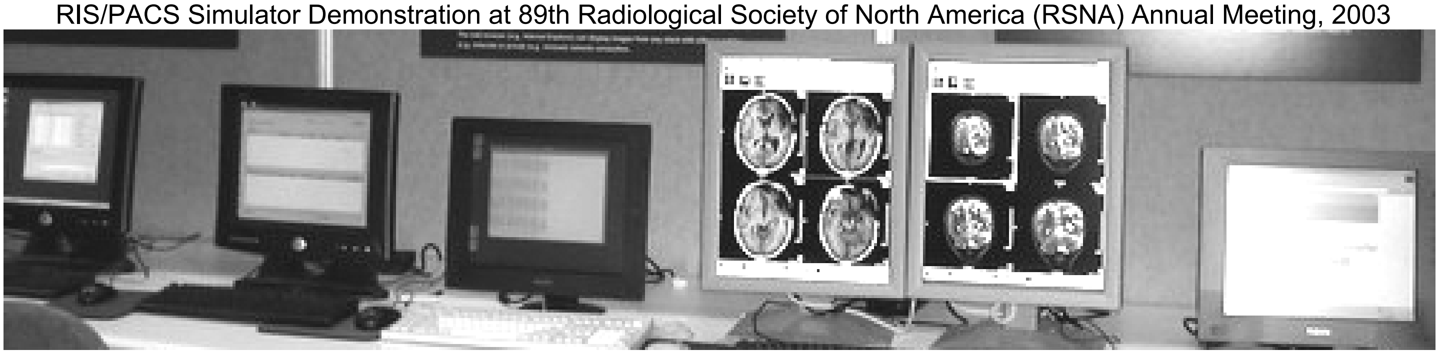


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IMAGE PROCESSING AND INFORMATICS LABORATORY

Department of Radiology
University of Southern California

2004 Annual Report

SUMMARY

The Image Processing and Informatics Laboratory (IPI) two major goals in 2003 were to relocate to a new site for larger-scale and longer-term projects which the current site at Childrens Hospital Los Angeles/USC would not be able to accommodate. The second goal was to train more students to be interested in Imaging Informatics research. Both goals have been accomplished. The IPI has moved to a new laboratory suite with 3,400 square feet at ISI (Information Science Institute), USC, Marina del Rey in February, 2004. Dr. Huang has been appointed as the Chief of Imaging Informatics Division, Department of Radiology with the responsibility of promoting imaging informatics research within the department. He has also been appointed as the Director of the MS Program in Medical Imaging and Imaging Informatics, Department of Biomedical Engineering (BME), School of Engineering. Graduate students at BME can obtain a MS degree in imaging Informatics and continue on for a Ph.D. in BME. Two of IPI consultants, Drs. Pietka and Zhang have been appointed as Visiting Professors of Radiology to form a closer collaboration between laboratories.

After the establishment of the Internet 2 (I2) connection with major research laboratories, our last year research agenda has been in research and development of image data security procedure, HIPAA compliance in medical imaging, Data Grid technology in image back-up storage, and ASP back-up archive. In the clinical area, we are working closely with the Department of Radiology to install a PACS in the soon-to-be-opened HCCII (Healthcare Consultation Center II) of the USC University Hospital, which will have an I2 connection to the IPI with a back-up archive. Some of these activities were reported in the preprints and reprints in this Annual Report.

Dr. Huang's new book: "PACS and Imaging Informatics" published by John Wiley & Sons will be out in the latter part of March 2004. This text provides a roadmap for the new direction from PACS to imaging informatics research. The Forewords by Drs. Angus, Lemke, and Staab, Preface, and Table of Contents in Brief of the book are enclosed in this Report. This Report also contains selected published and in-press papers during the year, as well as preprints to appear in the *Proceedings of the International Society for Optical Engineering SPIE Medical Imaging*, San Diego, California, February 14-19, 2004.

Our research has been supported by:

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- Reliance Health Care, Inc. 30-8034-400391
- Array Corporation, Japan

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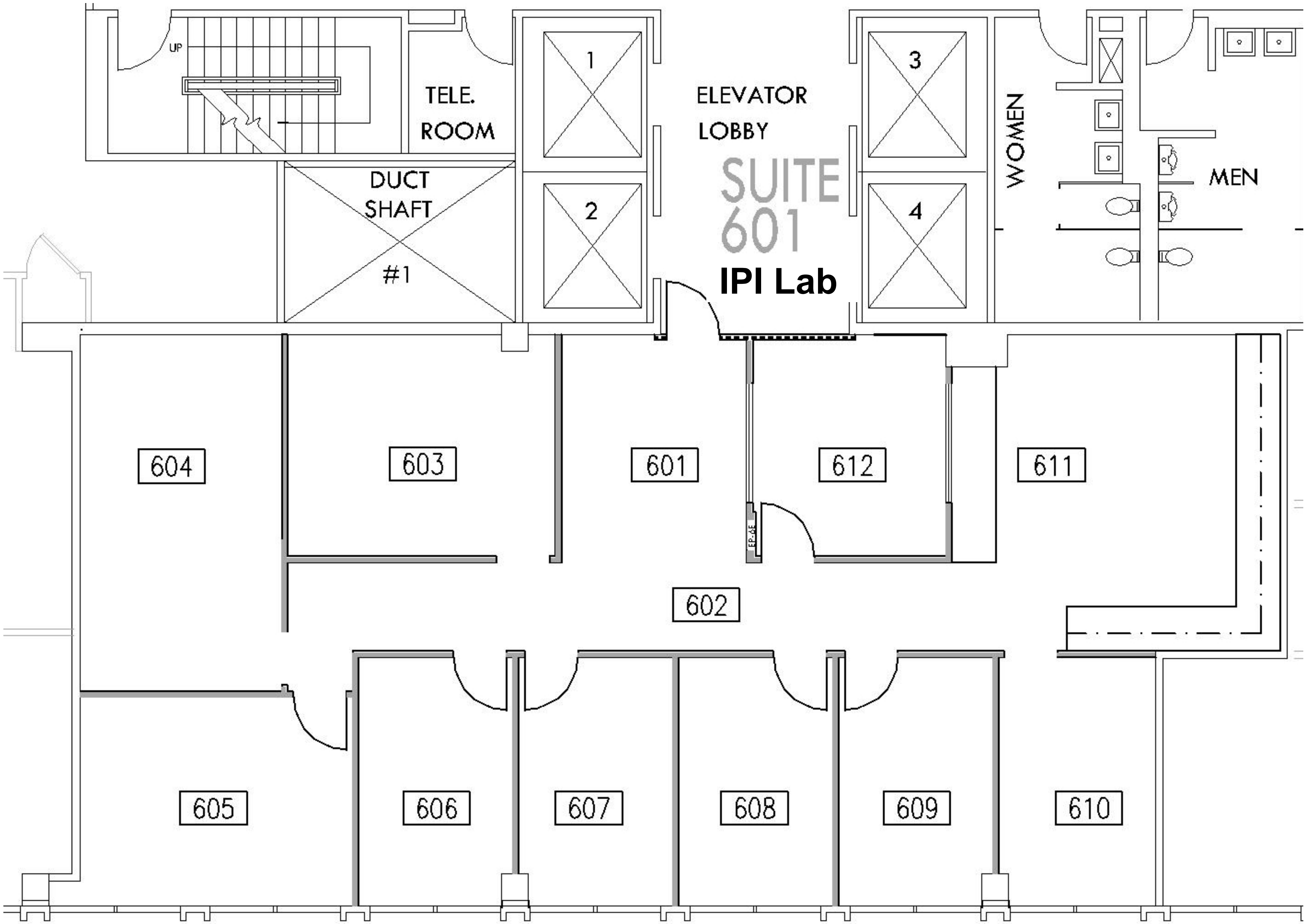
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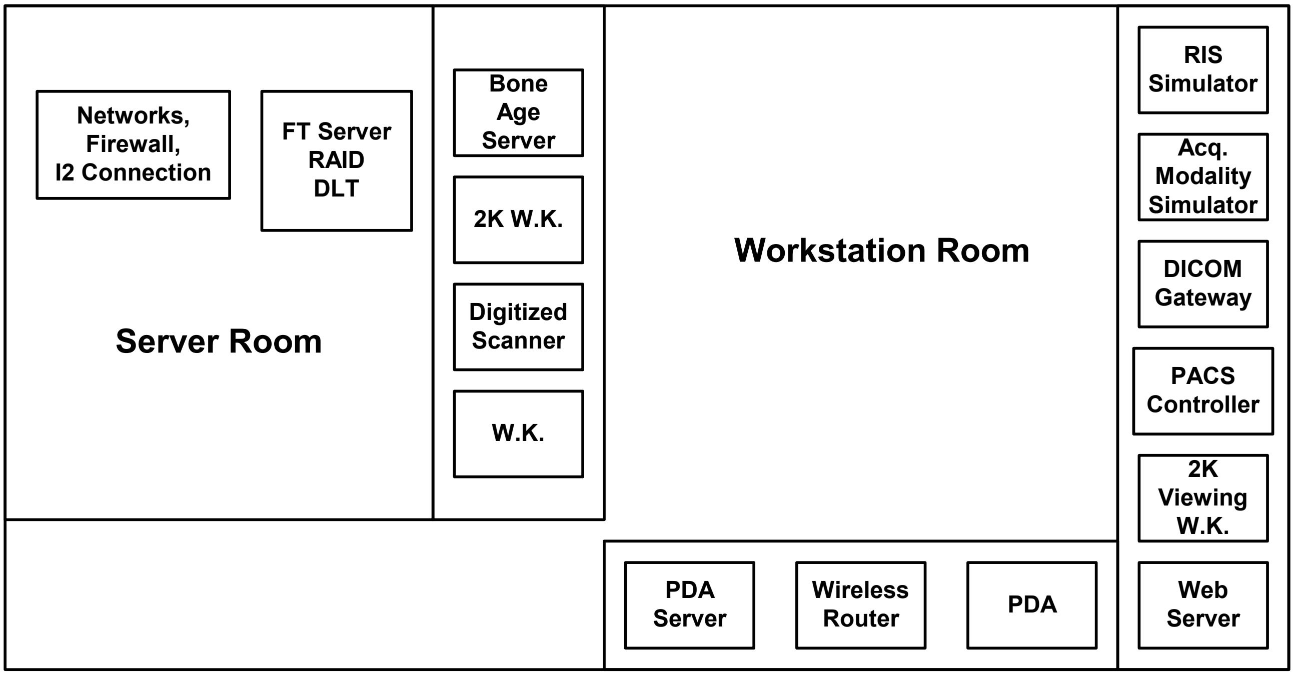
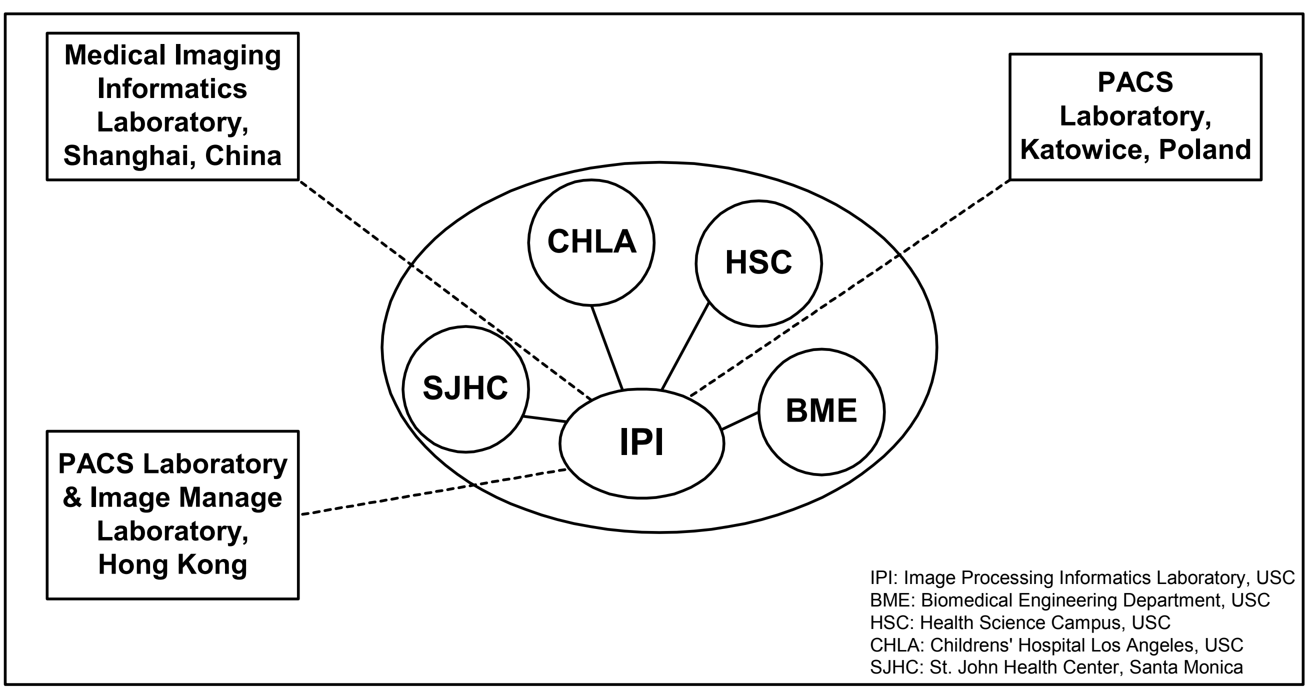


Imaging Equipment Layout at IPI



Current Collaborating Sites

Medical Imaging & Imaging Informatics

Career Paths for the Graduate

- Continue Graduate School or Medical School
- Healthcare industry including hospital, hospital enterprise, HMO, and private enterprise
- Medical imaging and health information industry
- Military healthcare system
- Healthcare entrepreneur

The Master's degree in Medical Imaging & Imaging Informatics is designed for completion in one calendar year.

Application Information

To request an application, please log on to the USC Graduate Admissions website at http://www.usc.edu/dept/admissions/grad/ or contact the Biomedical Engineering Department for application materials and information.

Application Deadlines

Fall 2004 – March 15
Summer 2004 – Feb 15
Spring 2005 – Oct 15

Secure your future

today with a Master's Degree in Medical Imaging and Imaging Informatics from the Department of Biomedical Engineering, University of Southern California and be among the leaders and innovators in this exciting and growing industry field.

University of Southern California
Department of Biomedical Engineering

Olin Hall of Engineering 500
3650 S. McClintock Ave.
Los Angeles, CA 90089-1451

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Visit the BME website: http://bme.usc.edu

Contact person: Hilde Baumann, Graduate Affairs & External Relations Coordinator, 213-740-0840 or baumann@usc.edu

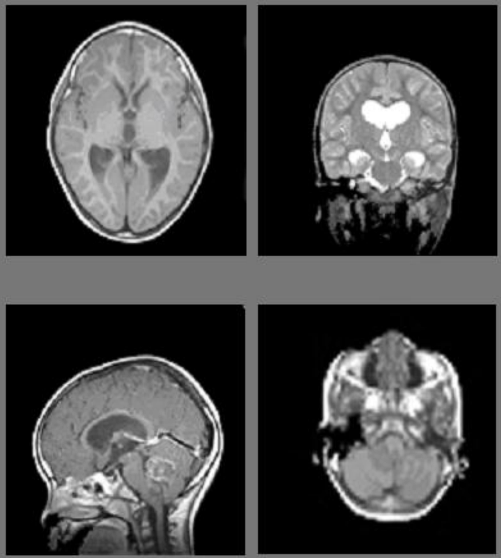
University of Southern California
Department of Biomedical Engineering

NEW!

Master of Science Degree

OFFERING

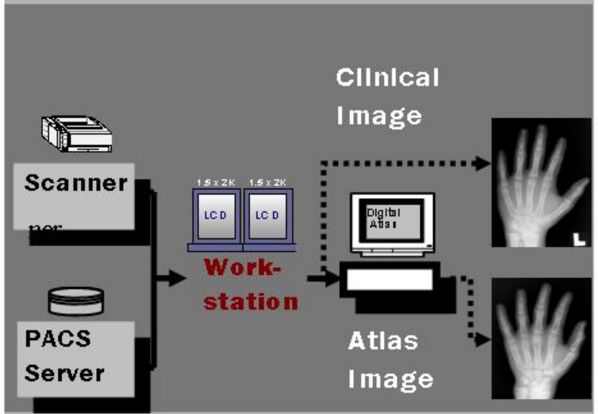
MEDICAL IMAGING & IMAGING INFORMATICS



Master of Science Medical Imaging & Imaging Informatics

Program Description

The Master of Science degree in the Medical Imaging & Imaging Informatics track under the Department of Biomedical Engineering aims to prepare students for further graduate training or professional careers in biomedical imaging, image processing and medical imaging informatics (including Picture Archiving & Communication Systems or PACS).



All professional staff and faculty members of the program play an active role in guiding each student's academic work, and are committed to help them achieve their educational, professional and personal goals.

Admissions Criteria

- Undergraduate or graduate degree in an appropriate discipline (engineering or the natural sciences) with a minimum grade point average of 3.0
- Qualifying scores on the GRE
- Two letters of reference (faculty or employer)
- One page letter expressing your career objectives

Degree Requirements

Completion of at least 29 credit hours of study, consisting of 8 required courses and 1 technical elective course.

Sample Student Schedule

<u>Fall</u>
BME-425: Basics of Biomedical Imaging (3)
BME-501: Advanced Topics in Biomedical Systems (4)
BME-513: Signal and Systems Analysis (3)
BME-527: Integration of Medical Imaging Systems (3)

<u>Spring</u>
BME-525: Advanced Biomedical Imaging (4)
BME-528: Medical Imaging Informatics (3)
BME-535: Ultrasonic Imaging (3)
Elective: Technical Approved Elective (3)

<u>Summer</u>
EE-569: Introduction to Digital Imaging Processing (3)

BME 501, 513 and EE 569 are available as live or archived web casts or distance education modules. The USC School of Engineering has a state of the art Distance Education Network to support these special needs.

Our program faculty consists of internationally renowned researchers in magnetic resonance imaging, ultrasound imaging & transducer development, signal processing and novel methods of managing and manipulating medical data & images.

Faculty

- H.K. Huang, D.Sc., FRCR (Hon.), Professor of Radiology and Biomedical Engineering & Program Director.
- Edward Grant, M.D., FACR, Professor and Chair of Radiology.
- Michael C.K. Khoo, Ph.D., Professor and Chair of Biomedical Engineering
- Kirk K. Shung, Ph.D., Professor of Biomedical Engineering.
- Manbir Singh, Ph.D., Professor of Radiology and Biomedical Engineering
- Richard Leahy, Ph.D., Professor of Electrical, Biomedical Engineering & Radiology
- Jesse Yen, Ph.D., Assistant Professor of Biomedical Engineering
- Brent Liu, Ph.D., Assistant Professor of Research Radiology & BME
- Greg Mogel, Ph.D., Assistant Professor of Research Radiology & BME
- Fei Cao, Ph.D., Assistant Professor of Research Radiology & BME
- Stephan G. Erberich, Ph.D., Assistant Professor of Research Radiology & BME

PACS Image Security Server

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ABSTRACT

Medical image security in a PACS environment has become a pressing issue as communications of images increasingly extends over open networks, and hospitals are currently hard-pushed by Health Insurance Portability and Accountability Act (HIPAA) to be HIPPA complaint for ensuring health data security. Other security-related guidelines and technical standards continue bringing to the public attention in healthcare. However, there is not an infrastructure or systematic method to implement and deploy these standards in a PACS. In this paper, we first review DICOM Part15 standard for secure communications of medical images and the HIPAA impacts on PACS security, as well as our previous works on image security. Then we outline a security infrastructure in a HIPAA mandated PACS environment using a dedicated PACS image security server. The server manages its own database of all image security information. It acts as an image Authority for checking and certificating the image origin and integrity upon request by a user, as a secure DICOM gateway to the outside connections and meanwhile also as a PACS operation monitor for HIPAA supporting information.

Keywords: DICOM, PACS, Teleradiology, Image Security, HIPAA

1. INTRODUCTION

PACS (Picture Archiving and Communications System) is an integrated management system for archiving and distributing medical image data [1-3]. Communication of medical images in a PACS environment is usually over the internal hospital network that is protected by a firewall from outside intruders. As the communication extends over public networks outside the hospital to the physician's and patient's home or to anywhere needed for teleradiology and other telehealth applications, it may bring thousands of opportunities for an intruder, casual or with malicious intent, to temper the image data over open networks or to slip right into the heart of the hospital network through the communication tunnel piggybacking on an entrusted user. Conventional Internet security methods are not sufficient to guarantee that medical image had not been compromised during data transmission. Techniques including VPN (Virtual Private Network), data encryption, and data embedding are being used for additional data protection in other fields of applications like financing, banking, and reservation systems. However, these techniques have not been systematically applied to medical imaging partly because of the lack of urgency until the recent HIPAA proposed requirements in patient data security (Health Insurance Portability and Accountability Act).

Three major organizations related to medical image/data security have issued guidelines, mandates, and standards for image/data security. The ACR (American College of Radiology) Standard for Teleradiology, adopted in 1994, defines guidelines for "qualifications of both physician and nonphysician personnel, equipment specifications, quality improvement, licensure, staff credentialing, and liability" [4-7]. Health Insurance Portability & Accountability Act (HIPAA) of 1996, Public Law 104-191, which amends the Internal Revenue Service Code of 1986 [8-9] requires certain patient privacy and data security. Part 15 of the DICOM Standard specifies Security Profiles and technical means for Application Entities involved in exchanging information to implement security policies (PS 3.15-2001) [10]. In addition, SCAR (Society of Computer Applications in Radiology) issued a premier on "Security issues in digital medical Enterprise" during the 86th RSNA 2000 (Radiological Society of North America), to emphasize the urgency and importance of this critical matter. Despite these initiatives, to our knowledge, there have not been active systematic research and development efforts in the medical imaging community to seriously tackle this issue. In this paper, we propose an infrastructure to implement an image security server system.

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2. SECURITY ISSUES IN DIGITAL MEDICAL IMAGES

Generally, trust in digital data is characterized in terms of confidentiality, authenticity, and integrity.

- Confidentiality is "the property that information is not made available or disclosed to unauthorized individuals, entities or processes."
- Authenticity is defined as "the corroboration that the source of data received is as claimed."
- Integrity is the "the property that data has not been altered or destroyed in an unauthorized manner."

Medical digital image often consists of two parts, a nominative image header and

an anonymous image body.

- Nominative data: containing the sensitive patient information needs to be well protected by all security means.
- Anonymous image body: the most concerned issue is image integrity.

Medical image security is to maintain privacy (confidentiality) of the patient information in the image and to assure data integrity that prevents others from tempering the image.

It is easy to compromise image data. As an example, the figure on the right shows a manually inserted artificial lesion camouflaged by pulmonary vessels. Artifacts would create confusion and misinterpretation during diagnosis.

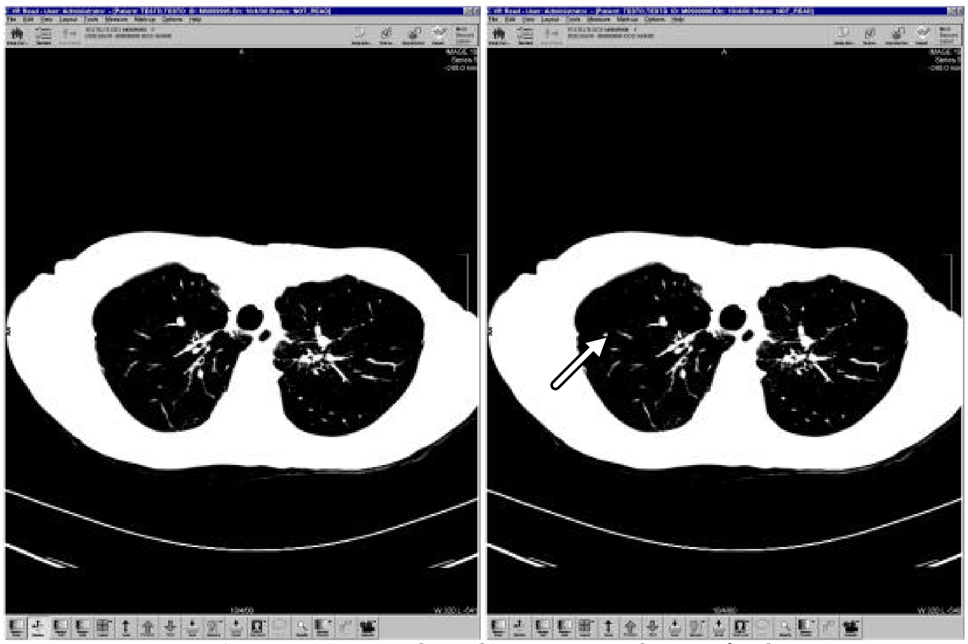

Figure 1. (a) A CT chest, (b) Same CT with an artificial lesion inserted (arrow). (Courtesy of Michael Zhou)

3. CURRENT SECURITY METHODS, STANDARDS AND GUIDELINES

1) Data Encryption.
   Encryption is the most useful approach to assure data security during its transmission through public communication networks. Image data scrambled by a sender cannot be understood by anyone other than an intended party to assure the data security during transmission, but not before or after the transition.

   - Virtual Private Network (VPN) is the most common application of data encryption techniques to assure data security during its transmission through public communication networks. Even gigabit hardware encryption is widely available and quite affordable right now.

- DICOM Security. DICOM standard part 15 has been released to provide a standardized method (selection of security standards, encryption algorithms and parameters) for secure medical image communication but has yet to be implemented by industrial and medical community.

2) Data Embedding.
It can be in a form of steganography that conceals patient information and digital signature in the image so that the visual quality of the image is not perceptually affected. It provides a permanent assurance of image data security no matter when and how the image has been manipulated. But there is no standard embedding method and it is also difficult to implement for variety of medical image modalities.

3) HIPAA and its Impacts on PACS Security.
PACS alone cannot be claimed as HIPAA compliant but implementation of addional functionalities in PACS is indispensable for hospital-wide HIPAA compliance. Security communication of images using encryption or embedding methods, plus a continuous PACS monitoring and its ability to generate a list of information on demand, related to the access of clinical information for a specific patient. The PACS monitoring and auditing will keep track the access information required by HIPAA, such as

- Identification of person (login, authorization)
- Patient data accessed (assessed patient exams)
- Time stamp (when accessed), type (read only or if change anything) and status of access

4. PACS IMAGE SECURITY SERVER

We propose as shown in Figure 2 an infrastructure to implement an image security system in a PACS environment [13]. The system is to use the modality gateway workstation for image embedding and to use a dedicated server to handle all PACS-related security issues. The PACS Security Server has the following three major functions and will acts as

1. A DICOM Secure Gateway to the outside connections, that is in compliance with DICOM Security Profiles ensuring integrity, authenticity, and confidentiality of medical images in transit. The gateway plays a role in securing communication of DICOM images over public networks. It is important to build a separate DICOM secure gateway for handing the CPU-intensive cryptography so as not to impact the performance of PACS in fulfillment of its daily radiological services. The current DICOM security standards are still evolving. It will take time for the standards to mature and to be fully implemented in PACS. So it is also important that the gateway can provide interoperability with the existing "non security aware" PACS.

2. An Image Authority for image origin authentication and integrity. In this system, medical images from modalities will be first digitally signed at the modality gateway machine (Figure 2) by the image creator and/or through physician's authorization or the PACS manufacturer. The signature plus relevant patient information will be sealed in a digital envelope using the Authority Server's public key. The digital envelope can either be embedded permanently in the image background or stored separated in PACS. The Authority server is designed to check the image origin and integrity.

   Whenever needed, a remote user can query the Image Authority to verify the origin authenticity and integrity of an image under review. The Image Authority is the only one who owns the private key that can be used to extract and decrypt the embedded permanently in the image or check with the record in PACS. The Image Authority serves as the authority for checking the image originality and integrity, in the same way as a Certificate Authority (CA) [**Error! Reference source not found.**] does for certificating the digital signature. In this way, the heavy computation jobs of assuring image authentication and integrity are now being taken over by the Authority Server, therefore reducing the workload at the client side. Meanwhile, it is also relatively easy to keep the digital envelop/embedding algorithms and attributes prearranged between the Image Authority and the DE creators/senders in a local PACS environment without requiring the open standard to define them.

3. A HIPAA Monitoring System for PACS operations, which at a minimum should keep a user access log and monitors security events, providing support for hospital-wide HIPAA compliance. Ideally, it should not only monitor the HIPAA-related security information but also control the user access to PACS.

In addition, the PACS security server should also be intelligent to deliver only the relevant information to a user. As the volume of clinical data, images and reports has significantly increased with digital imaging technology and government regulations continue to emphasis the information privacy, they have imposed an implementation challenge for each individual user to access specific data from a specific location – where and how can he/she access the information in a timely fashion. An intelligent security management is to find a secure way to match relevant information with a particular user, and control the outside access to PACS based on HIPAA-compliant security profiles, just as the way a firewall does to the hospital computer network systems.

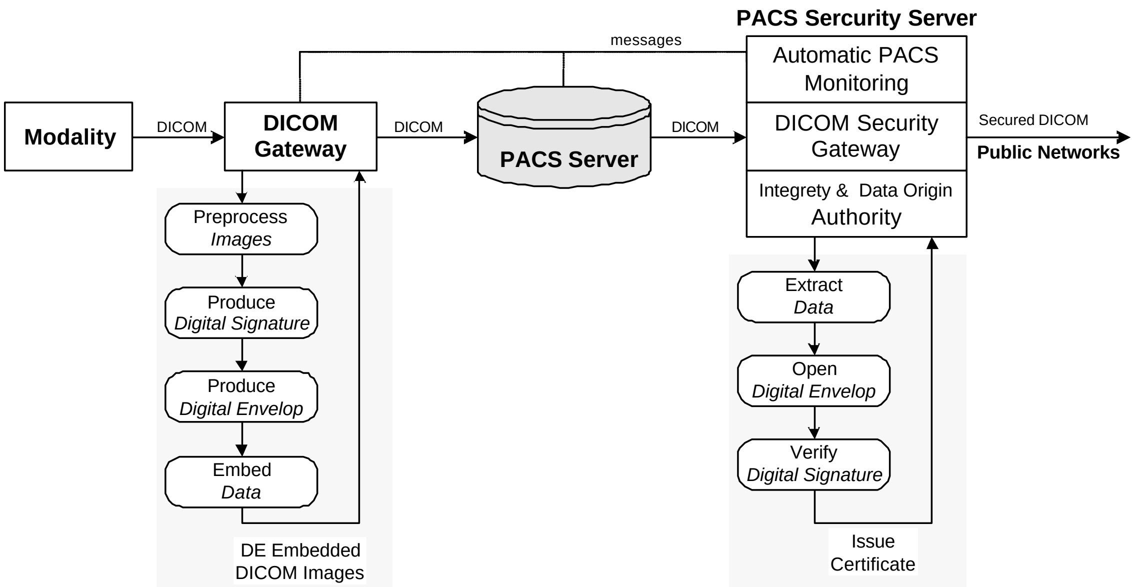

Figure 2. Image security system in a PACS environment. Shaded boxes are where data embedding and assurance of image authenticity and integrity are implemented.

5. SUMMARY

Medical image security in a PACS environment has become a pressing issue as communications of images increasingly extends over open networks, and hospitals are hard-pushed by government mandates, and security guidelines to ensure health data security. However, there has not been an infrastructure or systematic method to implement and deploy these standards in a PACS environment. We proposed an infrastructure to implement an image security system. When an image is generated at an imaging modality, the image signature is obtained, combined with the DICOM image header, sealed in digital envelope, and then embedded in the original image. The digital envelope embedded in the image can only be opened (extracted and decrypted) by a local PACS Security Server. The server acts as an image Authority that will check and certificate the image origin and integrity upon request by a user, and meanwhile acts also as a secure DICOM gateway to the outside connections and as a PACS operation monitor for HIPAA supporting information.

ACKNOWLEDGMENT

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Building a Digital Atlas from a Normal Hand Image Database

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[2]Division of Biomedical Electronics, Silesian University of Technology, Gliwice 44 100, Poland

ABSTRACT

Bone age assessment is a procedure frequently performed in pediatric patients to evaluate their growth disorder. A commonly used method is by atlas matching with a small reference set of Greulich-Pyle atlas that was developed in 1950s based on middle class white populations. The old Greulich-Pyle atlas is not fully applicable for today's children especially regarding the standard development in other racial groups. We have collected over 1000 hand and wrist images for normal boys and girls of Caucasian, African, Hispanic and Asian descents from newborn to 18 years of age. In this paper we present an atlasing method that will automatically select the reference images from the normal collection database to form a digital atlas. Compared with the book-based Greulich-Pyle atlas, the digital atlas is easy to access and can always be replenished with new images reflecting more accurately the current population and skeletal development.

Keywords: hand radiography, Internet, pediatric radiology, skeletal age assessment, database, PACS.

1. INTRODUCTION

A simple method frequently used in bone age assessment is atlas matching by a radiological examination of a left hand and wrist radiograph against a reference set of atlas patterns of normal standards. The pattern in the atlas, which appears to resemble the clinical image, is selected. Since each pattern in the atlas represents a certain year of age for a normal child, the selection assigns the patient's bone age. The difference between the assessed bone age and the chronological age indicates abnormalities in patient's skeletal development.

The current book-based reference set used extensively in radiological diagnosis is the Greulich and Pyle[1] atlas, unchanged from its initial publication in the early 1950s, with data collected entirely from upper middle class Caucasian populations in the first half of the 20th century. Not only does this create questions of accuracy for today's childhood populations, but applicability of these standards to children of other ethnic groups has not been accurately examined[2-3]. The hardcopy atlas book is also difficult to maintain and update. To remedy these shortcomings, we have collected a set of normal hand and wrist images (1,080) paired with expert bone age readings and built a reference atlas database for four ethnical groups of Caucasian, African, Hispanic and Asian descents[4].

Reference values of hand images rely on the selection and validation of normal children. Skeletal maturity of normal children in the same ethnicity, gender and age group can still vary greatly-- up to two standard deviations or as large as 2 years, even when evaluating individual bones of the same hand. Ideally, the reference image in a digital atlas should be selected from a group of clinically normal healthy children with a skeletal maturity close to an "average" of the group. It must also have a well-positioned hand and excellent image quality, for automated processing to succeed. The traditional (e.g. G-P) method of producing a reference image as a template for a group is through manual selection of the "most representative" image from a large set of normals; however, this is labor-intense and in practice not feasible for a digital atlas that needs to be continually replenished. Furthermore, human observation doesn't guarantee that the selected image is the most appropriate for computer processing. Another computer-aided method commonly used, templating, aligns and transforms the group images to a common shape—a template, and then calculates an average of their gray intensities to form a mean image. The resulting mean image is usually blurred especially in more variable joint regions due to spatial variability in the population. This blurring of the template limits its usefulness as a quantitative tool as the fine bony features reflecting skeletal maturity are degraded.

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Instead of manual selection or templating, an attempt has been made to automatically select the best representative image from a group of normal children based on their bone age readings. A reference or average hand image is defined as this best representative image, selected in such a way as to minimize the overall variation of bone age readings among all normal hand images in a group. In mathematical terms, the variation of all bone age readings relative to the average age of the normal group is the smallest one for the reference image. Figure 1, as a simple example in selecting a reference image from the group of African-American males age 12, shows 10 normal images in the group and their patient information on the table above, with an average chronological age of 12.5yr. The image number 5 (age 12.42yr) is the closest one in chronological age to the average age about 12.50yr in the group, but the image number 9 (age 12.82yr) is the most representative one, close to the average skeleton maturity in the group.

Row #	Group ID	Image Name	Age (yr)	Tanner	DOB	DOE	Height (cm)	Weight (kg)	Trunk Ht (cm)
1	BLKM12	3156.img	12.05	3	null	94.07.29	161.5	48.6	78.7
2	BLKM12	3157.img	12.12	1	1982.12.06	95.01.20	142.5	31.9	71.12
3	BLKM12	3159.img	12.35	1	1982.08.16	94.12.23	143.2	32.7	68.58
4	BLKM12	3763.img	12.41	1	1985.06.28	97.11.26	146.4	50.9	72.39
5	BLKM12	3160.img	12.42	1	1982.03.30	94.09.01	154	39.7	76
6	BLKM12	3161.img	12.61	2.5	1983.08.31	96.11.11	162	50.7	80.65
7	BLKM12	3162.img	12.61	2	1984.03.10	96.10.17	149	35.1	69.85
8	BLKM12	3163.img	12.61	3	1984.03.10	96.10.17	153	39.3	69.85
9	BLKM12	3164.img	12.82	2	1982.09.15	95.07.13	148.2	40.1	73.66
10	BLKM12	3165.img	12.91	3	null	96.06.26	159.9	48	79.38

Table 1. Relevant Information for normal hand images of African American Male Group (BLKM) of 12 years old.

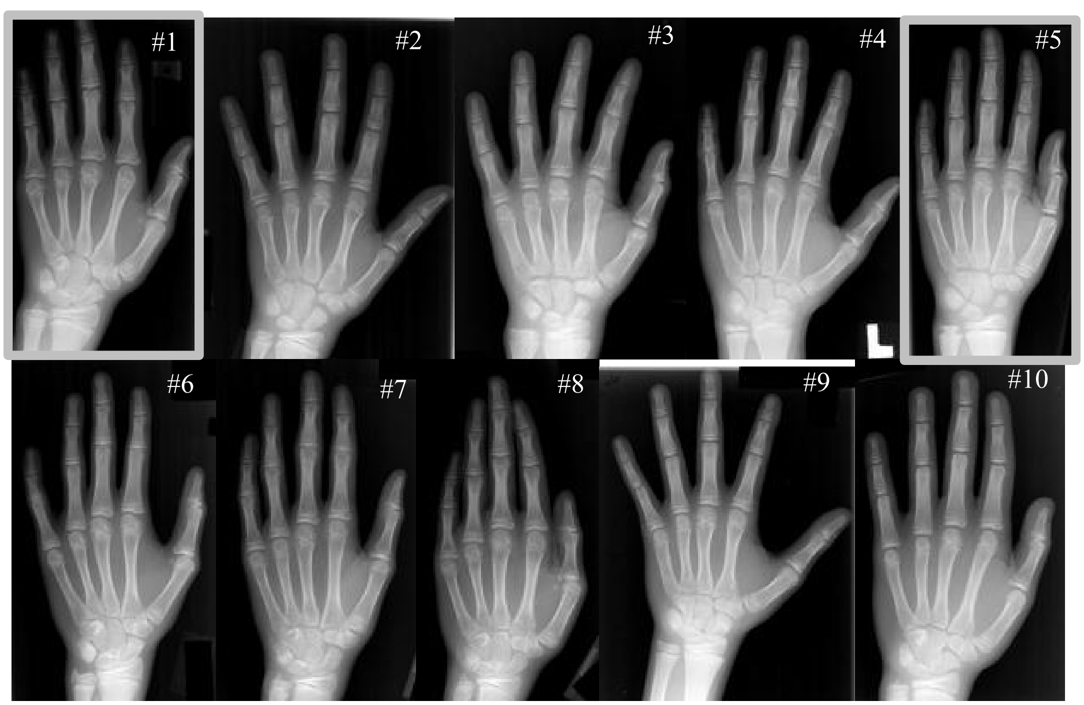

Figure 1. Automatic selection of an average or the most representative image in an age group.

This “averaging” algorithm can be built directly into database for automatically atlasing of normal image collection. With creation of an ever-expanding database, such an “averaging” method, statistic and population-based, assures a continuous accrual of the digital atlas best representing the average maturity of normal population. A digital atlas with such a well-selected reference set, which both the manual readings and CAD systems[5] are based upon, should improve the reliability, accuracy and efficiency in determining skeletal maturity.

2. METHOD FOR ATLASING THE NORMAL COLLECTION

Skeletal maturity of normal children in the same ethnicity, gender and age group can still vary greatly. The reference image in a digital atlas should be selected from a group of clinically normal children with a skeletal maturity close to an “average”, the best representative of the group. The best representative image is selected in such a way as to minimize the overall variation of chronological and bone age readings among all normal images in a group.

Here is the mathematical presentation. Below is the method to automatically build from the normal collection database a digital atlas based on the bone age readings.

Let x_{ij} be the chronological age and all bone age readings (subscript j= 1, 2, … m=3 at the moment for the chronological age plus two readings) for an image “i” in a group

Define the average bone age for the image i

$$\bar{x}_i = \frac{1}{m}\sum_{j=1}^{m} x_{ij}$$

Deviation from the average for the image i

$$\delta_i = \sqrt{\frac{1}{m}\sum_{j}(x_{ij} - \bar{x}_i)^2}$$

Deviation of image i to the group’s average bone age (BA) that is selected as a middle point in the range of the group’s chronological age distribution, e.g. BA=10.5 for a group from 10 to 11 yrs and BA=10 for a group from 9.5 to 10.5 yrs.

$$\Delta_i = \sqrt{\delta_i^2 + (\bar{x}_i - BA)^2}$$

The most representative image I in a group of *n* images is the one with the minimum deviation to the group’s average bone age (BA)

$$I_{avg} = \underset{1 \le i \le number}{\arg\min}\ \Delta_i$$

3. RESULT

3.1. An Example Atlas for Black Boys

Based on the above formula, the digital atlas can be automatically constructed and retrieved from our normal collection database for different race and gender. Figure 1 is an example of the digital atlas for **African American boys** with 1 year interval. Each reference image in the atlas is the best representative of an average skeletal maturity in the group. The table 1 below gives the relevant information of the selected reference images.

Row #	Group ID	IMAGE_NAME	Bone Age (yr)	STD (yr)	AGE	CAD Age (yr)	TANNER	BMI
1	BLKM00	3128.img	.5	.41	0.95	null	1	18.12
2	BLKM01	4485.img	1.5	.15	1.54	null	1	19.02
3	BLKM02	3133.img	2.5	.22	2.15	null	1	14.56
4	BLKM03	3730.img	3.5	.08	3.36	3.33	1	15.56
5	BLKM04	3134.img	4.5	.06	4.6	null	1	14.69
6	BLKM05	3740.img	5.5	.38	5.94	6.52	1	15.91
7	BLKM06	3743.img	6.5	.42	6.61	6.55	1	16
8	BLKM07	3747.img	7.5	.41	7.35	null	1	18.29
9	BLKM08	3749.img	8.5	.41	8.52	8.2	1	15.85
10	BLKM09	3752.img	9.5	.33	9.24	10.32	1	19.59
11	BLKM10	3146.img	10.5	.29	10.43	9.64	1	22.14
12	BLKM11	3151.img	11.5	.29	11.58	12.27	1	17.56
13	BLKM12	3164.img	12.5	.19	12.82	12.74	2	18.26
14	BLKM13	3167.img	13.5	.17	13.2	13.87	3.5	18.71
15	BLKM14	3764.img	14.5	.31	14.3	15.52	4.5	17.87
16	BLKM15	3771.img	15.5	.1	15.67	15.75	5	20.69
17	BLKM16	4342.img	16.5	.4	16.03	16.43	5	19.43
18	BLKM17	4491.img	17.5	.92	17.34	16.34	5	29.9
19	BLKM18	3776.img	18.5	.3	18.61	17.25	5	24.23

Table 2. Relevant Information for the reference images in the atlas of African American Male Group (BLKM). Bone Age (**BA**), chronological age (**Age**), standard deviation from the bone age (**STD**) which always is minimum one in the relevant group, Tanner maturity index (**Tanner**), Body Mass Index (**BMI**) and bone age assessed by our automatic CAD method (**CAD Age**). "null" in the CAD Age column indicates the CAD method fails in assessing this image.

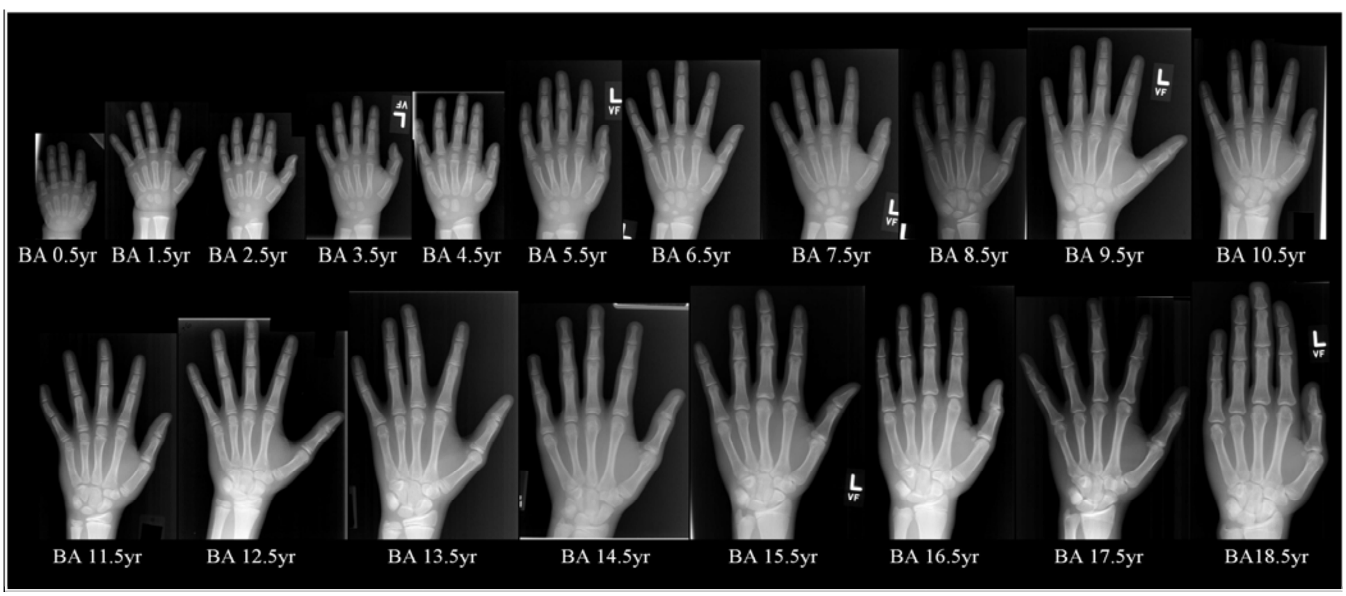

Figure 2. Digital Atlas for African American Boys

3.2. Clinical Evaluation of the Atlas

Vicente went through each age group of the black boys and manually selected the most representative ones. He found, of the 19 bone ages selected by above atlasing method, that four of 0.5 years, 2.5 years, 12.5 years and 14.5 years would be better suited by the images of subjects: filename 4728 (chronological age 0.64), 3724 (age 2.74), 3161 (age 12.61), and 3183 (age 14.69), respectively. The other 15 reference images are indeed representing the average maturity of their groups. The difference is about 20%.

4. SUMMARY

We have developed a new digital hand atlas best representing the current normal population. As of today, over 1000 hand and wrist images have been included in the image database for normal boys and girls of European, African, and Hispanic descent from newborn to 18 years of age. This paper presents the design and implementation of atlising method to automatically build the digital hand atlas from the normal image collection. With creation of an ever-expanding database, such an "averaging" method, statistic and population-based, assures a continuous accrual of the digital atlas best representing the average maturity of normal population.

ACKNOWLEDGMENT

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ACCEPTANCE TESTING FOR PACS: FROM METHODOLOGY TO DESIGN TO IMPLEMENTATION

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ABSTRACT

Acceptance Testing (AT) is a crucial step in the implementation process of a PACS within a clinical environment. AT determines whether the PACS is ready for clinical use and marks the official sign off of the PACS product. Most PACS vendors have Acceptance Testing (AT) plans, however, these plans do not provide a complete and robust evaluation of the full system. In addition, different sites will have different special requirements that vendor AT plans do not cover. The purpose of this paper is to introduce a protocol for AT design and present case studies of AT performed on clinical PACS. A methodology is presented that includes identifying testing components within PACS, quality assurance for both functionality and performance, and technical testing focusing on key single points-of-failure within the PACS product. Tools and resources that provide assistance in performing AT are discussed. In addition, implementation of the AT within the clinical environment and the overall implementation timeline of the PACS process are presented. Finally, case studies of actual AT of clinical PACS performed in the healthcare environment are reviewed. The methodology for designing and implementing a robust AT plan for PACS was documented and has been used in PACS acceptance tests in several sites. This methodology can be applied to any PACS and can be used as a validation for the PACS product being acquired by radiology departments and hospitals. A methodology for AT design and implementation was presented that can be applied to future PACS installations. A robust AT plan for a PACS installation can increase both the utilization and satisfaction of a successful implementation of a PACS product that benefits both vendor and customer.

Keywords: PACS, Acceptance Testing

1. INTRODUCTION

As more and more health care institutions move towards a filmless environment, the implementation process of PACS becomes crucial for a successful installation. However, it is difficult to judge how successful a particular implementation is within a health care facility without some form of validation of the PACS in its clinical environment. Acceptance Testing (AT) for PACS helps to fulfill the needs of an evaluation of how well a PACS has been implemented. The following are some of the key points that make AT so important:

1) Vendor Accountability – How does one know the vendor has delivered everything as promised?
2) In House Accountability – When something fails, does one have proof that it was adequately tested prior to turnover?
3) System Uptime – How does one know the PACS will function as promised?
4) System Performance – How does one know the system performs as promised?
5) System Functionality – How does one know the system has the functionality as promised?

A properly developed Acceptance Testing addresses all of the key points above and ensures that both customer and vendor are satisfied with the PACS installation. Most PACS installations are determined ready for clinical use with an official sign off of the PACS product upon completion of the AT. Furthermore, PACS vendors provide AT plans as part of their installation process, however, most of the time, these plans do not provide a complete and robust evaluation of the full system. One of the main factors is that each site is slightly different with special requirements that boiler plate AT plans do not cover.

This paper describes a methodology for AT design and presents some case studies of AT performed on clinical PACS. This methodology includes identifying testing components within PACS, quality assurance for both functionality and performance of a PACS, technical testing focusing on key single points-of-failure within PACS, and identifying tools and resources that can aid in the AT process. Implementation of an AT plan within the clinical environment and within the overall implementation timeline will also be discussed. Throughout this paper, case studies and experiences from various PACS Acceptance Tests performed at different healthcare institutions will be discussed and shared.

2. METHODS AND MATERIALS

There are six key steps to the AT methodology presented:

1) Identifying Staff Resources.
2) Identifying PACS components for Acceptance Testing.
3) Quality Assurance
4) Technical Testing
5) Acceptance Testing Tools
6) Acceptance Testing Implementation

2.1 Identifying Resources

One of the very first steps is to identify the resources that will be involved in the AT. Traditionally, the PACS vendors provides one person to be involved in the AT plan and the execution of the plan. However, it is important for the customer site to be involved as much as possible in the overall AT development process as well as during the testing phase. Three key resources that should be involved in the AT development and execution are a PACS System Administrator, a Technologist representative, and a RIS support representative. The PACS system administrator may have knowledge about the particular site that would help in the design and execution of the AT plan. If the PACS system administrator's knowledge is limited in the particular vendor PACS, the AT process will help to increase knowledge particular in the characteristics of system failure which will be discussed in the technical testing portion of this paper. The technologist representative holds key information regarding the image acquisition portion of end-to-end testing of PACS and can help to design a feasible AT plan. Finally the RIS support representative can assist in the RIS portion of the end-to-end testing of PACS. These three resources are the minimum requirements for the successful design and implementation of an AT plan for PACS.

2.2 Identifying PACS Components

Another step in this AT methodology is to identify the necessary PACS components to be involved in the AT plan. The following is a list of standard PACS components that should be included in the AT plan:

1) Archive Server
2) Short-Term Archive Storage
3) Long-Term Archive Storage
4) DICOM Gateway or Image Acquisition Gateway
5) Diagnostic Workstations
6) Review Workstations
7) RIS/PACS Interface
8) Web Server
9) Network

This is by no means an exhaustive list and the customer should include other components that are deemed crucial and part of the vendor PACS.

2.3 Quality Assurance

Quality Assurance is comprised of the three main parts: 1) PACS Image Quality; 2) PACS Functionality; and 3) PACS Performance. For PACS Image Quality, the focus is on the evaluation of the display monitor. Current trends for display monitors include Flat Panel LCD Grayscale Display Monitors that are available in 3 Megapixel (MP) and 5 Megapixel (MP) configurations. These Flat Panel technology also features self-calibration. In addition to the Flat Panel display monitors, there are 3MP and 5MP High-Brightness grayscale CRT monitors as well. Because there are various manufacturers as well as multiple types of display monitors and display software, proper evaluation is necessary to determine the best choices for the needs of the customer site. It is recommended that Radiologists from each specialty should be involved in the evaluation of which types of display monitors are acceptable. There are five characteristics that can be used to evaluate display monitors:

1) Sharpness – The ability to identify high frequency structure within an image (eg, Interstitial Lung Markings, Renal Filling Defects, Bony Trabecular Markings)
2) Brightness – The ability to display high brightness while maintaining best grayscale dynamic range
3) Flicker – Perception of raster lines while viewing image (in CRT monitors)
4) Angle of View – The ability to view an image at extreme side angles
5) Glare or Reflection – Glare emanating from ambient light source on display monitor

In a Case Study at UCLA Medical Center performed in June 2002, a variety of display monitors were evaluated from various manufacturers by eight Radiologists utilizing a survey with the above 5 characteristics. Three manufacturers provided 3MP and 5MP Flat Panel Display monitors as well as one 5 MP CRT monitor. Overall, the Radiologists preferred the 3 MP Flat Panel display monitor over the 5 MP version. The 5 MP CRT display monitor was least preferred. It is interesting to note that some manufacturers of the flat panel LCD display monitor utilized a glass panel to protect the monitor screen. However, the Radiologist did not prefer this feature since there was more monitor glare from the glass panel in comparison to other flat panel LCD displays that did not have this same feature

PACS Functionality is another key component of quality assurance. Generally, most vendors focus mainly on workstation functionality. These include the display worklist, the display images, and the image tool sets. Some workstation feature 3D post-processing tools that need to be evaluated as well. Workstation functionality acceptance usually occurs during the applications training phase of the PACS workstations for the Radiologists. However, equally important is the backend functionality of PACS, which sometimes is overlooked in AT design. These include the RIS/PACS interface, archiving and distribution functions, Prefetching, and Quality Control (QC) workstations. One of the most crucial tests for overall PACS functionality is end-to-end testing. End-to-end testing includes ordering a Radiology exam in Radiology Information System (RIS), acquiring a test PACS exam of images with a modality, archiving, distributing, and finally, displaying the PACS exam on a workstation. The in house staff resources are important in helping to facilitate this end-to-end testing as it includes different types of clinical staff within the imaging continuum (eg, technologist, RIS support personnel, clerk). Verification of all necessary RIS and PACS data that are captured and stored in PACS (eg, patient demographics, image characteristics) should be included in the end-to-end testing. Sometimes a DICOM tool to perform a DICOM header display for a PACS exam may be useful to trace any DICOM info back to the origin of the data (eg, organ field, procedure field, window/level field, private vendor attributes).

PACS performance should be included within the quality assurance assessment of the AT design. Most vendor's performance numbers are times when the first image arrives at the display workstation and is not a realistic view of the overall PACS performance. Any performance numbers should measured for an entire PACS exam. Performance numbers for the AT plan should be provided by the vendor and agreed upon by the customer prior to Acceptance Testing as benchmark for measurement. In addition, the performance numbers should reflect real-world clinical scenarios in a live PACS. Therefore, it is beneficial to test performance measurements both before and after the Go Live date for the PACS in the clinical environment to determine if there are any major differences in the measurements. The following is a list of dynamic performance tests that should be included in the AT design:

1) Display of entire PACS exam from worklist selection.
2) Query/Retrieve from short-term archive and ready for display on workstation.
3) Query/Retrieve from long-term archive and ready for display on workstation.
4) Multiple users query/retrieve from archive simultaneously.
5) Query/Retrieve multiple exam types from archive.
6) Prefetching of historical PACS exam from time an exam is ordered in RIS (if prefetching is a feature)

Table 1 shows a Case Study for Saint John's Health Center (SJHC) in Santa Monica, CA. The performance measurements were made during Phase I implementation of PACS in May 1999 and the long-term storage solution at the time was a Magneto-Optical Disk (MOD) jukebox [1][2].

	CR Exam 2 Images	MR Exam 80 Images	CT Exam 90 Images
RAID (Short-Term Storage)	**12 Sec**	**45 Sec**	**73 Sec**
MOD (Long-Term Storage)	**45 Sec**	**107 Sec**	**140 Sec**

Table 1: Performance Measurements for SJHC PACS.

It is important to note that the performance tests were measured on a loaded clinical network. In addition, the times measured were for the entire exam loaded onto the local workstation from the archive.

2.4 Technical Testing

The main focus of the technical testing portion of the AT design methodology is on identifying "single points of failure" within the vendor PACS product and to ensure that the PACS can continue to function should one or more components encounter a failover. This is crucial since failover of particular components can severely cripple the clinical operations dependent on the PACS. Some of these "single points of failure" are:

1) Archive server: Stand-Alone vs. Client-Server
2) Archive storage: RAID, Digital Tape, or MOD
3) DICOM or acquisition gateway
4) RIS/PACS Interface
5) Network Devices
6) Web Server: Single vs. Clustered
7) Contingency Plans

The latter is of significance especially since in a client-server architecture for PACS, should the archive server encounter a failure then all client workstation will not be able to view any new PACS exams let alone the historical PACS exams. A contingency plan is an absolute must in this architecture and should be included within the AT design. The technical testing should simulate real-world downtime clinical scenarios, which includes shutting down each of the above components to observe the effects on the entire PACS. During the technical testing, any downtime effects to the entire PACS should be noted. This will provide a level of comfort for the PACS System Administrator because it will provide tangible observed effects of a simulated downtime experience that will invariably help in the future should a real downtime event occur [3]. During the technical testing, any redundancy features should be validated as functional by performing shutdowns of one of the redundant components and verifying that the redundant component is operational (eg, redundant or clustered servers, redundant network switches). Figure 1 shows a Case Study of SJHC PACS where the hot spare switch was included in the AT design. During the test, the main switch was shut down, all cables were manually moved by hand to the new switch and powered up to verify that the hot spare was operational.

2.5 Acceptance Testing Tools

PACS vendors should provide a boiler plate System Acceptance Document or Checklist. However, utilizing the above steps, the customer should tailor the particular test plan to meet the criteria of the particular clinical environment where the PACS is implemented. The reason is the not all technical testing and performance testing portions are included in the vendor provided AT documentation. The checklist should include these four items:

1) Test Description and Method of Testing
2) Pass/Fail Criteria and any additional comments
3) Who performed the test

4) Performance times

In addition to the AT checklist, it is beneficial to determine a set of PACS data for use in the AT plan. This PACS data set should include multiple modality types (eg, CR, CT, MR) and comprise of a large number of images. This data set should be used throughout the AT plan for all tests in order to provide consistency in any of the measurements.

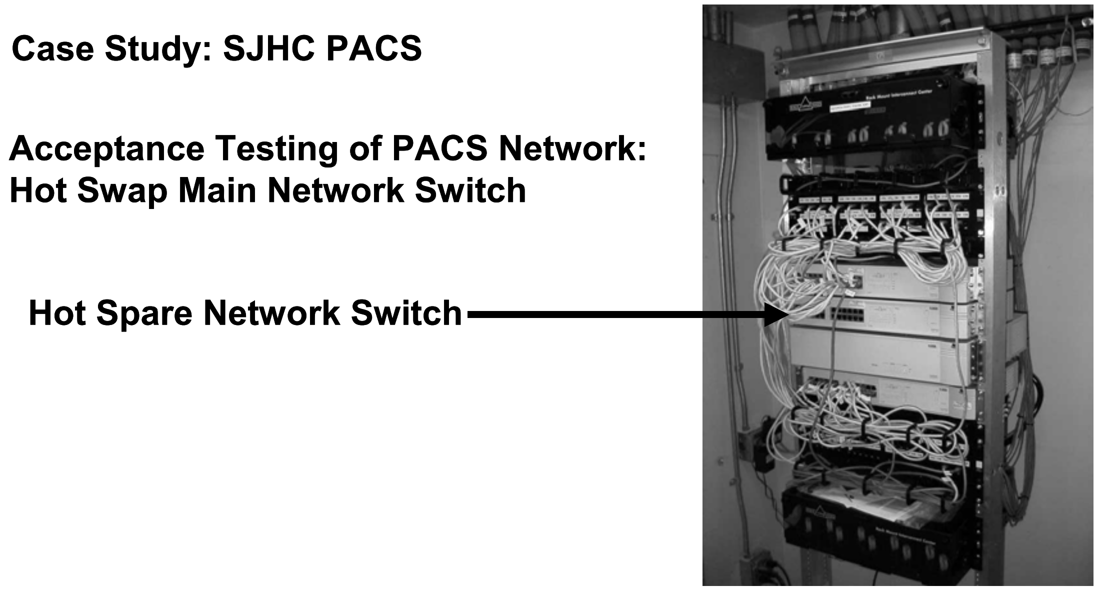

Figure 1: Technical Testing of the Hot Spare Switch for SJHC PACS AT Plan.

2.5 Acceptance Testing Implementation

Implementation of PACS in most clinical sites are either multi-phased in the approach or one entire implementation phase approach. In either case, each implementation phase whether multi-phased or single-phased should have an Acceptance Test performed. The implementation of the AT plan is a two-phased approach.

Phase one of AT should be performed approximately one week prior to Go Live date. The portions included in phase one testing are the technical components testing including "single points of failure", end-to-end PACS testing, contingency solutions, and baseline performance measurements. Because phase one testing is disruptive to the PACS, it is most desirable to perform these tests prior to Go Live date so as to minimize the effects of the downtime to the Radiologists and other clinical staff users.

Phase two of AT should be performed approximately two weeks after Go Live date. This will give the users ample time to acclimate themselves to the PACS in their respective workflows before resuming with the second phase of AT. The portions included in this phase are workstation functions, PACS dynamic testing, and PACS performance testing on a loaded clinical network. Table 2 summarizes the implementation schedule.

	Kinds of Testing	**Timeframe**
PHASE I Acceptance Testing	"Single Points of Failure Technical Testing, End-to-End Testing, Contingency Solutions, Baseline Performance Measurements	1 Week Before Go Live
PHASE II Acceptance Testing	Workstations Functions, PACS Dynamic Testing, PACS Performance Testing on Loaded PACS Network	2 Weeks After Go Live

Table 2: Summary of Acceptance Testing Timeline and Implementation

3. RESULTS AND DISCUSSION

Figure 2 shows the general configuration of the PACS that was implemented at SJHC as a Case Study. SJHC has a filmless PACS that acquires approximately 130,000 Radiological exams annually. The implementation was performed in two phases. Phase I implementation included the initial network infrastructure and CR image distribution to the ICU, CCU, and ER wards. Phase II implementation included Ultrasounds, CT, MR, and CR image distribution throughout the hospital. The following are some of the interesting points of the AT plan designed and implemented for SJHC. Phase I implementation included a redundancy feature for CR. Therefore, the AT plan included technical testing where one CR reader was shut down to observer whether CR exams could actually be acquired on the second CR reader. The RIS/PACS interface included a PACS broker which was a separate component that was included in the AT plan. The archive server, short-term RAID, and MOD jukebox was tested as one device but all three components were shut down as part of the AT plan. SJHC also featured a distribution workstation, which would distribute PACS exams to the clinical wards. This component was tested as well as contingency plans if the distribution server encountered a failure. For dynamic performance testing, multiple queries performed simultaneously were very challenging to coordinate. Phase II dynamic performance testing included querying for multiple modalities since the phase II implementation integrated multiple modality types. Finally, as discussed previously, a hot swap was performed during the AT plan to verify that the spare switch and the network was operational [1][2].

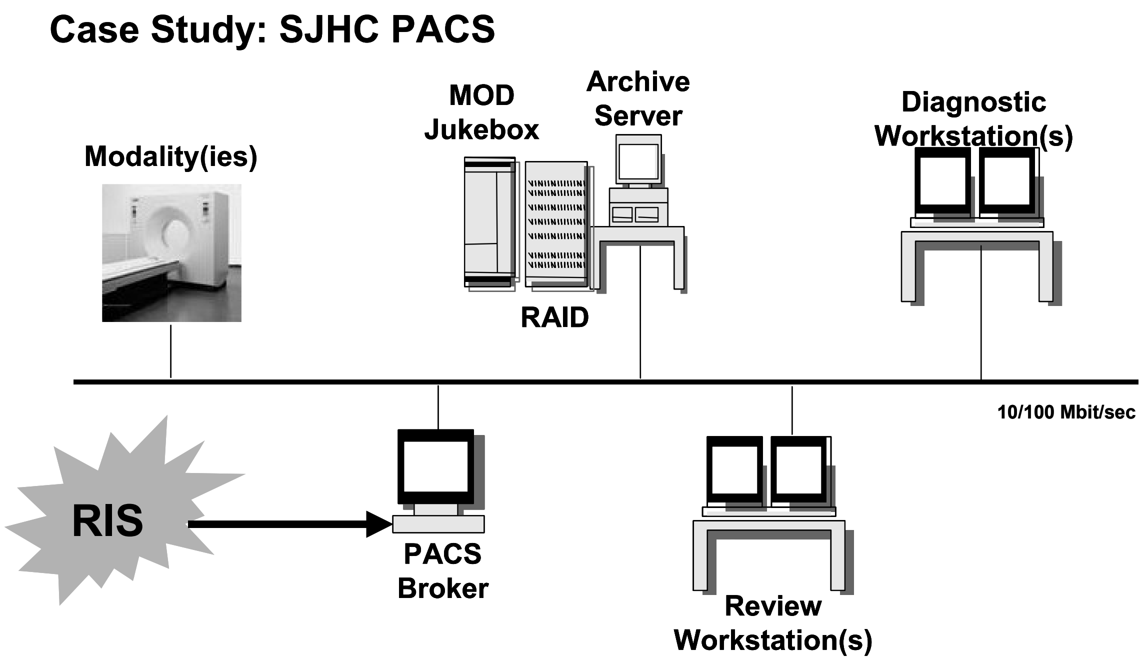

Figure 2: PACS configuration for Saint John's Health Center in Santa Monica.

In another Case Study for the PACS implementation at University of California Los Angeles Medical Center (UCLA), there were different features of which some are described in the following:

- Client Server Architecture requiring Contingency Plans
- Mirrored Cluster Archive Server
- Redundant Fiber Channel Path to large-scale RAID
- Network Infrastructure upgrade for PACS
- Backbone Network Switches featuring redundant supervisors and redundant power supplies
- Redundant DICOM gateways for modalities
- Clustered Web Servers
- ASP model based long-term storage archive
- OC-3 with DS-1 as backup for ASP network connectivity

Careful design and planning includes addressing within the AT plan all the redundant and clustered features. In addition, contingency plans must be tested as well prior to Go Live to insure that these processes are in place if the PACS encounters downtime during clinical operation. Tests which include shutting down one of the cluster archive servers, disconnecting one of the Fiber Channel paths, shutting down one of the network supervisors of the backbone switch, shutting down one of the DICOM gateways, disconnecting the OC-3 network connection, and shutting down one of the web servers and then verifying that the system continues to be operational are very key aspects of the AT plan.

4. CONCLUSION

The methodology described for designing and implementing a robust AT plan for PACS was documented and has been used in PACS acceptance tests in several sites. This methodology can be applied to any PACS from any manufacturers and can be used as a validation for the PACS product being acquired by radiology/imaging departments and hospitals. By presenting this methodology, both the customer and the vender can benefit from a robust AT plan. From the customer side, a robust AT plan can increase both the utilization and satisfaction of a successful implementation of a PACS product. From the vendor side, a robust AT plan driven by the customer's site needs and guided by the understanding of the PACS product being implemented can deliver a product that will be validated and documented successfully for all customer sites.

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WIRELESS REMOTE CONTROL CLINICAL IMAGE WORKFLOW: UTILIZING A PDA FOR OFFSITE DISTRIBUTION

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ABSTRACT

Last year we presented in RSNA an application to perform wireless remote control of PACS image distribution utilizing a handheld device such as a Personal Digital Assistant (PDA). This paper describes the clinical experiences including workflow scenarios of implementing the PDA application to route exams from the clinical PACS archive server to various locations for offsite distribution of clinical PACS exams. By utilizing this remote control application, radiologists can manage image workflow distribution with a single wireless handheld device without impacting their clinical workflow on diagnostic PACS workstations. A PDA application was designed and developed to perform DICOM Query and C-Move requests by a physician from a clinical PACS Archive to a CD-burning device for automatic burning of PACS data for the distribution to offsite. In addition, it was also used for convenient routing of historical PACS exams to the local web server, local workstations, and teleradiology systems. The application was evaluated by radiologists as well as other clinical staff who need to distribute PACS exams to offsite referring physician's offices and offsite radiologists. An application for image workflow management utilizing wireless technology was implemented in a clinical environment and evaluated. A PDA application was successfully utilized to perform DICOM Query and C-Move requests from the clinical PACS archive to various offsite exam distribution devices. Clinical staff can utilize the PDA to manage image workflow and PACS exam distribution conveniently for offsite consultations by referring physicians and radiologists. This solution allows the radiologist to expand their effectiveness in health care delivery both within the radiology department as well as offsite by improving their clinical workflow.

Keywords: PACS, Wireless Connectivity, PDA

1. INTRODUCTION

As real-time Radiology becomes more of a reality in a filmless environment, utilization of PACS workstations to perform specific tasks such as for diagnostic, review/consult, or quality assurance purposes become more and more crucial. However, in parallel to these specific tasks is the need to perform study management workflow. Offsite distribution of PACS studies to patients, physicians require distribution of PACS studies to various DICOM destinations. For example, PACS studies need to be sent to a CD-burning device, standalone web server, or a teleradiology server, or even a generic DICOM destination for special cases. Figure 1 shows a typical CD-burning device in a clinical environment. Traditionally, these workflow requests were performed utilizing the same PACS workstation needed for diagnosis, review, or QA and thus creating imaging workflow bottlenecks. The development of a study management tool utilizing wireless technology would help free up the clinical workstations to perform their specific tasks, which will in turn streamline the overall imaging workflow. This study management tool would allow the user to perform remote control PACS study distribution to the various DICOM destinations.

Figure 1: CD-Burning Device Implemented in the Clinical Environment

Table 1 lists both the clinical requirements and the technical features that are necessary for a wireless tool to be utilized for study management [1]. Based on these factors, the wireless handheld device that best suits all the requirements and features is a Personal Digital Assistant (PDA). Currently, there are other such wireless devices that suit the needs of a Study Management Tool, however, high cost and low availability make these devices more challenging to implement as compared to a PDA. This does not limit applications to only PDA's and in the future there are plans to test and evaluate other wireless devices as they become readily available.

CLINICAL REQUIREMENTS:	**TECHNICAL FEATURES:**
Need Ad Hoc Image & Report Retrieval	Platform Independent (HTTPS & DICOM Compliant)
Need Flexible & Mobile Solution	Fully Wireless (IEEE 802.11 Locally, GPRS/3G/UMTS Nationally)
Need Relevant Clinical Information	Secure (WEP, SSL)
Easy-To-Use All-Purpose Device	Text & Graphics Capable
PDA Applications: 1) Reference/Education 2) Mobile Medical Image Display 3) Workflow/Disaster Management	Scalable Implementation/Thin Client

Table 1: List of both Key Technical Features and Clinical Requirements that aid in the decision process of a Wireless Tool [1].

PDA's have traditionally been used as a portable database in the clinical environment for medical training, reference or education [2], to display DICOM images, or monitor vital signs of the patient [3]. The limitations in image display size does not provide sufficient diagnostic viewing of clinical images even though great strides and research have attempted to close the gap. The goal of this paper is not to debate the importance of image display on the PDA, but rather, propose a different approach for the PDA – that of a study management tool in the clinical environment. Last year, a

PDA application was demonstrated to perform remote control distribution of PACS studies utilizing standard wireless and web technologies and standards integrated with the DICOM standards. This paper describes the clinical experiences including workflow scenarios of implementing the PDA application in a clinical environment to route exams from the clinical PACS archive server to various locations for offsite distribution of clinical PACS exams. By utilizing this remote control application, users can manage image workflow distribution with a single wireless handheld device without impacting their clinical workflow on diagnostic PACS workstations. This powerful management tool can be utilized not only by the physicians but also by the imaging clerical staff, which also handles a variety of requests for offsite distribution of PACS studies.

2. METHODS AND MATERIALS

2.1 PDA Application User Interface Development

Figure 2 shows screenshots of the step-by-step process to perform remote control distribution of PACS studies [4].

Step 1): The user inputs criteria for the query with either the last name or partial last name of the patient or the Medical Record Number. The user can then select the archive server to make the query on if there is more than one server. In general, the archive server is the onsite clinical PACS archive server.
Step 2): The query results of patients are returned to the user. If the Medical Record Number is used, then the result would be a single patient. The user then selects the desired patient.
Step 3): The query results display all the studies located in the patient folder of the selected patient on the PACS archive. The user then selects the desired studies to be distributed and also selects the DICOM destination. For ease of use, fields such as the study date can be sorted in chronological order to assist in the selection of the desired study.
Step 4): The final status results of the requested study distribution are displayed and whether the distribution was successful.

The interface is easy to use and image display is not necessary to perform the study distribution. However, in the future, there are plans to include a thumbnail of the studies to aid in the proper selection of the desired study marked for distribution.

2.2 Clinical Implementation

Figure 3 shows the clinical implementation of a PDA application that performs remote control study management of PACS data within Saint John's Health Center (SJHC),Santa Monica. A wireless network was set up within the Radiology Department of SJHC utilizing a D-Link DI-614+ Access Point utilizing the IEEE 802.11b standard. The PDA device used in the clinical implementation was a Toshiba Pocket PC e740 running Internet Explorer for display of the PDA application and a built-in 802.11b wireless interface for connectivity. The PDA device communicates with a PDA server running Sun Solaris 5.9 and Apache/1.3.9. Security Comparisons of the PDA Internet Protocol (IP) address and the Media Access Control (MAC) address authorizes the user and grants restricted access for the specific user to the PDA server. The actual PDA application to perform queries and PACS study distribution requests was developed using Perl v.5.6.1. In addition, a Linux platform was developed for hardware platform flexibility of the PDA server running SuSe Linux 8.0 and Apache/1.3.23. The PDA server communicates with the clinical PACS network, specifically, the clinical PACS archive server via the SJHC Local Area Network (LAN). The various DICOM destinations that are utilized by the study management tool include a standalone DICOM CD-burning device, a standalone DICOM web server, a standalone DICOM teleradiology server, and PACS workstations located within the hospital.

Figure 4 shows the detailed data workflow steps and the standards used for the PDA application as follows:

1) Query for a Patient List made from the PDA utilizing the HTTP standard. To provide security to the communication, HTTPS can be used.
2) PDA Server translates into a DICOM query to the PACS archive.
3) PACS archive returns a DICOM patient list to the PDA server.
4) PDA server converts patient list for display on PDA utilizing the HTML standard.
5) PDA selects the appropriate study and DICOM destination utilizing the HTTP standard.
6) PDA server translates request into a DICOM C-Move command to the PACS archive
7) PACS archive DICOM sends requested PACS studies to the desired DICOM destination.

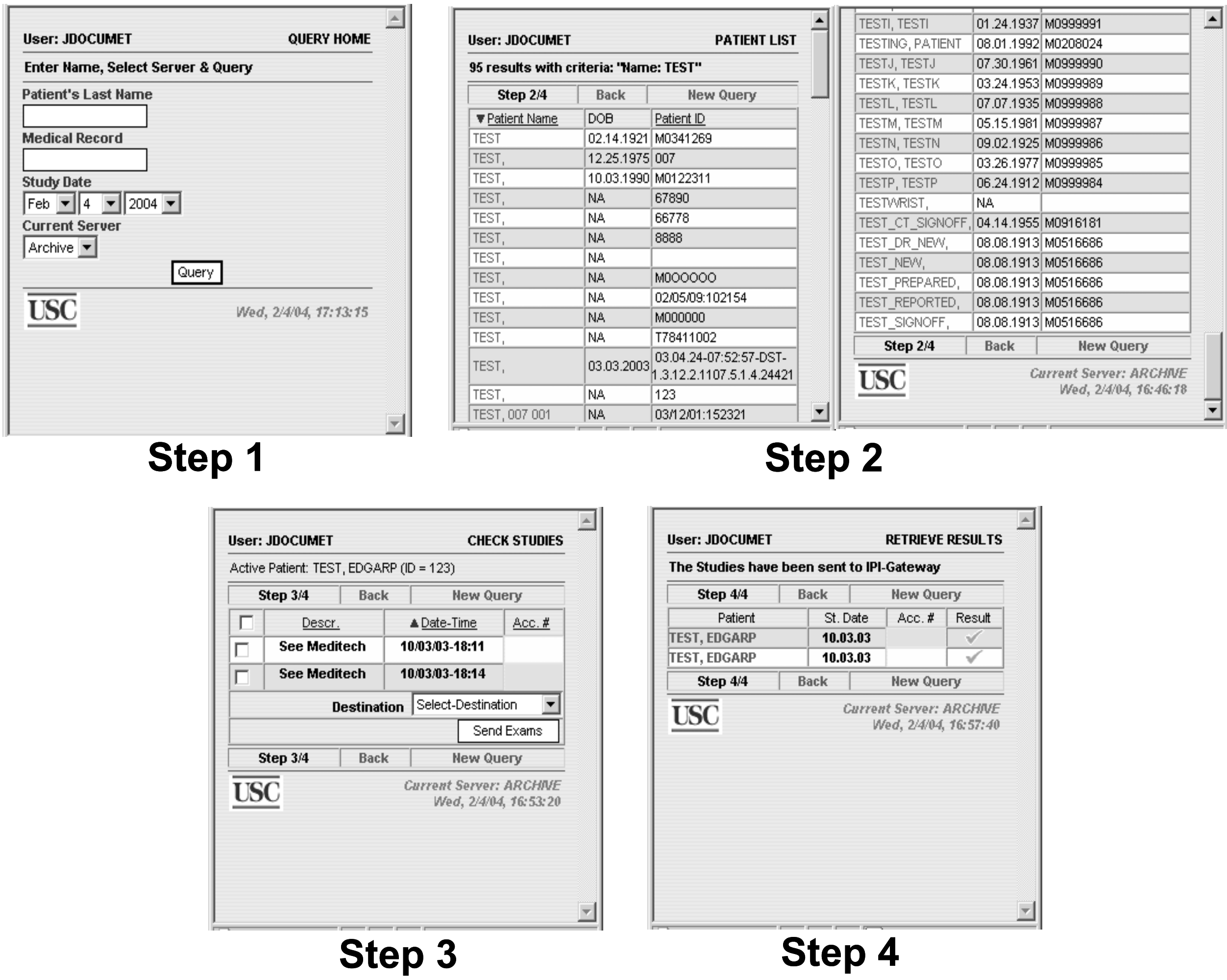

Figure 2: Screenshots showing the user interface and the steps involved to perform a PACS study distribution.

In summary, some of the key features of this PDA application for study management include:

1) Both Radiologists and Film Clerks/Librarians utilize the application for PACS study management.
2) Toshiba E740 PDA utilizing IEEE 802.11b WLAN.
3) D-Link Access Point
4) Linux/Unix/Solaris/Windows 2000/Windows XP platforms making the application platform flexible.
5) Fully DICOM and Web compliant.

3. RESULTS AND DISCUSSION

Saint John's Health Center has a filmless PACS that acquires approximately 130,000 Radiological exams annually. SJHC has implemented a Siemens PACS with a DatCard PACSCube CD-Burning device for offsite distribution of their PACS studies, a Stentor Web Server, and a Canon PACS teleradiology server. The study management tool utilizing a PDA was implemented along with a wireless network within the Radiology Department. Figure 5 shows one of the clinical staff performing a study distribution request from the PDA to the CD-Burning device in the background.

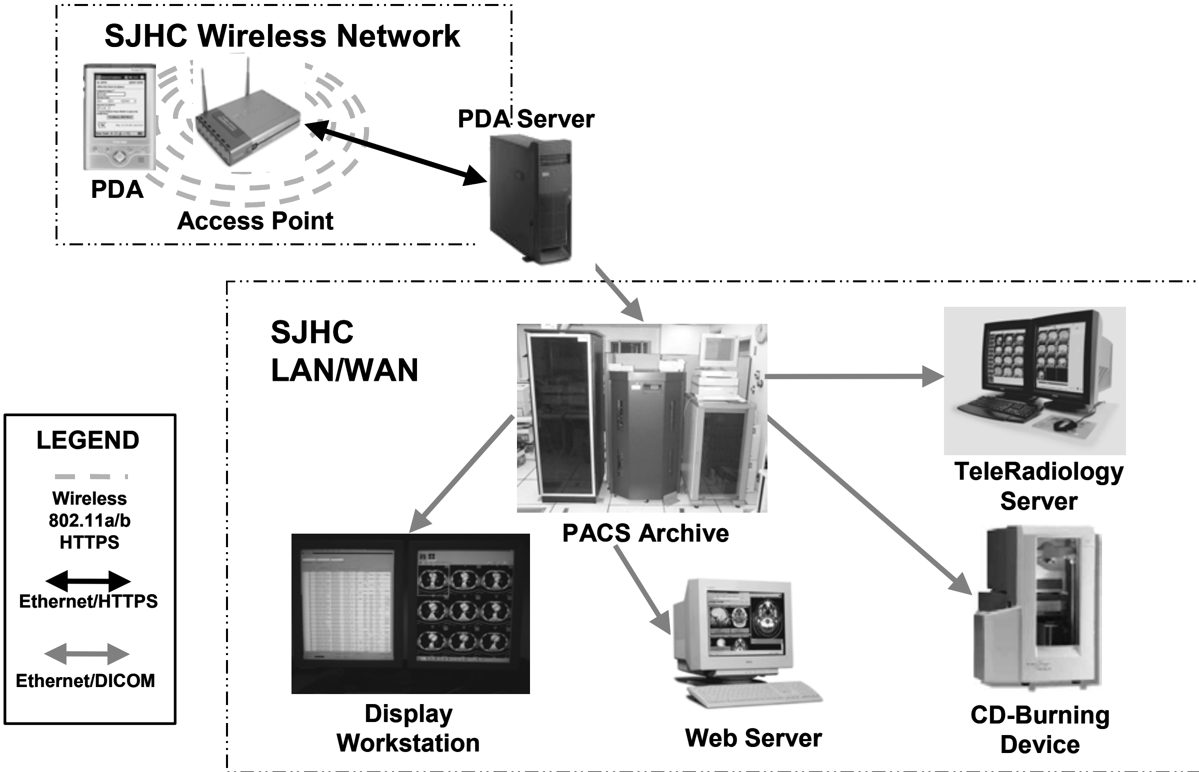

Figure 3: Clinical Implementation of a PDA Application for Remote Control Workflow Management of PACS Exams.

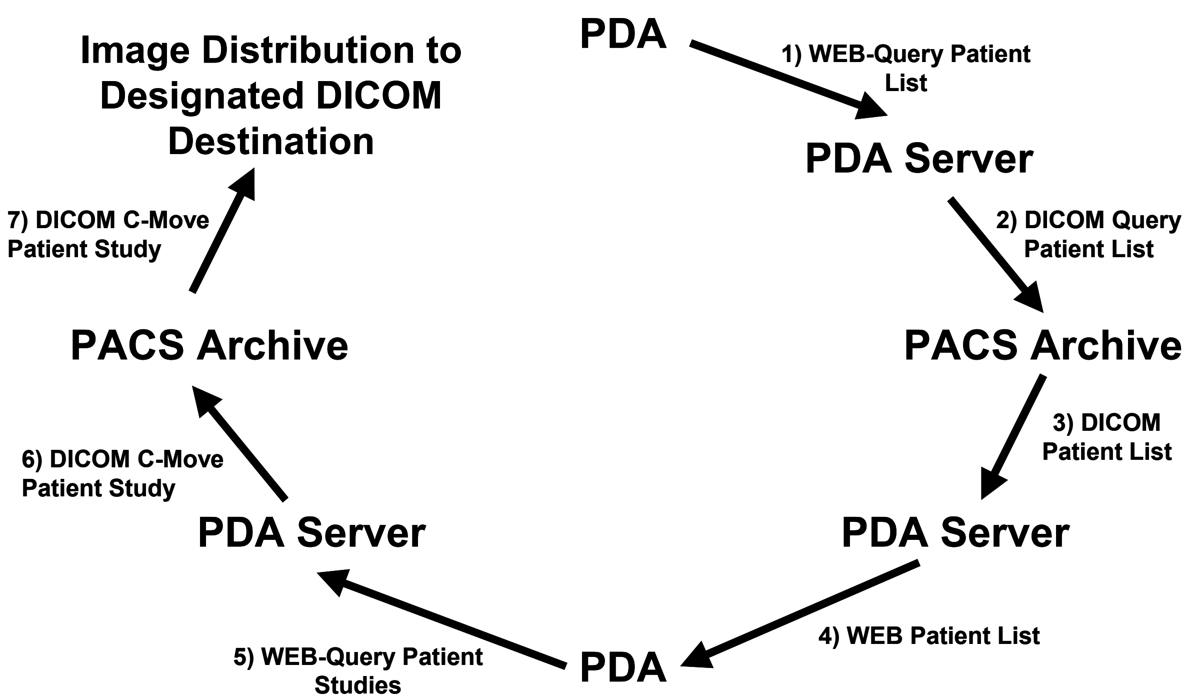

Figure 4: Detailed Data Workflow Steps and Standards Used in the PDA Application.

Figure 5: Clinical User Performing Remote Control Distribution of a PACS Study Using the Study Management Tool.

This implementation has been in clinical use for over six months. During the past six months, the study management tool has been used not only by Radiologists, but also by the film clerk/librarian. For the Radiologist, a typical clinical scenario is that the Radiologists receives a phone call from a referring physician with a request for a particular PACS study. The Radiologist can then utilize the PDA to request the study to be sent to the CD-burning device for offsite distribution to the physician office without having to interact with the diagnostic workstation especially if the Radiologist is in the middle of a difficult case displayed on the workstation. Another scenario is a request that has been made that an offsite Radiologist needs to read a particular case using the teleradiology server. The onsite Radiologist can use the PDA to forward the particular PACS exam to the teleradiology server once again without having to use the diagnostic workstation.

Equally important is the fact that the film clerk and film librarians at SJHC receive a large amount of requests daily for offsite distribution of particular PACS studies. Since they have only one workstation to perform the study management requests, the staff usually finds that the single workstation is a bottleneck to perform all the requests. The PDA application thus becomes a powerful tool as not only Radiologists but now also film clerks can perform study management remote control workflow of PACS studies, which streamlines the workflow immensely.

In addition to the above-mentioned destinations, SJHC has been archiving PACS studies offsite in an ASP model Backup Archive for Disaster Recovery. Should the onsite clinical PACS archive encounter a downtime, the users can query/retrieve with the PDA the most current 2-3 months PACS exams from the backup archive and have it distributed directly to a diagnostic or review workstation [5][6].

Table 2 shows some of the statistics of the number of PACS studies that have been distributed using the study management tool to different DICOM destinations. The numbers were collected during a period of 2.5 months from November, 2003 to February, 2004. Based on the total amounts, on average, approximately 27 PACS studies were distributed via the study management tool daily. From the table, study management is heavily favored amongst the diagnostic workstations. Especially with standalone architecture for PACS, the study management tool is extremely useful and this was true for SJHC. Besides the diagnostic workstations, the CD-burning device was the second most popular destination.

DICOM Destination:	Diagnostic Workstations	Fileroom Workstation	CD-Burning Device	Web Server	Teleradiology Server	TOTAL
No. of PACS Studies Sent:	1663	42	246	13	53	2017

Table 2: Breakdown of the Number of PACS Studies Sent to Various DICOM Destinations Using the Study Management Tool. Statistics Gathered Over a Period of 2.5 Months.

4. CONCLUSION

In summary, a PDA application was implemented in a clinical environment as a Study Management Tool. Clinical staff can utilize the PDA to manage image workflow and offsite PACS exam distribution conveniently for referring physicians and radiologists. The study management tool is powerful because of its combination of ease-of-use and flexible hardware/software platform. In addition, because of its thin-client architecture, the application can run on any device supporting Internet Explorer. This solution allows the radiologist to expand their effectiveness in health care delivery both within the radiology department as well as offsite by freeing the workstations to perform diagnosis, review, and QA while the study management tool streamlines their clinical workflow by allowing for remote control distribution of PACS exams.

ACKNOWLEDGMENT

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CLINICAL EXPERIENCES UTILIZING WIRELESS REMOTE CONTROL AND AN ASP MODEL BACKUP ARCHIVE FOR A DISASTER RECOVERY EVENT

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ABSTRACT

An Application Service Provider (ASP) archive model for disaster recovery for Saint John's Health Center (SJHC) clinical PACS data has been implemented using a Fault-Tolerant Archive Server at the Image Processing and Informatics Laboratory, Marina del Rey, CA (IPIL) since mid-2002. The purpose of this paper is to provide clinical experiences with the implementation of an ASP model backup archive in conjunction with handheld wireless technologies for a particular disaster recovery scenario, an earthquake, in which the local PACS archive and the hospital are destroyed and the patients are moved from one hospital to another. The three sites involved are: (1) SJHC, the simulated disaster site; (2) IPIL, the ASP backup archive site; and (3) University of California, Los Angeles Medical Center (UCLA), the relocated patient site. An ASP backup archive has been established at IPIL to receive clinical PACS images daily using a T1 line from SJHC for backup and disaster recovery storage. Procedures were established to test the network connectivity and data integrity on a regular basis. In a given disaster scenario where the local PACS archive has been destroyed and the patients need to be moved to a second hospital, a wireless handheld device such as a Personal Digital Assistant (PDA) can be utilized to route images to the second hospital site with a PACS and reviewed by radiologists. To simulate this disaster scenario, a wireless network was implemented within the clinical environment in all three sites: SJHC, IPIL, and UCLA. Upon executing the disaster scenario, the SJHC PACS archive server simulates a downtime disaster event. Using the PDA, the radiologist at UCLA can query the ASP backup archive server at IPIL for PACS images and route them directly to UCLA. Implementation experiences integrating this solution within the three clinical environments as well as the wireless performance are discussed. A clinical downtime disaster scenario was implemented and successfully tested. Radiologists were able to successfully query PACS images utilizing a wireless handheld device from the ASP backup archive at IPIL and route the PACS images directly to a second clinical site at UCLA where they and the patients are located at that time. In a disaster scenario, using a wireless device, radiologists at the disaster health care center can route PACS data from an ASP backup archive server to be reviewed in a live clinical PACS environment at a secondary site. This solution allows Radiologists to use a wireless handheld device to control the image workflow and to review PACS images during a major disaster event where patients must be moved to a secondary site.

Keywords: PACS, Disaster Recovery, Wireless Connectivity, PDA

1. INTRODUCTION

In a clinical PACS one single point of failure during a disaster scenario is the main archive storage and server. During a major disaster, it is possible to lose an entire hospital's PACS data. Some common disaster scenarios include earthquake, fire, flood, sabotage, or any combination of these that results in the complete destruction of the archive storage and server. With the increasing presence of fully filmless hospitals it becomes more and more crucial to provide procedures to protect the PACS data. Some reasons for this include the fact that in a filmless environment, only one data copy of the PACS exam may be available in PACS. In addition, future HIPAA (Health Insurance Portability and Accountability Act of 1996) requirements may necessitate a disaster recovery solution for PACS data. Other factors include the importance of previous PACS exams for accurate diagnosis of the current exam. Even though new PACS exams can be acquired during a disaster scenario, previous exams may not be accessible if the archive storage and server has been destroyed. The overall damages and costs associated with a destroyed PACS archive storage and server is comparable to losing the entire onsite film archive of the hospital department. In addition, in a real time disaster event, patients from one hospital site may need to be transferred to another location where the PACS data will need to be accessed at the new site [1]. Because of these factors, a Disaster Management Tool is crucial in managing PACS data during a disaster event.

This paper describes the necessary building blocks for a Disaster Management Tool that can not only recover PACS data from an ASP backup archive but also manage the data workflow within various disaster scenarios to provide the physicians with the pertinent information for review and diagnosis.

2. METHODS AND MATERIALS

There are five key building blocks for a Disaster Management Tool:

1) ASP backup archive of PACS data for the primary hospital site.
2) Wireless tool for remote control distribution of PACS data (eg, PDA).
3) Application to perform remote control management of PACS data.
4) WAN, wireless, LAN, & multi-site connectivity.
5) Disaster scenario drills to evaluate the Disaster Management Tool.

Each of these building blocks will be described in the following sections.

2.1 ASP Backup Archive

Figure 1 shows the General Architecture of how the ASP backup archive would integrate with a clinical PACS. The separate sites would be connected via some broadband connection. Currently, a T1 line can be established. However, as newer connectivity solutions become cost-effective and available (eg, wireless, Next Generation Internet or NGI), they can potentially replace the current T1 connection. On the hospital side, any new exam acquired and distributed in the PACS is sent from the clinical PACS Archive server to a DICOM Gateway. The DICOM Gateway proceeds to transfer an exam in its queue through the T1 router across the T1 line to a receiving T1 router at the offsite area. At the PACS storage site another PACS gateway receives the PACS exams and queues these exams to be stored into a Fault-Tolerant Backup Archive. This fault-tolerant backup is a continuously available (CA) archive has 99.999% availability utilizing triple modular redundancy architecture [2][3]. It is interesting to note that all PACS data transmitted throughout this architecture conform to the DICOM protocol standard.

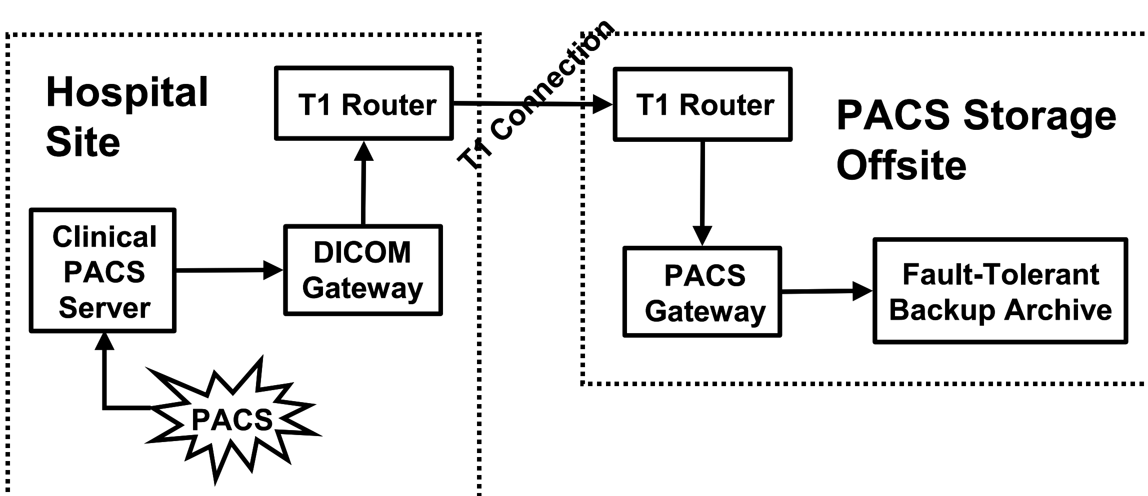

Figure 1: General Architecture of the ASP Backup Archive [4].

Figure 2 shows the recovery procedure of the PACS data should a hospital encounter a disaster scenario. If the connectivity between the two sites is still live, then the stored PACS exams can be migrated over to the hospital using DICOM compliant network protocols. At this point, the radiologist will have previous and current PACS exams to continue reading until the new hardware is replaced and the hospital archive is brought back online. However, in most disaster scenarios, there is likelihood that the connectivity between the two sites is not functional in addition to the damage to the hospital PACS archive. In this case, the PACS exams are imported into the hospital PACS from the fault-tolerant backup archive server using a portable **Data Migrator**. The portable data migratory will export the PACS exams from the fault-tolerant archive server. Then, it is physically brought to the hospital where the PACS exams can be imported directly into a workstation or server so that the radiologists will have previous cases to read. Since the portable data migrator is DICOM compliant the PACS exams can be directly imported into the hospital PACS without any additional software or translation. This recovery procedure can serve as an interim solution until the hospital PACS archive has been brought back online. The Data Migrator contains up-to-date PACS data since it is always synchronized with the clinical PACS workflow.

The following is a list of some of the key features [4]:

1) Copy of PACS exam is created and stored automatically
2) Backup archive server is CA fault-tolerant with 99.999% availability
3) No need for operator intervention
4) Backup storage capacity easily configurable and expanded based on requirements and needs
5) Data recovered and imported back into hospital PACS within one day using a portable Data Migrator
6) DICOM-compliant and ASP model-based
7) System does not impact normal clinical workflow
8) Radiologists can read with previous exams until hospital PACS archive is recovered.

The ASP backup archive has been in clinical operation for over one year. IPIL in Marina del Rey has been storing clinical PACS data acquired by SJHC in Santa Monica using the ASP model and a Fault-Tolerant backup archive server [5].

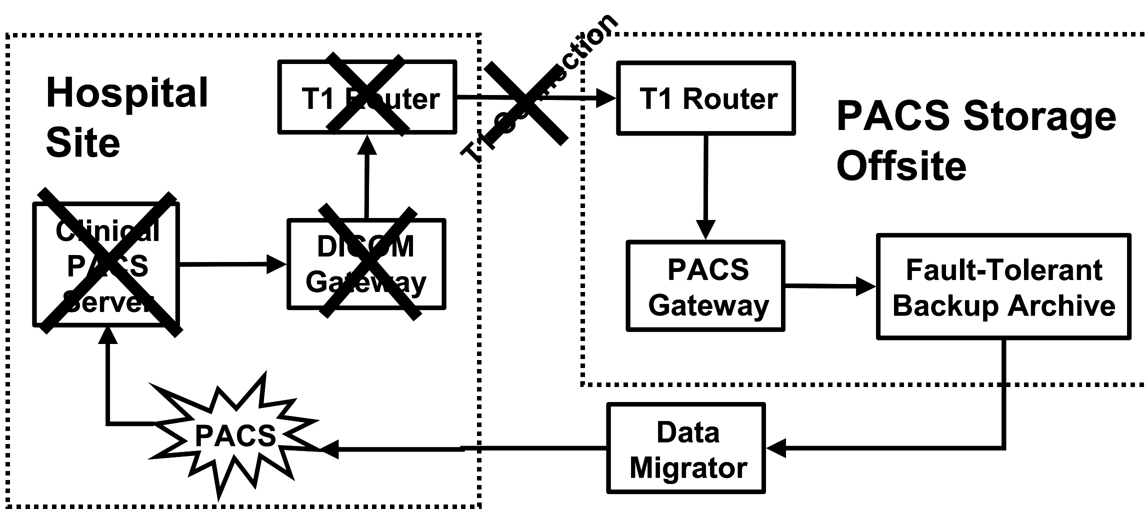

Figure 2: Disaster Recovery Procedure [4].

2.2 Wireless Tool for Remote Control Distribution

Table 1 lists both the clinical requirements and the technical features that are necessary for a wireless tool to be utilized for disaster management. Based on these factors, the wireless handheld device that best suits all the requirements and features is a Personal Digital Assistant (PDA). Currently, there are other such wireless devices that suit the needs of a Disaster Management Tool, however, high cost and low availability make these devices more challenging to implement as compared to a PDA. This does not limit applications to only PDA's and in the future there are plans to test and evaluate other wireless devices as they become readily available.

CLINICAL REQUIREMENTS:	**TECHNICAL FEATURES:**
Need Ad Hoc Image & Report Retrieval	Platform Independent (HTTPS & DICOM Compliant)
Need Flexible & Mobile Solution	Fully Wireless (IEEE 802.11 Locally, GPRS/3G/UMTS Nationally)
Need Relevant Clinical Information	Secure (WEP, SSL)
Easy-To-Use All-Purpose Device	Text & Graphics Capable
PDA Applications: 1) Reference/Education 2) Mobile Medical Image Display 3) Workflow/Disaster Management	Scalable Implementation/Thin Client

Table 1: List of both Key Technical Features and Clinical Requirements that aid in the decision process of a Wireless Tool.

2.3 Remote Control Management Application

Another important building block for a Disaster Management Tool is an application that utilizes the PDA to perform remote control distribution of PACS data in a clinical environment. Figure 3 shows the clinical implementation of a PDA application that performs remote control management of PACS data within the hospital site. The end user utilizes the PDA to perform a query from the clinical PACS archive for a particular PACS exam or an entire patient folder. Once the query has been made and the desired exam(s) selected, the user can then request the PACS exam(s) to be forwarded to a particular DICOM destination for offsite distribution. A wireless network was set up within the Radiology department where the PDA communicates with the PDA application server via a wireless access point. The PDA application server then communicates to the clinical PACS archive through the LAN to execute a command for the PACS archive to forward a particular PACS exam to the designated destination for offsite distribution [6]. At SJHC, there are multiple DICOM destinations for distribution of PACS exams to offsite locations. A few of this components include a Web server for viewing of PACS exams via the internet, a CD-burning device to distribute PACS exams to physician's offices, and a Teleradiology server. Because there is a high volume of requests for offsite distribution of SJHC PACS exams, it became necessary for a workflow management tool to forward these PACS exams to the proper destinations without having to utilize a dedicated diagnostic workstation to perform these particular tasks.

Some of the key features of this application include:

1) Both Radiologists and Film Clerks/Librarians utilize the application for PACS Study Management.
2) Users surveyed agreed that Images are not necessary for tool to be useful.
3) Toshiba E740 PDA utilizing IEEE 802.11b WLAN.
4) D-Link Access Point
5) Linux/Unix/Solaris/Windows 2000/Windows XP platforms making the application platform flexible.
6) DICOM compliant.

This application was implemented at SJHC and has been in clinical use for approximately one-half year [7].

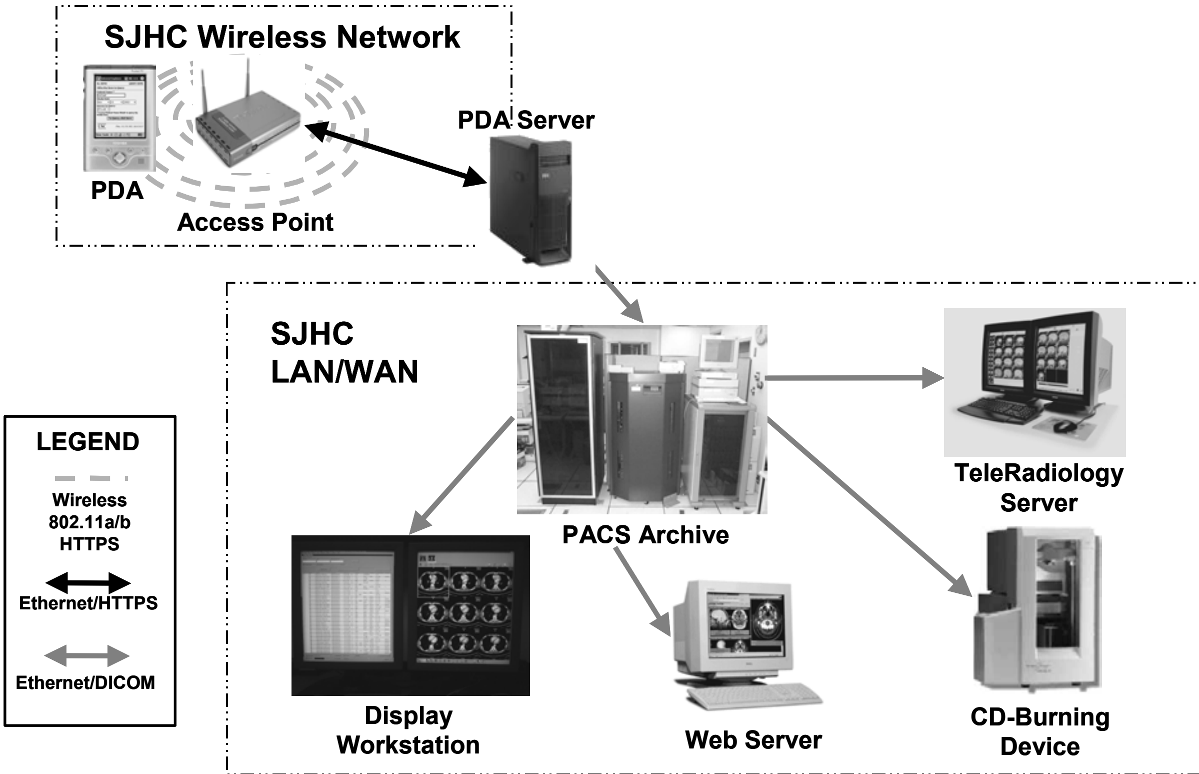

Figure 3: Clinical Implementation of a PDA Application for Remote Control Workflow Management of PACS Exams [7].

2.4 Multi-Site Connectivity

In a disaster event, the need for PACS data may not necessarily be at the local site where the disaster occurred. Therefore, a key building block is to establish network connectivity between multiple sites where PACS data can be transferred. Figure 4 shows one implementation where three separate sites are connected. Because each site is different, the types of network connections can vary from site to site. For example, from SJHC to IPIL a T1 Connection was implemented since SJHC does not have access to cost-effective higher bandwidth solutions. However, from UCLA to IPIL, Internet2 is utilized since both sites have established Internet2 connectivity. Also, it is important for each of the three sites to have an internal wireless network as well as an internal high-speed LAN.

2.5 Disaster Scenario Drills

Once all the key building blocks are implemented, the Disaster Management Tool can be evaluated by creating Disaster Scenario Drills. This is an important final step not only to evaluate the success of the overall application but also to fine tune any components or network connectivity issues. A disaster scenario is created first and then the drills are designed accordingly. Assuming all the building blocks are in place, the following is the assumed disaster:

1) SJHC encounters a disaster event that cripples the site.
2) The clinical PACS archive is destroyed.
3) Patients are transferred to nearby UCLA Medical Center.
4) Historical PACS exams are needed at the secondary site.
5) Physician and/or Radiology needs to view PACS exam immediately at secondary site, UCLA.
6) A second copy of the PACS exam is stored offsite in the ASP backup archive, IPIL.

This disaster scenario was tailored after a real incident – the Northridge Earthquake in California in 1994.

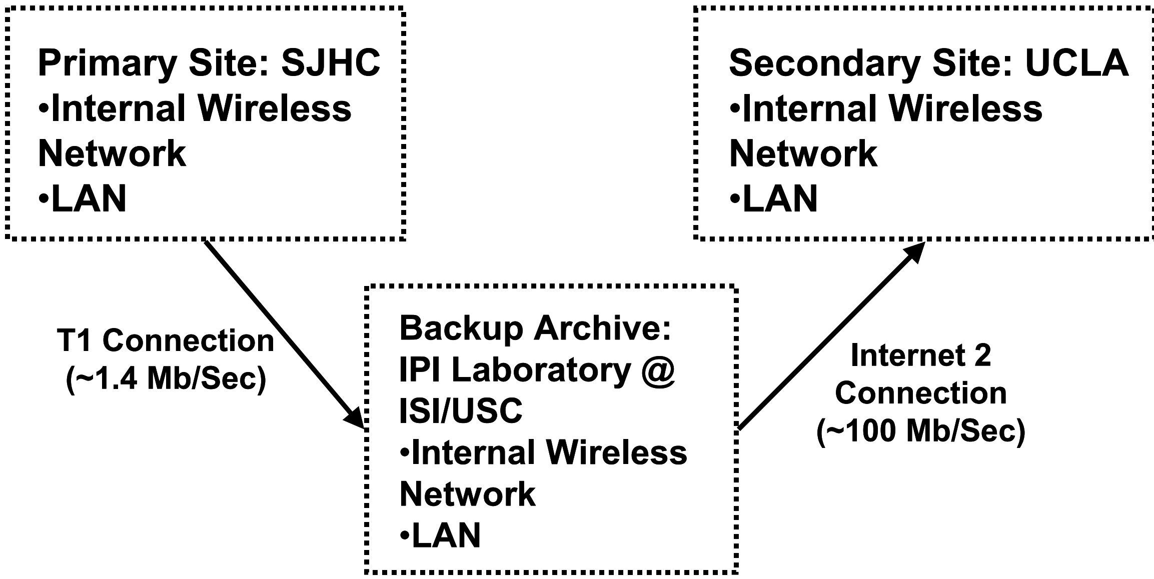

Figure 4: Network Connectivity for Disaster Recovery Application at Multiple Sites

Based on this disaster event, three disaster recovery scenarios were designed. Figure 5 is the "Primary Site Scenario" where the user is still at SJHC. The following is the scenario workflow:

1) During normal operation, a copy of the PACS exam is stored offsite at the ASP backup archive, IPIL.
2) Utilizing a PDA and the wireless network, the user at SJHC queries for particular PACS exams from the ASP backup archive, IPIL.
3) Once exam is located, a request is made for the ASP backup archive to forward the exam to the secondary site, UCLA, for viewing when the user arrives.

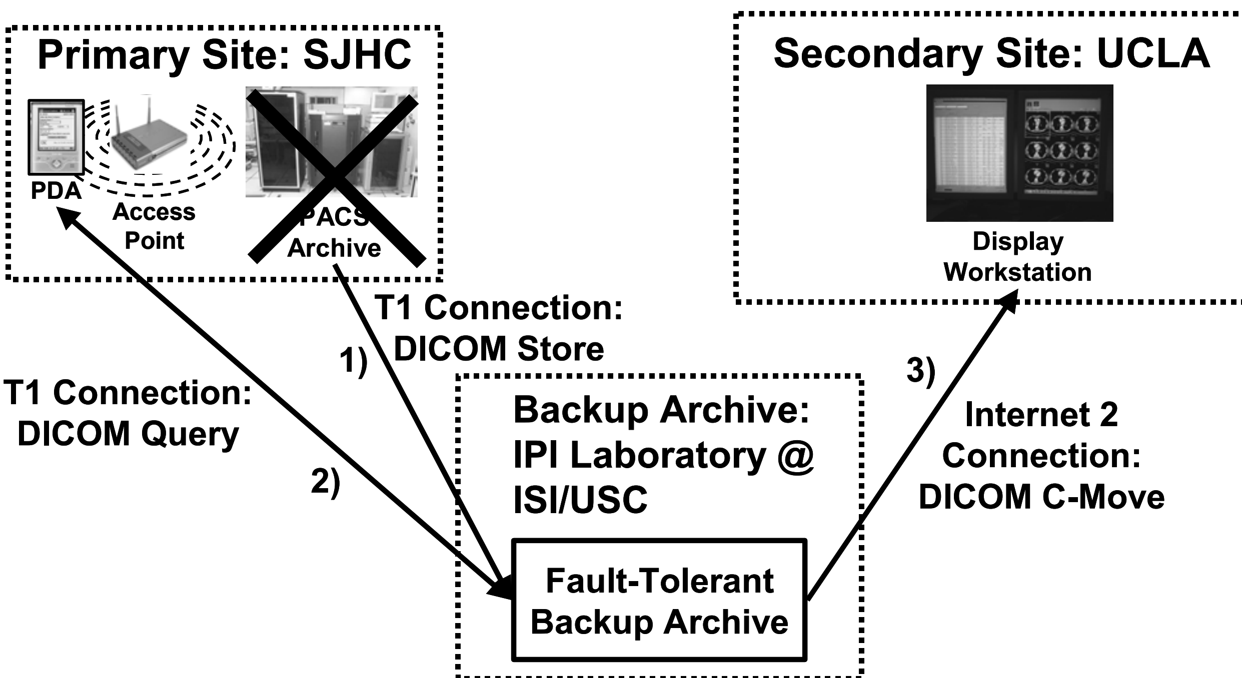

Figure 5: "Primary Site Scenario" Disaster Drill

Figure 6 is the “Secondary Site Scenario”, where the user is already at the secondary site, UCLA. The following is the scenario workflow:

1) During normal operation, a copy of the PACS exam is stored offsite at the ASP backup archive, IPIL.
2) Utilizing a PDA and the wireless network, the user, who is already at UCLA Medical Center, queries for particular PACS exams from the ASP backup archive, IPIL.
3) Once exam is located, a request is made for the ASP backup archive, IPIL, to forward the exam for viewing at UCLA.

Both scenarios described above are initial scenarios that provide a good basis for evaluation of the Disaster Management Tool. However, a more likely and real-life scenario is the “Mobile Transit Scenario” shown in Figure 7 and the workflow is as follows:

1) During normal operation, a copy of the PACS exam is stored offsite at the ASP backup archive.
2) Utilizing a PDA in a mobile wireless network, the user, while in transit to the secondary location, queries for particular PACS exams from the ASP backup archive, IPIL.
3) Once exam is located, a request is made for the ASP backup archive, IPIL, to forward the exam for viewing when the user eventually arrives at UCLA.

This final scenario is most challenging to implement since it will utilize wireless mobile technologies integrated with the multi-sites where data security becomes an issue and a factor.

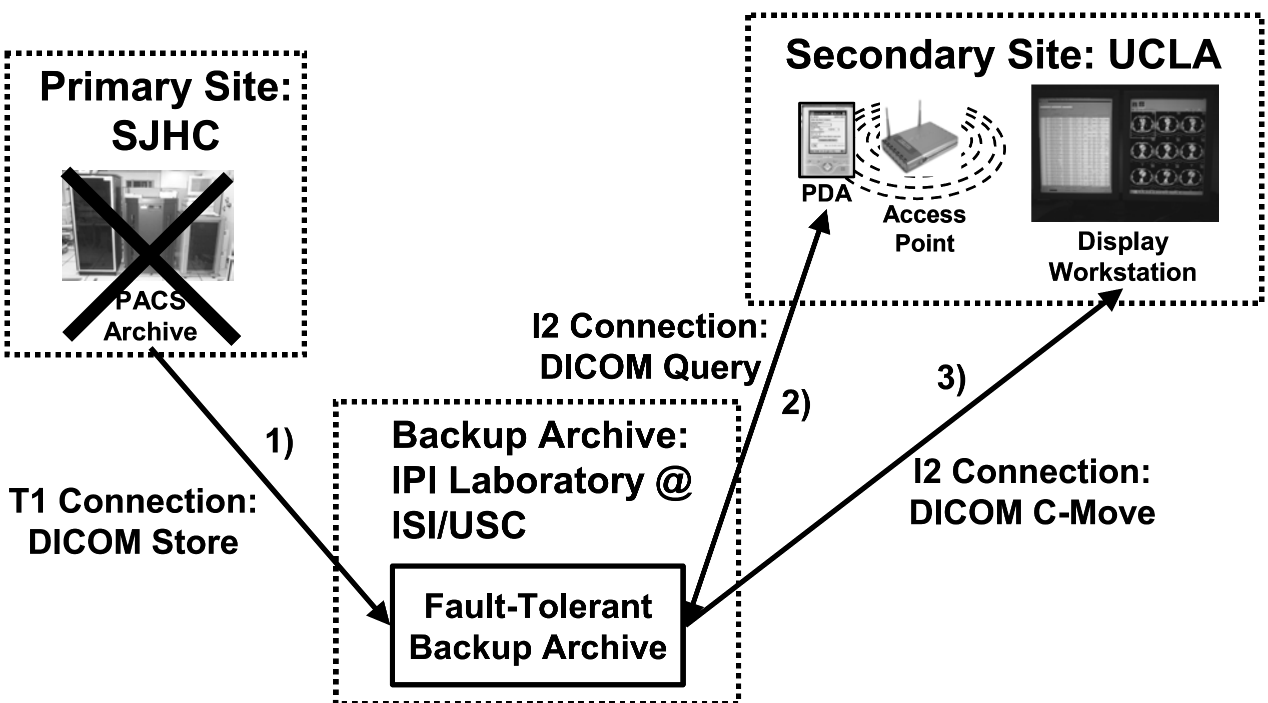

Figure 6: “Secondary Site Scenario” Disaster Drill

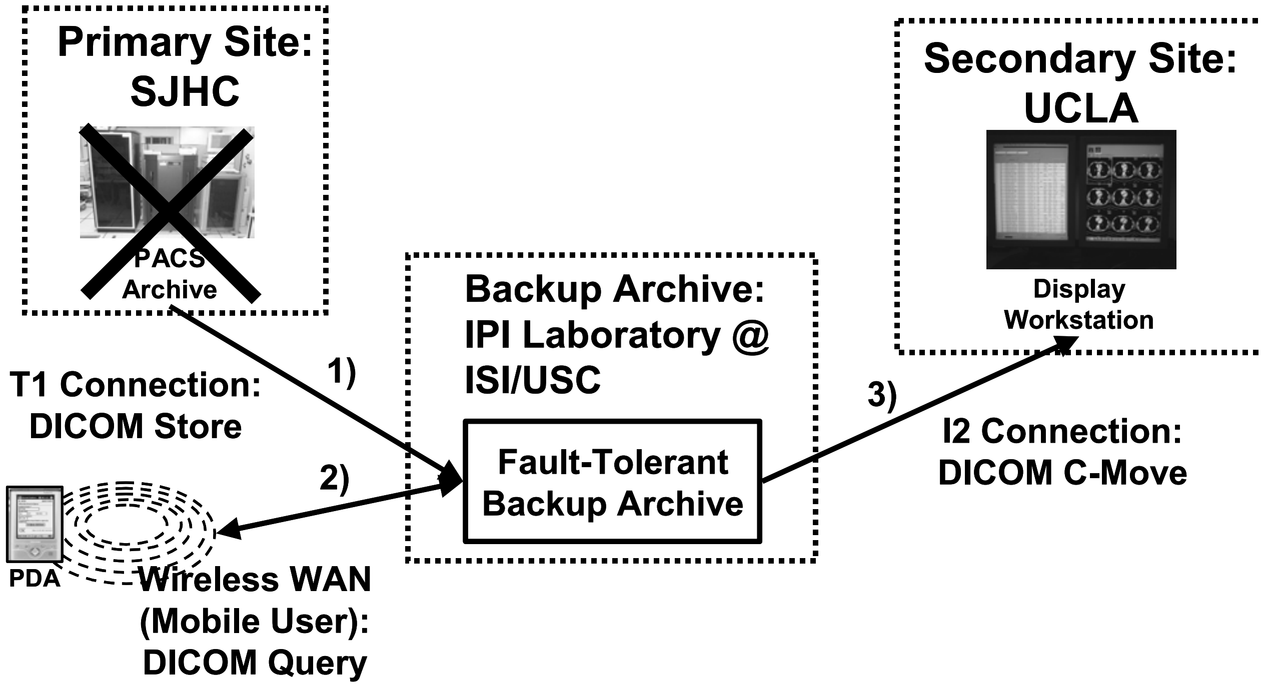

Figure 7: "Mobile Transit Scenario" Disaster Drill

3. RESULTS AND DISCUSSION

Saint John's Health Center has a filmless PACS that acquires approximately 130,000 Radiological exams annually. Utilizing the building blocks described above, a Disaster Management Tool was implemented between the hospital site, the Image Processing and Informatics Laboratory (IPI) at ISI/USC in Marina del Rey, CA, and the University of California Los Angeles Medical Center (UCLA). Scenarios one and two were designed and implemented between the three sites. Clinical PACS exams were utilized to test and evaluate the two scenarios drills.

It is important to note that a T1 connection was implemented between SJHC and IPIL since SJHC does not have cost-effective solutions for internet2 connectivity. However, an internet2 connection between UCLA and IPIL was implemented for the disaster scenario drills.

Disaster scenario drill number three has been designed, however, the implementation and testing is future work. The biggest challenge of the implementation of scenario number three is the establishment of a mobile wireless network. Solutions are being researched currently that are tailored for both cost-effectiveness as well as robust connectivity. Since this is a growing technology field, more solutions become available for implementation.

4. CONCLUSION

In summary, a PDA application was implemented in a clinical environment as a Disaster Management Tool. Three sites were integrated as part of the Disaster Management Tool – Primary, Secondary, & Offsite Backup Archive – at SJHC in Santa Monica, UCLA Medical Center, and IPIL at ISI/USC Marina del Rey, CA respectively. Three disaster scenario drills were designed for evaluation. Two of the three disaster scenario drills were implemented and tested successfully. The third scenario will be implemented and tested as future work. The PDA application as a Disaster Management Tool is a powerful solution in the event of a real life disaster to a filmless PACS hospital site.

ACKNOWLEDGMENT

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The DICOM-based Radiation Therapy Information System

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ABSTRACT

Similar to DICOM for PACS (Picture Archiving and Communication System), standards for radiotherapy (RT) information have been ratified with seven DICOM-RT objects and their IODs (Information Object Definitions), which are more than just images. This presentation describes how a DICOM-based RT Information System Server can be built based on the PACS technology and its data model for a web-based distribution. Methods: The RT Information System consists of a Modality Simulator, a data format translator, a RT Gateway, the DICOM RT Server, and the Web-based Application Server. The DICOM RT Server was designed based on a PACS data model and was connected to a Web Application Server for distribution of the RT information including therapeutic plans, structures, dose distribution, images, and records. Various DICOM RT objects of the patient transmitted to the RT Server were routed to the Web Application Server where the contents of the DICOM RT objects were decoded and mapped to the corresponding location of the RT data model for display in the specially-designed Graphic User Interface. The non-DICOM objects were first rendered to DICOM RT Objects in the translator before they were sent to the RT Server. Results: Ten clinical cases had been collected from different hospitals for evaluation of the DICOM-based RT Information System. They were successfully routed through the data flow and displayed in the client workstation of the RT Information System. Conclusion: Using the DICOM-RT standards, integration of RT data from different vendors is possible.

Keywords: data model, PACS, radiation therapy, server, DICOM RT

1. INTRODUCTION

DICOM standard is the cornerstone to the successful implementation of PACS (Picture Archiving and Communication System) in radiology. By using the DICOM format and communication protocol, images acquired from equipment of different vendors can readily communicate with one another[1]. Following the implementation of DICOM format, seven DICOM radiotherapy (RT) objects in DICOM format have been ratified by the DICOM Committee for transmission and storage of radiotherapy images and related information[2] The seven DICOM RT objects include RT Image, RT Plan, RT Stucture Set, RT Dose, RT Beams Treatment Record, RT Brachy Treatment Record and RT Summary Record. However, for various reasons, the utilization of the RT objects has not been implemented in daily clinical operation. One of reasons is the lack of a DICOM-based RT server.

The PACS is the first system that has successfully implemented the DICOM standard for image data format and communication. Since DICOM RT objects are also based on the DICOM standard, the data model of the PACS Server and the PACS data flow can be deployed for the construction of the RT Archive Server[3], which is central to the DICOM-based Radiation Therapy Information System being presented.

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2. METHODOLOGY

The development of the DICOM-based radiation therapy information system involved two stages of development. The first stage was the design of the workflow, data flow and data model of the system. The second stage was collecting data to test out of the system.

2.1. Stage 1: System design and development

The first step in the design of an information system is to study the workflow. This defines the types of users and reviews the requirements of the users. From this study, a conceptual data model that summarizes the users' requirements can be constructed. The detail radiotherapy workflow and its conceptual data model were reported in previous proceedings and publications[2,3,4] and thus only a brief workflow diagram (Figure 1) would be given in this paper. From the conceptual data model, the physical data models of the RT Archive Server and that of the Web Application Server are developed. The physical data models will be described later.

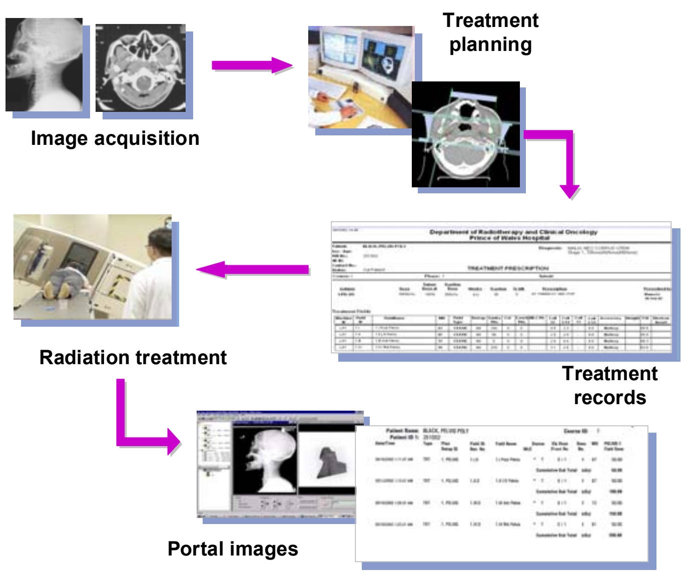
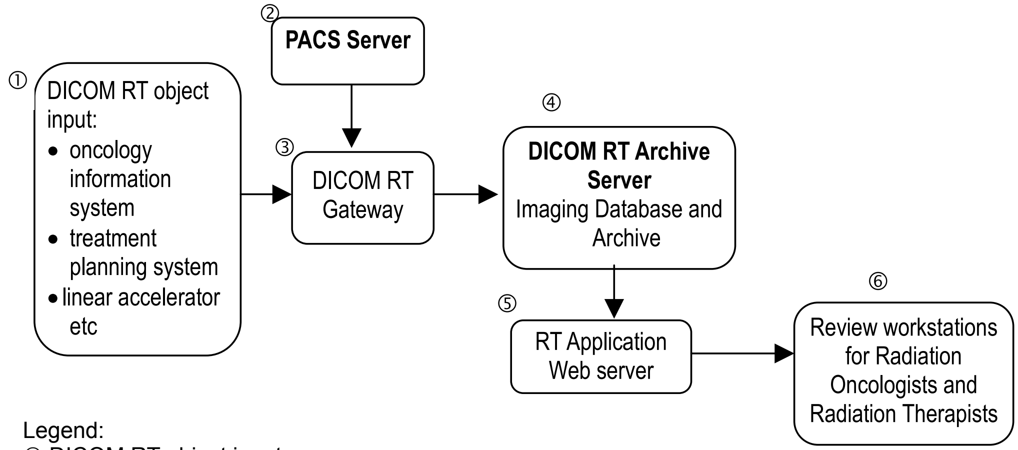


Figure 1. Radiotherapy workflow

The next step is to design the data flow through the radiotherapy information system. Based on the generic PACS data flow, Figure 2 illustrates a similar data flow design for the various components of the radiotherapy information system. The detail data flow is illustrated in Figure 3. The explanation for each component in Figures 2 and 3 is given in the next paragraph.

① DICOM RT object Input

The DICOM RT objects are generated from the various RT modalities as seen in Figure 3. The RT modalities include the Treatment Planning System, Virtual Simulator, Conventional Simulator, Film Digitizer, Linear Accelerators and Portal Imager. The CT Simulator, like any radiology modality, generates DICOM Images for radiotherapy planning on the TPS or Virtual Simulator. The Information System generates non-DICOM textual data that can be translated to DICOM RT Plan and RT Records. For testing the input and flow of DICOM RT objects, a Radiotherapy Modality Simulator was installed. All DICOM images and RT objects could be exported from the Modality Simulator to the RT Archive Server.



Legend:
① DICOM RT object input
② PACS Server
③ DICOM RT Gateway
④ DICOM RT Archive Server
⑤ RT Web Application Server
⑥ Web client workstations

Figure 2. Radiotherapy data flow

② PACS
From the PACS, radiotherapy related images are forwarded either to the TPS/Virtual Simulator for treatment planning or to the RT Archive Server for storage to be reviewed later.

③ RT DICOM Gateway
The Gateway receives all DICOM objects, acknowledges receipt of the objects and extract information from the objects and put them into the RT data model as required in the RT Archive Server.

④ RT Archive Server
The RT Archive Server is a PACS-based server in that the data model of the PACS Server was adopted for this research with minimal modifications to accept all DICOM RT objects. For the RT Archive Server, the SUN Ultra 2 computer with the Oracle database operating in the UNIX Solaris 8 environment was used. The database schema is shown in Figure 4. It shoulders all the functions of storage, management, controlling and being a database server. On receiving DICOM RT objects and images from the DICOM RT Gateway, the RT Archive Server abstracts only the essential aspects of the object entities and auto-route all the data to the Web Application Server.

⑤ RT Web Application Server
The Application Server consists of an SCP RT Receiver to receive the DICOM objects from the RT Archive Server. An RT Decoder program written in SQL is used to parse the objects. The Microsoft Access was used to build the database of this server. After being decoded, the data are put into the database schema of the MS Access database (Figure 5), from which the data are arranged into RT Views in the manner that they are displayed in the clients. The web site of RT Web Application Server is hosted by the Microsoft Internet Information Services (IIS), which is a web application infrastructure for Microsoft Windows. The web pages are created in the form of Active Server Page (ASP), which is a feature of IIS. The interactive functions of the web graphic user interfaces (GUI) are implemented by Visual Basic (VB) scripts embedded in the ASP. The VB scripts connect to the Microsoft Access database through Jet (Object Link Embedding) OLEDB provider, which is provided by the library of Microsoft Visual Studio.

⑥ RT Web clients
For web distribution, the data are sent using the Hypertext Transfer Protocol (HTTP). Two types of clients were identified. They are the radiation oncologists and the radiation therapists. Seven graphic user interface windows were

designed to suit their uses.

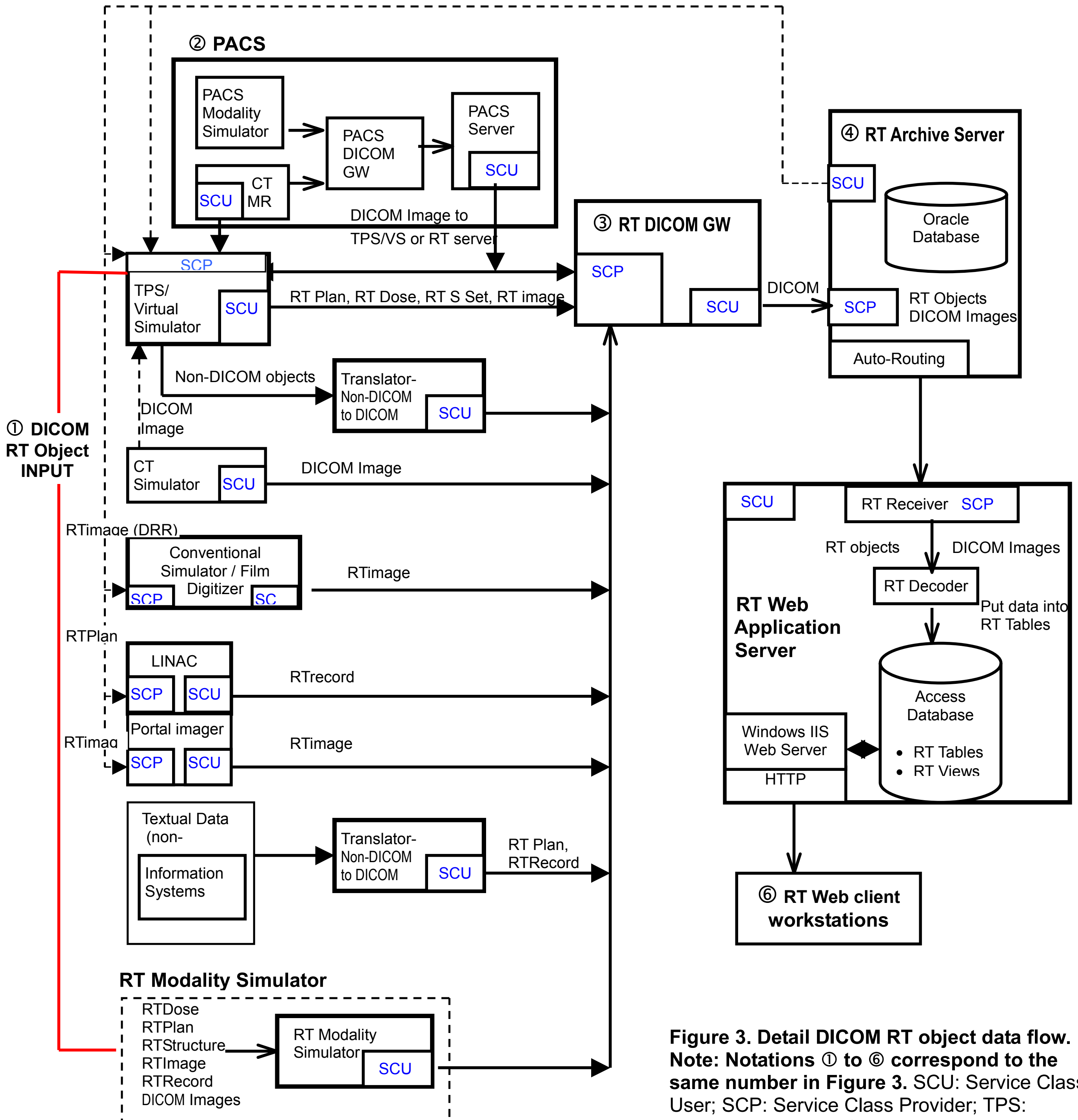


Figure 3. Detail DICOM RT object data flow. Note: Notations ① to ⑥ correspond to the same number in Figure 3. SCU: Service Class User; SCP: Service Class Provider; TPS: Treatment Planning System; DRR: Digitally Reconstructed Radiograph; GW: Gateway

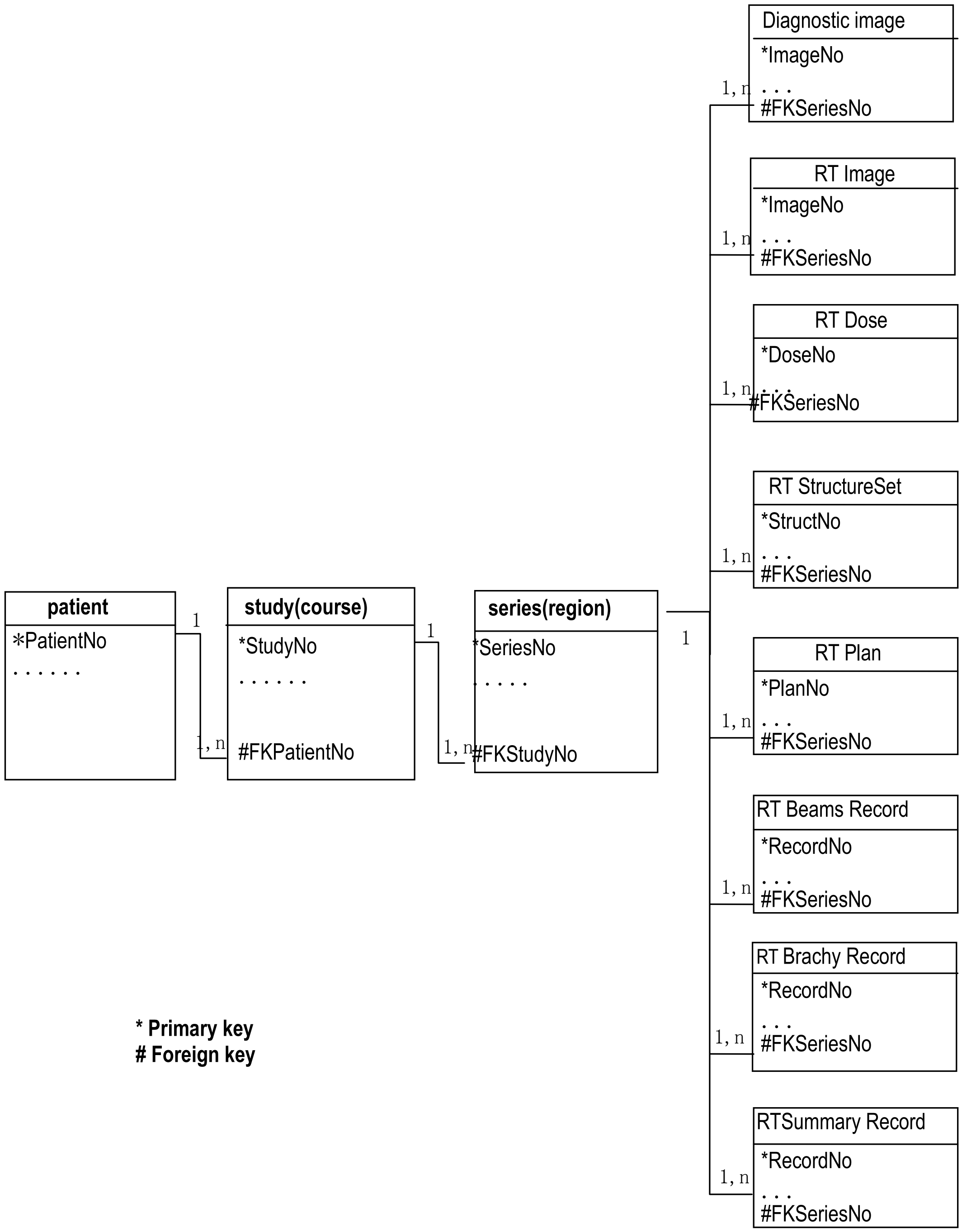


Figure 4. Database Schema of RT Archive Server

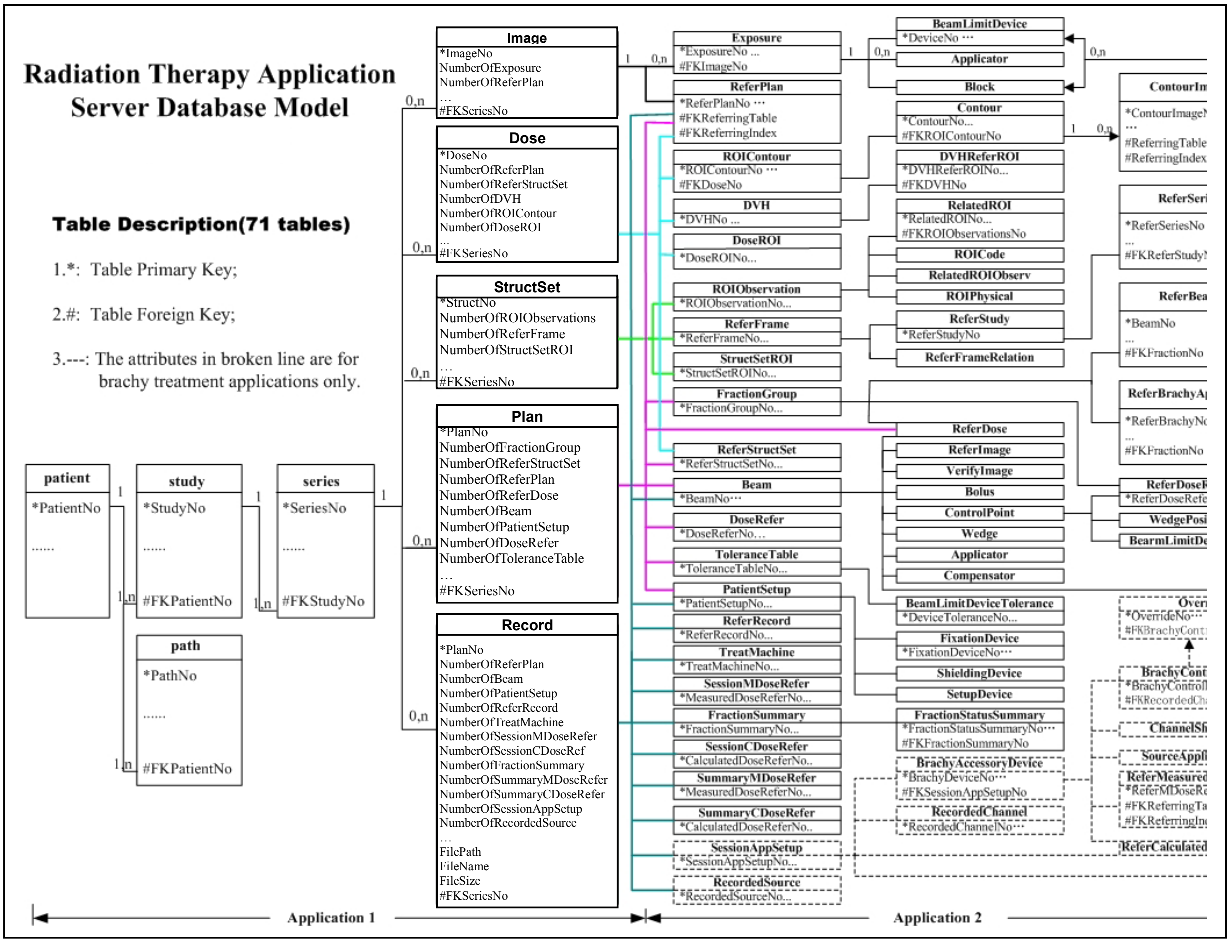


Figure 5. RT Web Application Server Database Model

2.2. Stage 2: Data collection

After the installation of all the components of the radiotherapy information system, all the DICOM RT objects and related images were needed to try out the data flow through the system. Figure 6 summarizes the input and output data from each modality/workstation. Arrows pointing towards the modalities/workstations indicate input while arrows pointing away from the workstations indicate output. Labels by the side of the arrows are objects/files flowing through. For example, at the Virtual Simulator, the input data is **DICOM images**. They are needed for planning the treatment in the Virtual Simulator. The planning process in the Virtual Simulator involves contouring of body outline, organs at risk and the target volumes on the DICOM images. This procedure generates the RT Structure Set files (**RT SS**). Then the radiation beams are positioned one by one in a manner that is likely to produce the best treatment, the details of which include radiation field size, gantry angle, collimator size, treatment distance etc. This procedure generates the **RT Plan** files. From the cross sectional CT images, a digital reconstructed radiograph (DRR) can be generated with the planned radiation field superimposed on it. This is an **RT Image**. Therefore, in the output arrow from the Virtual Simulator, there are RT Image, RT SS and RT Plan.

The DICOM RT objects are in no way complete with any current radiotherapy vendors. Most vendors can only implement RT Image, RT Plan, and RT Structure Set. Some have DICOM RT Dose export in their TPS but it is not functioning yet. Also no DICOM RT records could be found from any RT clinical department or RT vendors at the time of the data collection. Hence it was impossible to have a complete set of DICOM RT objects from any cases treated.

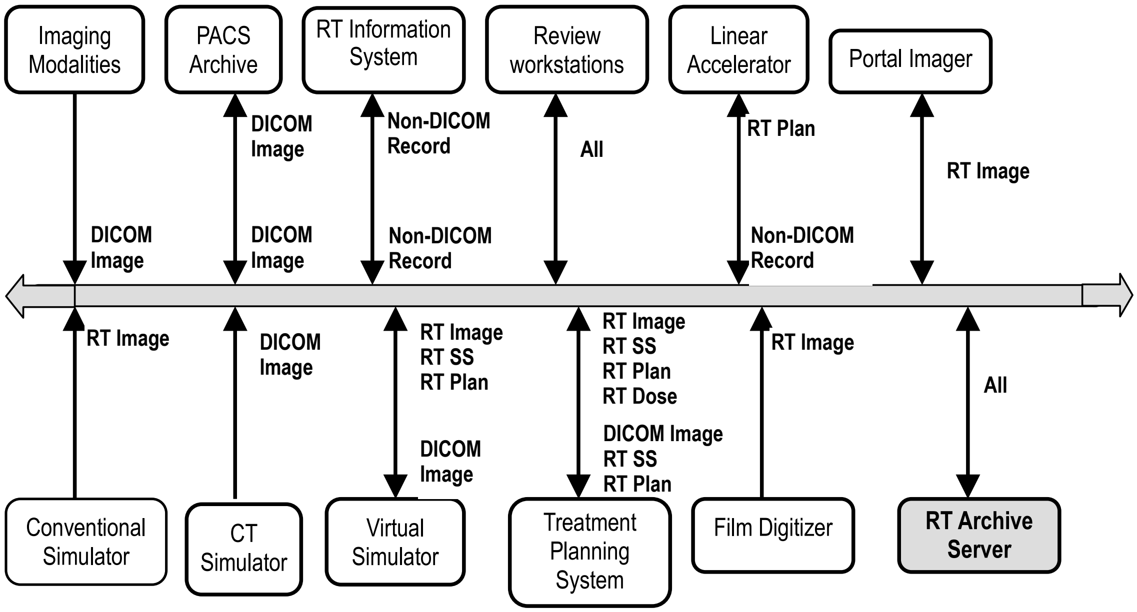


Figure 6. Input and output of objects through different RT modalities

As a matter of fact, it was envisaged that in spite of the current trend of computerization and digitization, not all procedures would be computerized in the near future. There would still be manual input of treatment planning data for those procedures that do not require a TPS or Virtual Simulator. Such data need conversion to DICOM objects and is explained in the next few paragraphs.

Because of the situations described above, different sources and methods were used to collect different types of files in order to make up 10 virtual patients for testing the RT Information System in this study. In general four sources of data were identified: 1. real patient data from clinical department, 2. data generated using anthropomorphic phantom using clinical RT modalities, 3. files from vendors, and 4. self-generated files.

Among the files collected, there were DICOM and non-DIOCM files, the latter of which required conversion. Two translation programs were written, one for conversion of non-DICOM textual files to DICOM files (Translator 1) and the other for conversion of non-DICOM images e.g. bmp, tiff images to DICOM images (Translator 2). The non-DICOM files were converted using either of the two translators before they were input to the RT Modality Simulator.

The files collected would be organized to form into folders, one for each of the virtual patients. They were input to the the RT Modality Simulator to be forwarded to the RT Gateway. From the RT Gateway, the data would be auto-routed to the RT Archive Server, and then the RT Web Application Server. In the Application Server, the objects were decoded by an RT decoder and the attributes were mapped into the database schema using the Microsoft Access. The information was then put into the views as required by the client graphic user interface. At the client workstations, the patients' information could be retrieved and this served as a proof of successful transmission.

3. RESULTS

From the data, ten virtual patients were made up from different types of objects. These data are summarized in Table 1.

The textual Excel files were collected from an information system. They contained patients' information, treatment prescription, some treatment setup details and treatment session records. . In some cases, based on the excel files collected from a clinical department, the Excel files were self generated. Each Excel file can be converted into DICOM RT Plan and DICOM RT Record objects using Translator 1. The non-DICOM (tiff or bmp) image files were converted by Translator 2 to DICOM RT Image objects by adding the DICOM header to the image.

Table 1. Summary of data objects of 10 virtual patients

Patient	File / object collected	No. of files	Source	Conversion by	After conversion	No. of files
1 Cheung Wing Kong	DICOM Image DICOM RT Plan DICOM RT SS DICOM RT Dose DICOM RT Image	86 4 2 220 27	Pamela Youde Eastern Hospital	 Nil	DICOM Image DICOM RT Plan DICOM RT SS DICOM RT Dose DICOM RT Image	86 4 2 220 27
2 Yau Mee Mee	DICOM Image DICOM RT Plan DICOM RT SS DICOM RT Dose DICOM RT Image	150 1 1 57 28	Pamela Youde Eastern Hospital	 Nil	DICOM Image DICOM RT Plan DICOM RT SS DICOM RT Dose DICOM RT Image	150 1 1 57 28
3 Otto Prostate	DICOM Image DICOM RT Plan DICOM RT SS DICOM RT Dose DICOM RT Image (DRR)	39 1 1 16 1	Helax TMS Service Team	 Nil	DICOM Image DICOM RT Plan DICOM RT SS DICOM RT Dose DICOM RT Image (DRR)	39 1 1 16 1
4 Black Thorax	DICOM Image Excel file tif Image	63 1 3	Prince of Wales Hospital	 Translator 1 Translator 2	DICOM Image DICOM RT Plan ?RT Record DICOM RT Image	63 1 3
5 Black Pelvis	DICOM Image Excel file tif Image	48 1 1	Prince of Wales Hospital	 Translator 1 Translator 2	DICOM Image DICOM RT Plan ? RT Record DICOM RT Image	48 1 1
6 White Delta	Excel file bmp Image	1 1	Self-generated Hong Kong Baptist Hospital	Translator 1 Translator 2	DICOM RT Plan ? RT Record DICOM RT Image	1 1
7 Whit chi pelvis	Excel file bmp Image (Portal) tif image (Sim)	1 3 2	Self-generated Hong Kong Baptist Hospital	Translator 1 Translator 2	DICOM RT Plan ? RT Record DICOM RT Image	1 5
8 Bap Lung (Lam WK)	DICOM RT Image (DRR) bmp Image (Portal Image) Excel file	2 2 1	Hong Kong Baptist Hospital Self-generated	Nil Translator 2 Translator 1	DICOM RT Image (DRR) DICOM RT Image DICOM RT Plan ? RT Record	2 2 1
9 Bap Head Tung Tat Ming)	DICOM Image (MR) (CT) bmp Image Excel file	 65 47 1 1	Hong Kong Baptist Hospital Self-generated	 Translator 2 Translator1	DICOM Image MR CT DICOM RT Image DICOM RT Plan ? RT Record	 65 47 1 1
10 SomaVision Pelvic	DICOM Image CT DICOM RT SS DICOM RT Plan	52 1 1	Varian TPS	 Nil	DICOM Image CT DICOM RT SS DICOM RT Plan	51 1 1

Each object was input into the RT Modality Simulator, which in turn transmitted it to the DICOM RT Gateway. The Gateway automatically routed the objects to the RT Archive Server, which while keeping a copy, also forwarded the objects to the RT Web Application Server. In the Application Server, the objects were parsed into the corresponding fields in the MS Access database. Objects that could not be transmitted were examined and debugged. At the client workstations, the seven graphic user interfaces (GUIs) were designed and used to view the information inside the DICOM objects.

4. DISCUSSION

Central to the radiation information system is a DICOM-based RT Archive Server for receiving all DICOM objects. Being DICOM-based, this is a generic archive server for any radiation therapy information in the DICOM format to be stored. In the past, radiotherapy departments have to adhere to the equipment vendor who provides the information system. With the DICOM-based RT Information System in place, this is no longer the case. A department can acquire equipment from different vendors and the DICOM-based archive server can be the central storage for all.

The Web-based RT Application Server and its graphic user interfaces described above also illustrate the fact that we can use a generic platform for viewing all sorts of information contained in the DICOM RT objects to serve the needs of the clinical practitioners. Using the web browser, all RT information can be viewed in one workstation. It helps save space on the working benches or in the clinic offices.

Currently, not all DICOM RT objects have been implemented. Many vendors show a non-functioning DICOM RT Dose export button on the GUI of their TPS. No RT Records has been implemented. On the other hand, the data in the RT Dose object is prescribed in pixel format (grey scale) in the DICOM document. The grey scale expresses the radiation dose values. For clinical use, this needs to be converted to isodose lines for display which is the usual format used in radiotherapy. Lines can be superimposed on top of an (CT) image (Figure xxx) to indicate the dose to the planning target volume or an organ while grey scale will only obscure the image when they are put one on top of the other. Nevertheless, conversion from grey scale to lines for display has been proved to be feasible though some processing time would be needed and that depends on the number of image slices.

5. CONCLUSION

Based on the data model of the PACS server, a DICOM-based RT server can be constructed with the RT specific attributes added. All radiotherapy related data are archived in the RT server. There, they are staged and routed to the Web Application Server where the RT objects are decoded and organized into web viewing mode. Seven web-based display windows with graphic user interfaces have been designed customized to the client needs in the RT workflow. The DICOM-based RT Server derived from the PACS data model is a logical extension of successful PACS implementation to radiation therapy application.

ACKNOWLEDGMENT

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Data Mining for Average Images in a Digital Hand Atlas

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ABSTRACT

Bone age assessment is a procedure performed in pediatric patients to quickly evaluate parameters of maturation and growth from a left hand and wrist radiograph. Pietka and Cao have developed a Computer-aided diagnosis (CAD) method of bone age assessment based on a digital hand atlas. The aim of this paper is to extend their work by automatically select the best representative image from a group of normal children based on specific bony features that reflect skeletal maturity. The group can be of any ethnic origin and gender from one year to 18 year old in the digital atlas. This best representative image is defined as the "average" image of the group that can be augmented to Piekta and Cao's method to facilitate in the bone age assessment process.

Keywords: Bone Age Assessment, Data Mining, Average Image, Digital Hand Atlas

1. INTRODUCTION

Bone age assessment is a procedure performed in pediatric patients to quickly evaluate parameters of maturation and growth from a left hand and wrist radiograph. The method most commonly used in clinical practice is the atlas matching by a patient's hand image against a reference set of normal standard images in the atlas. The reference set of images includes serial hand images of the developing children, which have both the chronological and bone ages. The hand image of the patient with known chronological age is compared with the atlas images. The closest match is subjectively selected by the radiologist thus generating the bone age of the patient. The difference between the assessed bone age and the chronological age indicates the degree of abnormalities in patient's skeletal development.

The current book-based reference set used extensively in radiological diagnosis is the Greulich and Pyle Atlas [1], unchanged from its initial publication in the early 1950s with data collected entirely from only upper middle class Caucasian populations in the mid west of the US. Due to changes both in population diversity and diet, an updated data collection becomes crucial in improving the bone age assessment process. Recently, work has been completed in our Laboratory in developing a digital hand atlas with images and their corresponding predetermined features that were extracted and stored in a database. The digital hand atlas contains 1080 images for 19 age groups (newborn, 1 – 18) of eight categories (i.e. Caucasian, African-American, Hispanic, and Asian and by gender).

The purpose of this paper is to present a new feature in the digital atlas called Average Image Module (AIM). The AIM uses data mining method in the digital hand atlas and selects an "average" hand image of each category group. The system design, development and implementation, and pilot results are presented in the following sections. The "average" reference image in this digital atlas selected for each of the groups of clinically normal healthy children with a particular skeletal maturity can greatly aid in the bone age assessment process. Keeping such a reference updated and accurate is now within reach by exploiting the PACS (Picture Archiving and Communication System). [4]

2. METHODS AND MATERIALS

Ewa Pietka [2] and Fei Cao [3] have developed a CAD method of bone age assessment. 1,080 normal images were collected from the Childrens Hospital of Los Angeles (CHLA) from boys and girls of European, African, Hispanic and Asian descent and developed an automatic bone age assessment system. The image database for digital hand atlas was built successfully. [7] The feature data of Region of Interest has been extracted by Ewa's group [2,5] and they found that the distance-related features are important in bone assessment. And the weight of each feature was assigned.

Currently, there is no automatic system to data mine for average images in a digital hand atlas. The aim of this paper is to develop an Average Image Module (AIM) to automatically select the best representative image from a group of normal children based on specific bony features that reflect skeletal maturity. These images could provide clinicians with an "average" image to aid in the bone age assessment process.

The AIM is designed using object-oriented methodology to integrate the system with the established digital hand atlas. In this way, should the digital hand atlas and better "averaging" techniques evolve and grow, the system can accommodate these changes in a modular fashion. Most importantly, with an ever-expanding digital hand atlas, such an object-oriented designed system can assure a continuous accrual of the best representation of the "average maturity" of a normal population. The AIM minimizes the overall deviation of the group in bony feature vector space. Euclidean distance in bony feature vector space is calculated and the smallest value between the average image and all other images in the group is used to select the average image. Due to the object-oriented nature of the system, if better averaging techniques are developed, then they can easily be integrated with the system without major changes.

2.1 System Architecture

The AIM (Fig. 1a) is based on the Bone Age Atlas that contains 1080 hand images and the extracted features. The Data Exchange Module works as the interface between database and data mining module. Fig. 1b shows the detail. From N images of each age group, the image A is picked as the average image based on the bony features assigned with a certain weight. Matlab is used to implement the average image algorithm. Then a user-interface was developed to display the images.

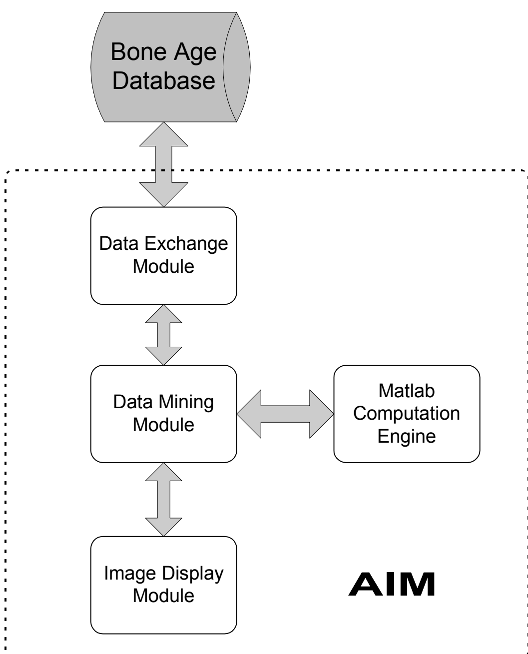


Fig. 1a. Architecture Diagram

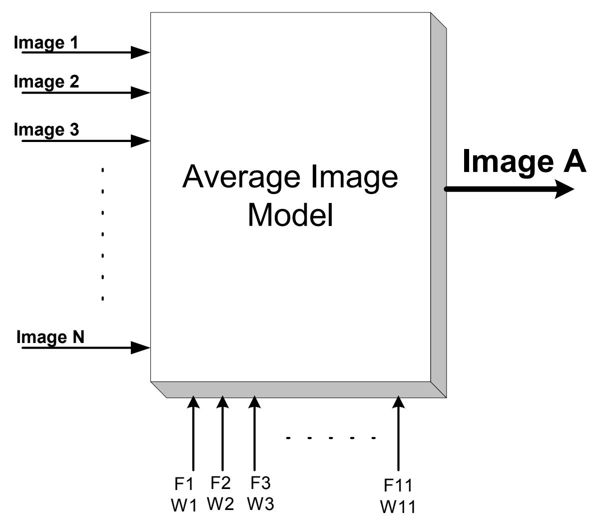


Fig. 1b. Data Mining Module Workflow

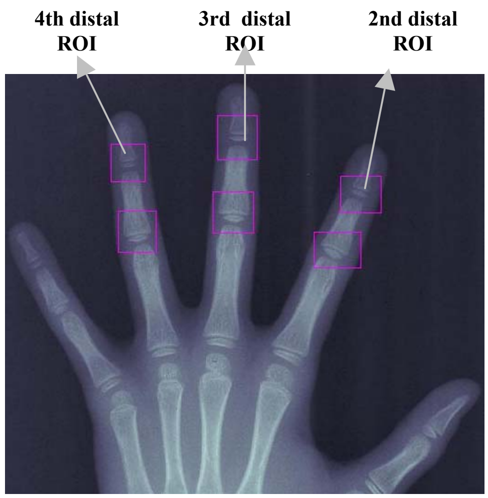
2.2 Data Collection

2.2.1 Bone Images Collection

Fei Cao [3] collected a total of 1,080 normal hand images, 5 images for each group of pre-pubertal children and 10 images for children during puberty from the Childrens Hospital of Los Angeles (CHLA) from boys and girls of European, African, Hispanic and Asian descent.

2.2.2 Bony Feature Extraction

Image processing software has been successfully developed by Ewa's group to segment a hand image and extract its bony features. [2, 5, 6] Image analysis is performed on a left hand wrist radiogram in a standard upright position. At the early stage of skeletal development, the epiphysis is separated from the metaphyses. In the process of development, it changes from a concave disc to a full size and then capping and fusion with the metaphysis. In this phase the features describing the size and shape of epiphysis are of high discrimination power. There are 11 distance-related features extracted (Fig. 2b) from each of the 3 distal ROIs (Region of Interest) of 2nd, 3rd and 4th fingers (Fig. 2a).



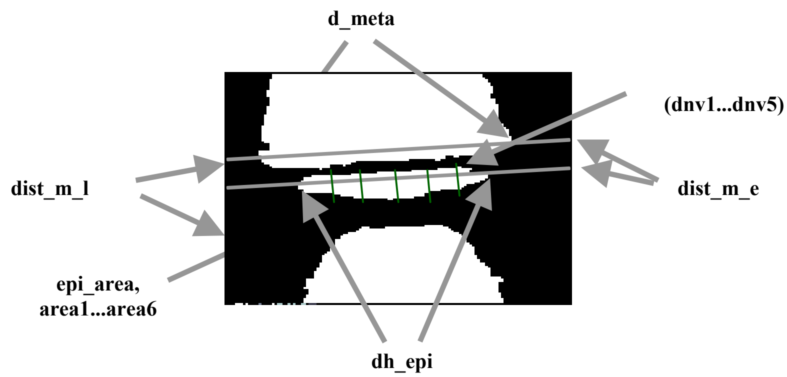


Fig. 2a. Epi/metaphyseal ROIs marked on 3 fingers.

Fig. 2b. Radiological findings superimposed on the thresholded ROI.

Each region is subjected to a procedure, which extracts the radiological findings (as marked in figure above). They serve as a basis for the calculation of features. The set of features contains distance-related features defined as:

$$F1 = \frac{dh\_epi}{d\_meta} \qquad F2 = \frac{d\_meta}{dist\_m\_l} \qquad F3 = \frac{dist\_m\_e}{dh\_epi}$$

$$F10 = \frac{dh\_epi * dist\_m\_e}{dist\_m\_l * d\_meta} \qquad F8 = \frac{dh\_epi * dist\_m\_et}{dist\_m\_l * d\_meta}$$

Area-related features defined as

$$F4 = \frac{area1 + area6}{dnv3 * d\_meta} \qquad F5 = \frac{area3 + area4}{dnv3 * d\_meta}$$

$$F7 = \frac{epi\_area}{dh\_epi * d\_meta} \qquad F6 = \frac{area1 + area6}{(dnv1 + dnv5) * d\_meta}$$

And contrast features defined as

$$F11 = \frac{\bar{\mu}_{bony} - \bar{\mu}_{soft}}{\bar{\mu}_{soft} + \bar{\mu}_{bony}} \bar{\mu}_{bcg} \quad (normalized\ contrast - for\ a\ whole\ region\ of\ interest)$$

$$F9 = \frac{\bar{\mu}_{bony} - \bar{\mu}_{soft}}{\bar{\mu}_{soft} + \bar{\mu}_{bony}} \bar{\mu}_{bcg} \quad (normalized\ contrast - for\ an\ epiphyseal\ sub-region)$$

But due to image quality and algorithm limitation, in some cases features may fail to be extracted automatically. The statistics of the missing features in the database is shown in section 3.

2.3 Least Square Model

2.3.1 Feature Weight Vector *W*

Tanner – Whitehouse (TW) [10] standard compares the horizontal size of epiphysis and metaphysis in almost each stage. From this, we can say TW standard regards the ratio between the epiphyseal and metaphyseal diameters as the most important feature in bone age assessment. And also, Ewa's group found that F1 (ratio between the epiphyseal and metaphyseal diameters) has the highest discrimination power over the other features and F2, F9 and F11 have very low discrimination power. Based on the standard deviation around mean value in each age group, Ewa's group assigned weight vector *W* as [1, 0.25, 0.6, 0.45, 0.45, 0.6, 0.5, 0.6, 0.25, 0.6, 0.3] for feature F1 to F11. It means that more discrimination power the feature has, more weight is assigned. Our average image algorithm described in this paper is based on this weight vector.

2.3.2 Algorithm Workflow

Finding average image per each of the age groups is done by minimizing the distance in bony feature vector space. For an age group that has N images, the following steps are performed:

1. The i^{th} image is chosen as an initial guess for the age group;
2. The square error of *F1* is calculated between each corresponding feature of the i^{th} image and any other image (k^{th}) in the same age group; the equation is shown as (1);

$$E_{i\_k\_F1} = (V_{i\_m\_2d} - V_{k\_m\_2d})^2 + (V_{i\_m\_3d} - V_{k\_m\_3d})^2 + (V_{i\_m\_4d} - V_{k\_m\_4d})^2 \quad (1)$$

   Where $V_{i\_m\_xd}$ stands for value of x^{th} distal ROI of m^{th} feature for i^{th} image shown as Fig. 2. The errors between i^{th} and all the other images are added together into square error of *F1* shown in equation (2);

$$E_{i\_F1} = \sum_{k=1}^{N-1} E_{i\_k\_F1} \quad (2)$$

3. The step 2 is repeated 11 times for all the 11 features, the resulting error vector is:

$$E_i = [E_{i\_F1}, \quad E_{i\_F2}, \quad E_{i\_F3}, \quad ..., \quad E_{i\_F11}] \quad (3)$$

   Then we get the square error for *i*th image as the product of array multiplication of E_i and square of weight vector $W.^2$ shown in equation (4);

$$e_i = E_i.\times W.^2 \quad (4)$$

   where $W.^2 = W.\times W$ and "$.\times$" is the array multiplication as defined in Matlab. [13]

4. The step 1, 2 & 3 are repeated until we go through all the images of the group; So, we get error series $\{e_1, e_2, e_3, ..., e_N\}$;
5. The images are sorted according to the error series $\{e_1, e_2, e_3, ..., e_N\}$; the image that has the minimum error is selected as the first candidate of the average image of the age group.

3. RESULTS

3.1 Image Number Overview

In this study, we use a subset of the image database described in Section 2.2.1. The subset includes all good images described in Table 1. Table 1 is an overview of number of images for both male and female of race African American

(BLKF & BLKM) and Caucasian (CAUF & CAUM). Each image has 3 region of interest (ROI) which are 2nd distal, 3rd distal and 4th distal. And 11 features were extracted from each ROI. But in the image processing procedure, some features weren't correctly extracted due to image quality and image processing procedures. We regard images without missing feature value as good images. To make a rank among the images in the same age group, minimal 3 good images are needed. Out of 52 age groups, there are 33 age groups, which have 3 or more good images.

Distance-related features are only available to the children under 12-14. In older children, the gap between epiphysis and metaphysis undergoes mineralization and becomes radiographically unapparent. Features measuring the size of bones are no longer pertinent at this developmental stage.

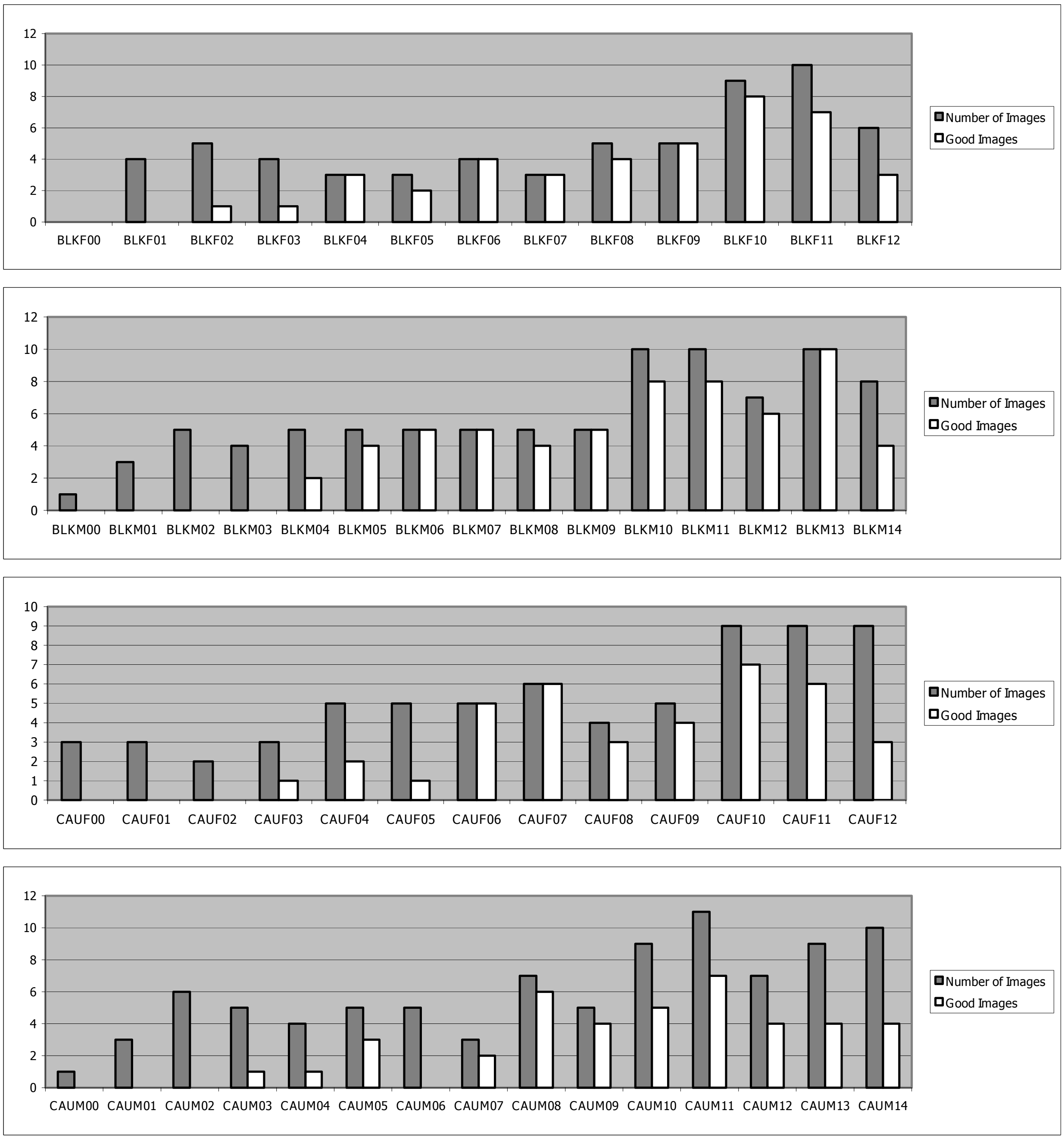


Table 1. The overview of number of images and good images for BLKF, BLKM, CAUF and CAUM.

3.2 Results of Two Age Groups

As an example, here we present average image candidates for two age groups: BLKM13 and CAUF10. BLKM13 stands for group of 13 years old male African American. CAUF10 stands for group of 10 years old female Caucasian American.

1) BLKM13

Candidate No.	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Image No.	3169.img	3170.img	3167.img	3168.img	3176.img	3171.img	3173.img	3172.img	3175.img	3166.img
Chron Age	13.27	13.28	13.2	13.23	13.86	13.35	13.58	13.38	13.82	13.12

Table 2. Ranking Table for Age Group BLKM13. Among the ten images of group BLKM13, 3169.img (Fig. 3a) is selected as the best one of the average image for 13 years old male African American.

2) CAUF10

Candidate No.	1st	2nd	3rd	4th	5th	6th	7th
Image No.	4377.img	4375.img	3289.img	4091.img	4090.img	4378.img	4093.img
Chron Age	10.55	10	10.35	10.43	10.43	10.97	10.49

Table 3. Ranking Table for Age Group CAUF10. 4375.img (Fig. 3b) is selected as the best one of the average image for 10 years old female Caucasian.

Fig. 3a 3169.img

Fig. 3b 4377.img

3.3 User Interface

The user interface was designed, an example is shown for BLKM12. All 10 images are shown as thumb icons (Lower right). The average image is determined and shown in normal size (Left).

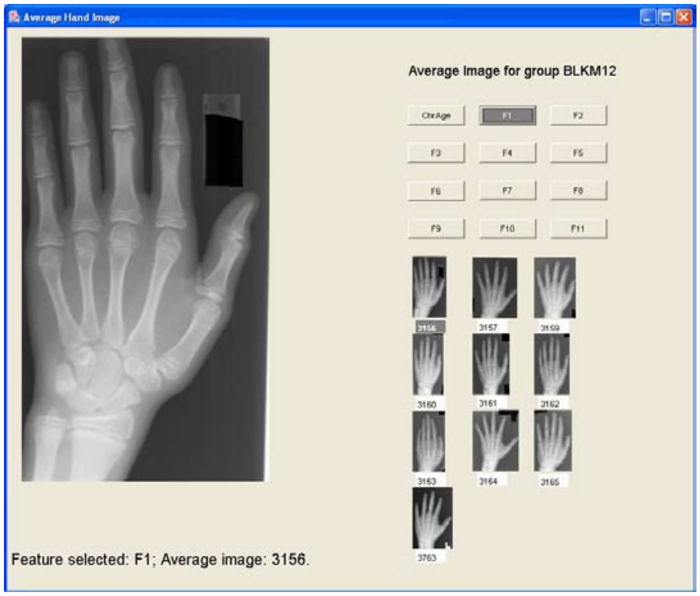


Fig. 4. Sample User Interface Showing the BLKM12 Group

4. DISCUSSION

4.1 Model Interpretation

From table 2 & 3, we can see that image 3169.img with chronological age at 13.27 and 4377.img at 10.55 are selected as the best average images. The ages of both images are close to the medium of chronological ages of all the images in the same group.

4.2 Missing Data Processing

As we can see from the Table 1, we can see that almost half of all the images are missing some features. So, it's very desirable to find some way to deal with the missing data. We are going to adopt interpolation method based on the correlation among the three distal ROIs. In other words, we can fill the feature values of the third ROI using other two available ROIs' values. The preliminary work has begun.

4.3 Wavelet Features

In older children, calculation of features is based on the horizontal component and wavelet angle of the wavelet decomposition. [9] Further work will be done based on wavelet features.

4.4 Validation of Result Images

We will compare our average images atlas with references defined by three existing standards: (1) Year 2000 BMI (body mass index) for children; [11] (2) Tanner Maturity Index; [10] (3) Chronological age vs. Skeletal Age of 1940 Brush Foundation Study. [12]

5. CONCLUSION

Statistical evaluation of our previous work indicates the need for more cases during the fast period of rapid maturation. For this reason, we will collect 400 additional cases in the age group of 5-12, male and female. As future data is added to the digital hand atlas as well as future techniques, this system can also grow to provide clinicians with an "average" image to aid in the bone age assessment process. By the end of this study, there will be a medically accepted standard digital hand atlas ready for use as a reference. Image matching is then a process of finding the minimum distance between an input image and the references in the atlas.

ACKNOWLEDGMENT

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Developing Image-based Electronic Patient Records for Collaborative Medical Applications

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ABSTRACT

We developed a Web-based system to interactively display image-based electronic patient records (EPR) for intranet and Internet collaborative medical applications. The system consists of four major components: EPR DICOM gateway (EPR-GW), Image-based EPR repository server (EPR-Server), Web Server and EPR DICOM viewer (EPR-Viewer). We have successfully used this system two times for the teleconsultation on Severe acute respiratory syndrome (SARS) in Shanghai Xinhua Hospital and Shanghai Infection Hospital. During the consultation, both the physicians in infection control area and the experts outside the control area could interactively study, manipulate and navigate the EPR of the SARS patients to make more precise diagnosis on images with this system assisting. This presentation gave a new approach to create and manage image-based EPR from actual patient records, and also presented a way to use Web technology and DICOM standard to build an open architecture for collaborative medical applications.

Key Words: Images, Electronic Patient Record, Web Technology, Collaborative Applications.

1. INTRODUCTION

During the past years, using PACS diagnostic workstations and Web technologies as a means to access digital image data were being implemented with different architectures. Also, more and more multi-media medical documents or records were used in hospitals and medical community, and these documents usually were stored in different formats or systems. Most medical applications need to access these medical documents through intranet or Internet. Also, there are a lot of collaborative medical applications needing to share or interactively to exchange medical information through the networks. Here, we developed a Web-based system to interactively display image-based electronic patient records (EPR) for intranet and Internet collaborative medical applications.

2. BACKGROUND

Collaborative medical applications were often happened in some medical practices, procedures and education events. For example, local and remote doctors collaboratively discuss cases in telemedicine procedures. Medical students or residents study or learn the cases from medical experts through network. Physicians and experts in different departments or areas in infection control hospital collaborative study patient records to avoid infection exposures. All they need interactively discuss cases, and experts may explain the images with other patient medical examination records combining image manipulation to show the results to remote participants through the network.

For most difficult or complicated cases, the medical record usually contains medical images with other patient records, which come from hospital information system and other clinical information systems. So, building image-based electronic patient record for collaborative medical applications is important to hospitals and medical institutions for their collaborative healthcare activities. In past few years, we have built teleconsultation system with high resolution and large volume medical images for collaborative applications [1], which integrated remote control functionality to enable both expert and referring physicians interactively to manipulate medical images to study cases. Also the dual cursors of the system can synchronize their operation and image processing results to make both participants feel no distance and no misunderstanding between them on studied images. Figure 1 shows the system configuration of the point-to-point teleconsultation developed for collaborative image applications [1].

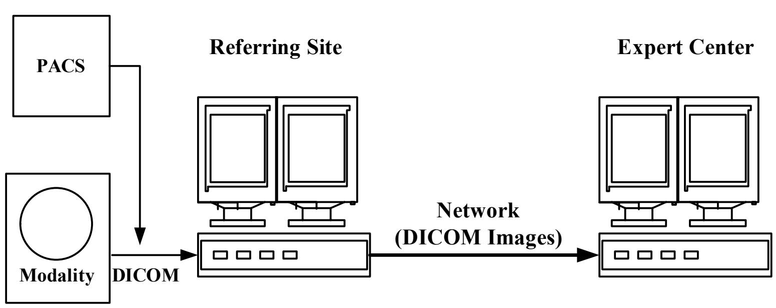

Figure 1. The System configuration of the point-to-point image teleconsultation.

But, there were two drawbacks in this system, first, it only support DICOM image consultation, and could not receive other medical records; Second, the consultation mode was point-to-point, it would re-send images to third party, if other party was interested in or invited into the collaborative applications, this would make collaborative application be more complicated.

So, we designed and developed a new collaborative system, which operated with central mode, and supported image-based EPR for collaborative applications. It can be integrated with PACS and other hospital clinical information systems, and provides Web interface to let users access the image-based EPR either through intranet or Internet for different applications. In the following sections, we will present the design of the system architecture and the implementation of the major components, as well as the data flow and work flow used for collaborative medical applications.

3. SYSTEM ARCHITECTURE OF THE IMAGE-BASED ELECTRONIC PATIENT RECORD FOR COLLABORATIVE APPLICATIONS

3.1 The System Configuration and Components

In our design, the system consists of four major components: EPR DICOM gateway (EPR-GW), Image-based EPR repository server (EPR-Server), EPR Web Server (Web-Server) and EPR DICOM viewer (EPR-Viewer). The EPR-GW is used to convert non-DICOM medical records or documents such as scanned images, XML-based structured reports, stream data, RT treatment plans, and ECG curves to DICOM objects, and send them to the EPR-Server. The EPR-Server stores the EPR in the way of patient oriented management, the Web-Server provides Web interface to let EPR-Viewers communicating with the EPR-Server. The EPR-Viewer, plugged in a Web browser, can display and manipulate EPR with different functions. During networked collaborative applications, the both local and remote users can use the Web browsers plugged-in EPR-Viewer to retrieve the EPR from the EPR-Server through http protocol, display, manipulate and navigate EPRs interactively. The EPR-Viewer has remote control mechanism on both local and remote EPRs to synchronize operations, e.g., image manipulation, report reviewing, playbacks on stream data and waveform curves. Figure 2 shows the system configuration.

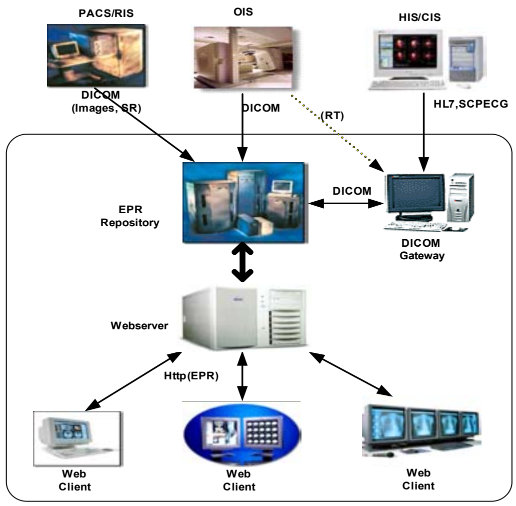

Figure 2. The system configuration of the image-based EPR

3.2 The data model of the image-base electronic patient record

We use the general DICOM information object model as our EPR data model as shown in Figure 3. This is why we give the name of the system: Image-based EPR, since the data model is much similar with that used in general DICOM image management. But, in order to manage other complex medical objects such as used in oncology treatment procedures, our data model also has the extension for radiation therapy (RT) objects defined by DICOM committee. Figure 3 shows the diagram of the data models used in our EPR. The up-left part of the diagram relates to the general medical record management, e.g., DICOM images, reports, and other medical data, the down-right part covers the RT object management.

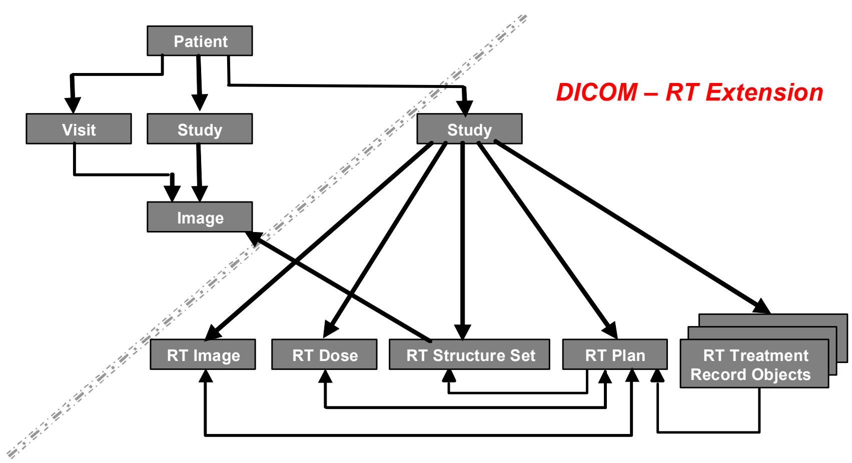

Figure 3. The diagram of the image-based EPR data model

4. THE DATA FLOW AND COLLABORATIVE OPERATION MODE

The data flow of the image-based EPR presented in this paper is shown in Figure 4. There are three steps to play the collaborative applications. First, the medical data, retrieved from hospital PACS and clinical information systems, are sent to the EPR-GW for data formatting if their are not in DICOM format; Second, the image or DICOM based medical data are sent to the EPR Repository Server for archiving; Third, any authorized user or Web Client can access the EPR-Web Server by using the Web browser plugged-in the EPR-Viewer component to get the medical data, and can interactively communicate with an online user to collaborative study or manipulate the data.

4.2 Central Collaborative Operation Mode

Comparing to the point-to-point operation mode mentioned in the second section of this paper, the collaborative operation mode in this image-based EPR system can be looked as a central mode, since any user or a client gets the collaborative data from the central server, EPR Repository Server, and there is only one data sending operation before making them ready to users. Figure 5 gives an example about how the system operating among three participants. First, the medical records or images are sent to the EPR Repository Server from the Clinet 1 by using EPR-GW, then, Client 2 or 3 can get the records or images from the Web Server and manipulate the records interactively with Client 1 or between them. So, the collaborative operation procedures of the system in central mode are much simple and easy comparing to the point-to-point mode.

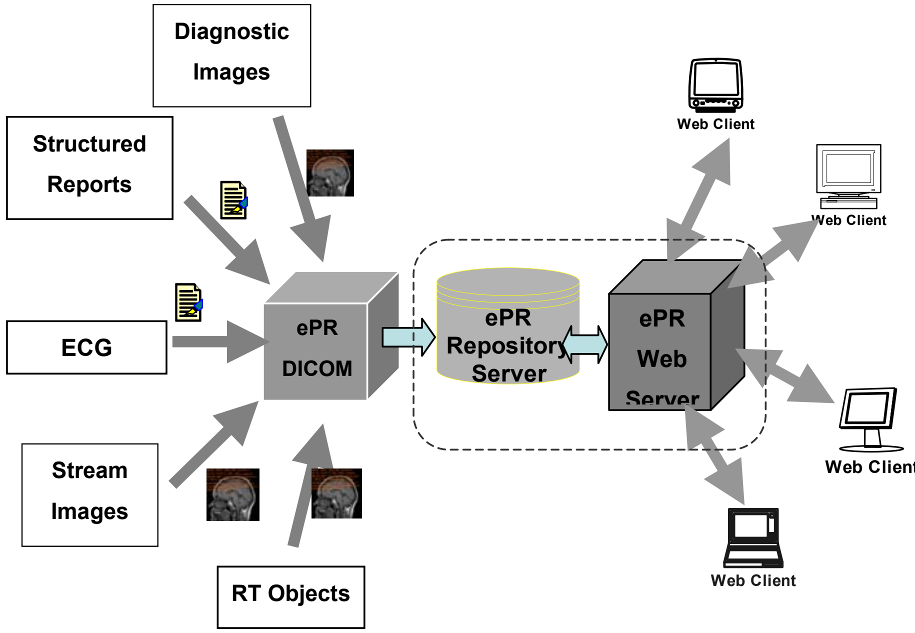

Figure 4. The data flow of the image-based electronic patient record for collaborative applications

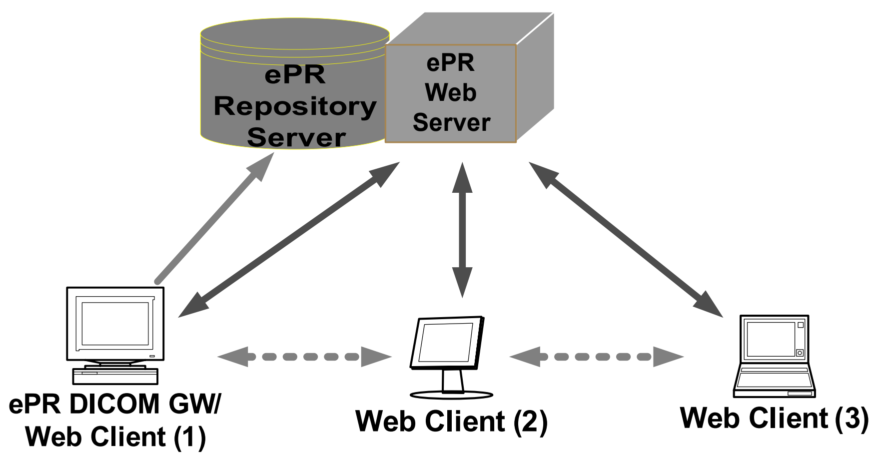

Figure 5. The central collaborative operation mode among three Web clients

5. INTERACTIVE WEB DISPLAY OF THE IMAGE-BASED ELECTRONIC PATIENT RECORD

We have developed a Web-based image processing and display component to display and manipulate the various DICOM images in a Web browser [2]. Since this component has an open and scalable architecture with multi-thread processing capability, it is easy to integrate multi-media display and manipulation modules and functions into this component to display the image-based electronic patient records if they were in DICOM format. Figure 6 shows a EPR GUI of a patient with multiple examination records, e.g., CR, MR, CT, RT and ECG, as well as DSA stream image and DICOM structured report.

We integrated special remote control module in the display and processing component to enable the component have collaborative operation features on the played EPR objects, such image manipulation and processing functions of Window/Level, zoom, overlay, orientation, and measurements. We used dual cursors to let both local and remote users synchronize their operations to understand each other on studied cases. Figure 7 shows the dual cursors pointing same MR images on the displayed EPR GUI, which includes the DSA image, MR image, chest image, ECG curve and structured report.

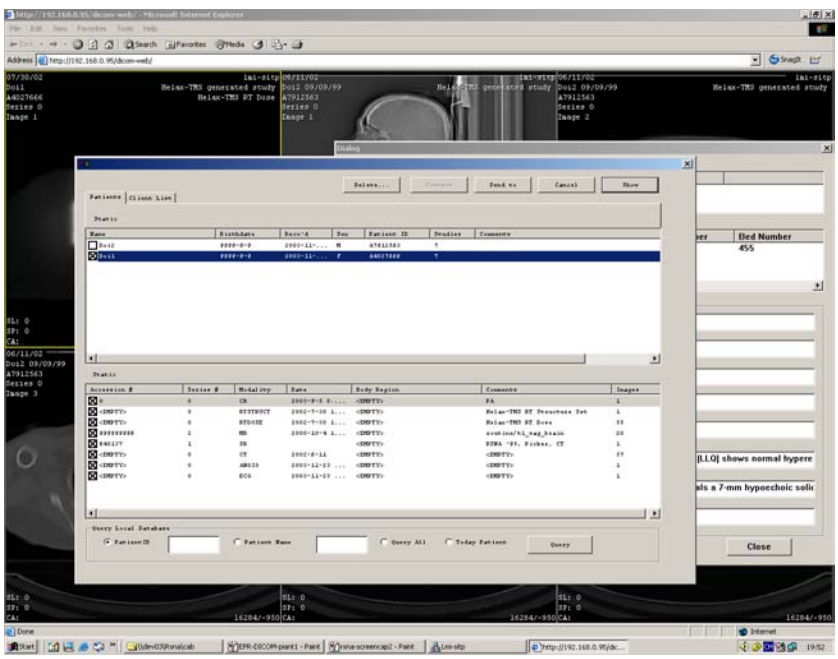

Figure 6. The list of a patient with multiple examination records in a Web client.

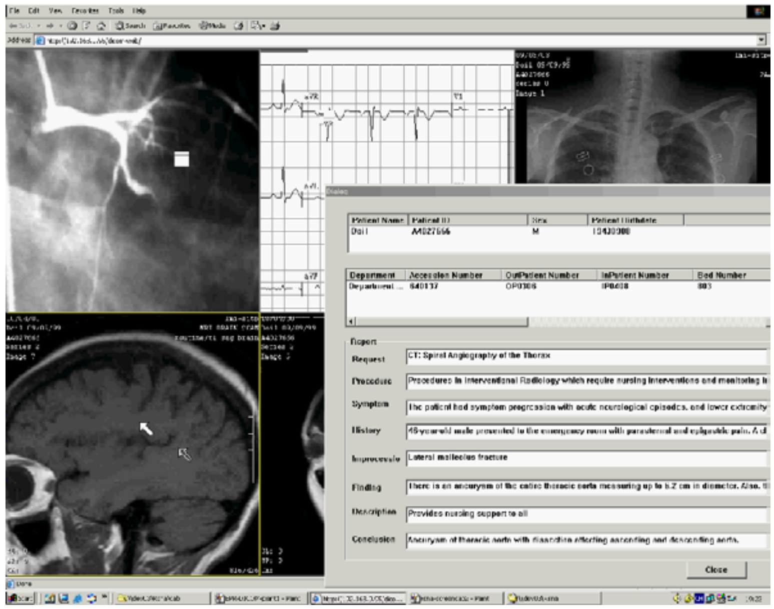

Figure 7. The dual cursors make both local and remote users synchronize their operations on displayed EPR

6. COLLABORATIVE APPLICATION ON SARS DIAGNOSIS

The major advantage of our system is that it can provide collaborative functions for Internet and intranet applications with same configuration if the network speeds are fast enough to down load the images from local area network and wide area network. One of the successful collaborative applications of the developed system was used in SARS teleconsultation in Shanghai Xinhua Hospital and Shanghai Infection Hospital in the May of 2003. Figure 8 shows the network connection of the image-based EPR for SRAS collaborative diagnosis. There were three areas in the SARS hospital: the infection area, in which SRAS patients were stayed and taken cared by clinical SARS physicians; non-infection area, in which the radiologists and other experts of the hospital worked to support the diagnosis and treatment done in infection area; and the data center where the HIS, PACS, CIS and the image-based EPR were located. Also, there was an off-site SARS expert center out side the SARS hospital, where the other hospital experts can provide teleconsultation services to help the SARS hospital on SARS diagnosis and treatments. There were three the EPR clients (Web browser integrated with EPR-Viewer component) installed in the infection and non-infection areas and the remote expert center, and they all can access the SARS patient records from the image-based EPR located in the data center through the LAN and WAN. The clinical SARS physicians, radiologists in the SARS hospital, as well as the experts in expert center can collaborative study the cases instantly and efficiently with the remote interactive functions provided by the EPR. We also equipped video conference kits in three sites to let them face to face talk and see the patient real status during the teleconsultation.

We have successfully used this system two times for the teleconsultation on SARS in Shanghai Xinhua Hospital and Shanghai Infection Hospital. During the consultation, both the physicians in infection control area and the experts outside the infection control area could interactively study, manipulate and navigate the patient records of the SARS patients to make more precise diagnosis on images with this system assisting.

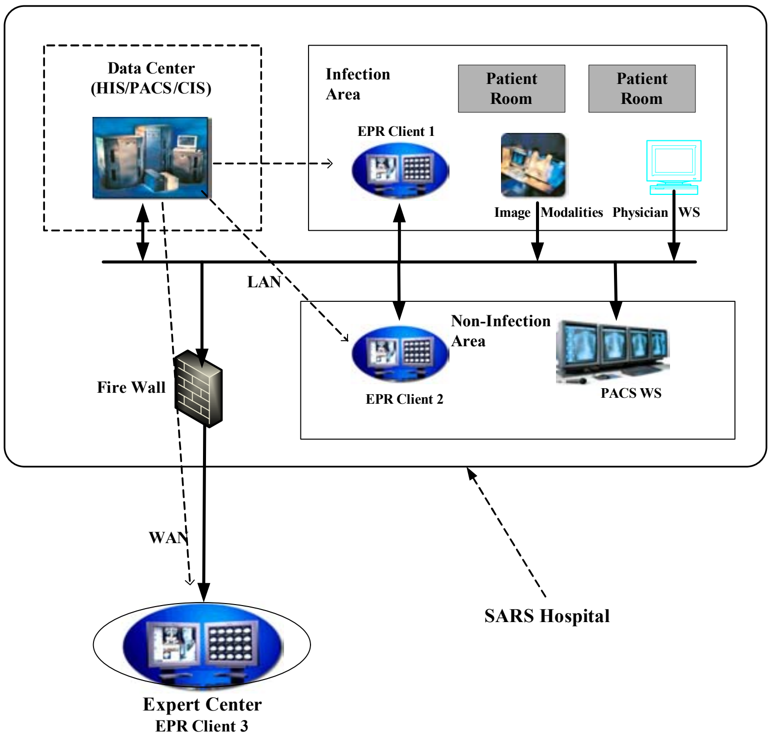

Figure 8. The network connection of the image-based EPR for SARS collaborative consultation.

7. CONCLUSIONS

This paper gave a new approach to create and manage image-based EPR from actual patient records, and also presented a way to use Web technology and DICOM standard to build an EPR with open architecture for collaborative medical applications. New Web-based EPR system provides new method to enhance the value of interactive and collaborative studying on EPR for difficult cases, especially for SARS diagnosis. The on-time interactive communication features of the system on manipulated EPR can improve the efficiency and the quality of collaborative healthcare. The system can be used for both intranet and Internet medical applications such as tele-diagnosis, teleconsultation, and distant learning.

8. ACKNOWLEDGEMENT

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9. REFERENCES

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Developing Interactive Teleradiology System for SARS Diagnosis

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ABSTRACT

Severe acute respiratory syndrome (SARS) is a respiratory illness that had been reported in Asia, North America, and Europe in last spring. Most of the China cases of SARS have occurred by infection in hospitals or among travelers. To protect the physicians, experts and nurses from the SARS during the diagnosis and treatment procedures, the infection control mechanisms were built in SARS hospitals. We built a Web-based interactive teleradiology system to assist the radiologists and physicians both in side and out side control area to make image diagnosis. The system consists of three major components: DICOM gateway (GW), Web-based image repository server (Server), and Web-based DICOM viewer (Viewer). This system was installed and integrated with CR, CT and the hospital information system (HIS) in Shanghai Xinhua hospital to provide image-based ePR functions for SARS consultation between the radiologists, physicians and experts inside and out side control area. The both users inside and out side the control area can use the system to process and manipulate the DICOM images interactively, and the system provide the remote control mechanism to synchronize their operations on images and display.

Keywords: Interactive Teleradiology, SARS diagnosis, PACS

1. INTRODUCTION

Severe acute respiratory syndrome (SARS) is a respiratory illness that has been reported in Asia, North America, and Europe. In general, SARS begins with a high fever (temperature greater than 38.0 C°). After 2 to 7 days, SARS patients may develop a dry cough. Most patients develop pneumonia. During the winter of 2002 through the spring of 2003, World Health Orgnization received reports of >8,000 SARS cases and nearly 800 deaths. The main way that SARS seems to spread is by close person-to-person contact. The virus that causes SARS is thought to be transmitted most readily by respiratory droplets (droplet spread) produced when an infected person coughs or sneezes. Most of the China cases of SARS have occurred by infection in hospitals or among travelers. To protect the physicians, experts and nurses from the SARS during the diagnosis and treatment procedures, the infection control mechanisms were built in SARS hospitals in China, e.g., medical workers in SARS control area could not contact out side people and even medical records could not bring out the control area. In order to make radiologists, physicians and experts both inside and out side control area collaborate efficiently on SARS image diagnosis, we built a hospital-integrated interactive teleradiology system to assist the radiologists and physicians both in side and out side control area to make image diagnosis.

2. SYSTEM TECHNOLOGIES AND ARCHITECTURE

We had built teleconsultation system with high resolution and large volume medical images for collaborative applications[1], which integrated remote control functionality to enable both expert and request interactively to manipulate medical images to study difficult cases. Also the dual cursors of the system can synchronize their operation and image processing results to make both participants feel no distance and no misunderstanding between them on studied images. We also have developed a Web-based PACS image distribution server based on component architecture and used the image display and processing (DP) components to display DICOM images in a Web browser [2].

Since the teleconsultation on SARS diagnosis and treatments may involve more than two sites in infection control mechanism: infection and non-infection areas, and off-site expert center as indicated in the paper [5371-20] of this proceeding, the interactive teleconsultation system developed with point-to-point operation mode could not be used for SARS applications. So, we developed a Web-based interactive teleradiology system for SARS teleconsultation with central operation mode. We used our Web PACS architecture to store and manage the SARS images and other medical records, and the DP component of the Web display with remote control module integrated to display the images and medical records and to synchronize the remote control operations on the images. Figure 1 shows the system architecture, major components and modules in our interactive teleradiology system.

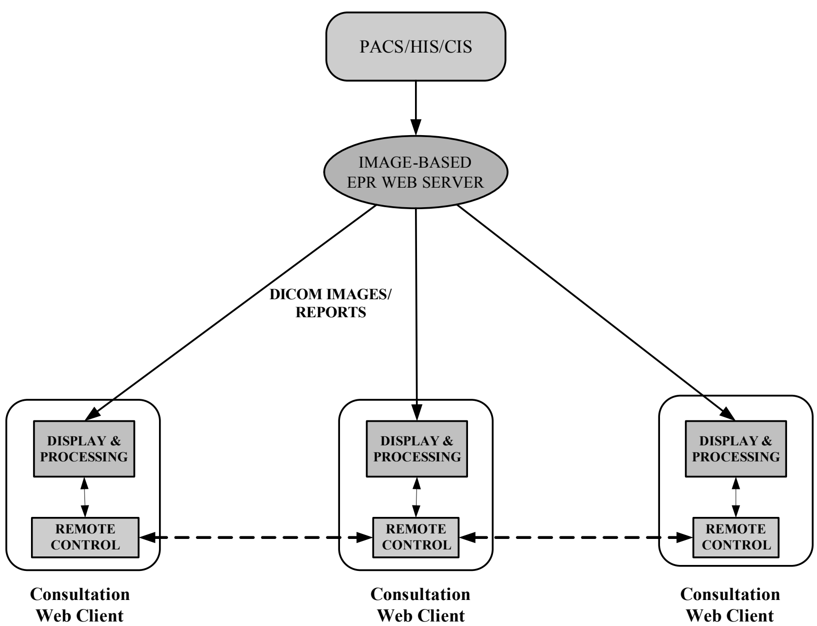

Figure 1. The system architecture and components of the interactive teleradiology.

3. NETWORK CONNECTION AND IMPLEMENTATION FOR SARS TELECONSULTATION

Since there were at least three user clients accessing SARS patient images and medical records during the teleconsulation as indicated in the paper [5371-20] of this proceeding. The activities of the diagnosis, treatments, information technical supporting and consultation for SARS patients were located in different areas of the SARS hospital: the SRAS patients were stayed and taken cared by clinical SARS physicians in the infection area, the radiologists and other experts of the hospital worked together to support the diagnosis and treatment done in non-infection area, and the HIS, PACS, CIS and the image-based EPR were located in the data center, also, there was an off-site SARS expert center out side the SARS hospital, where the other hospital experts could provide on-time teleconsultation services to help the SARS hospital on SARS diagnosis and treatments.

The network connections of these clients with hospital infection and non-infection areas, as well as data center were shown in Figure 2. With the Web architecture and the intranet and Internet connections of the system to different clients located in side and out side hospitals, the real-time teleconsultation with interactive image manipulation can taken place between the infection and non-infection areas, the non-infection and off-site expert center, and even between the infection area and off-site expert center, as indicated by Figure 2.

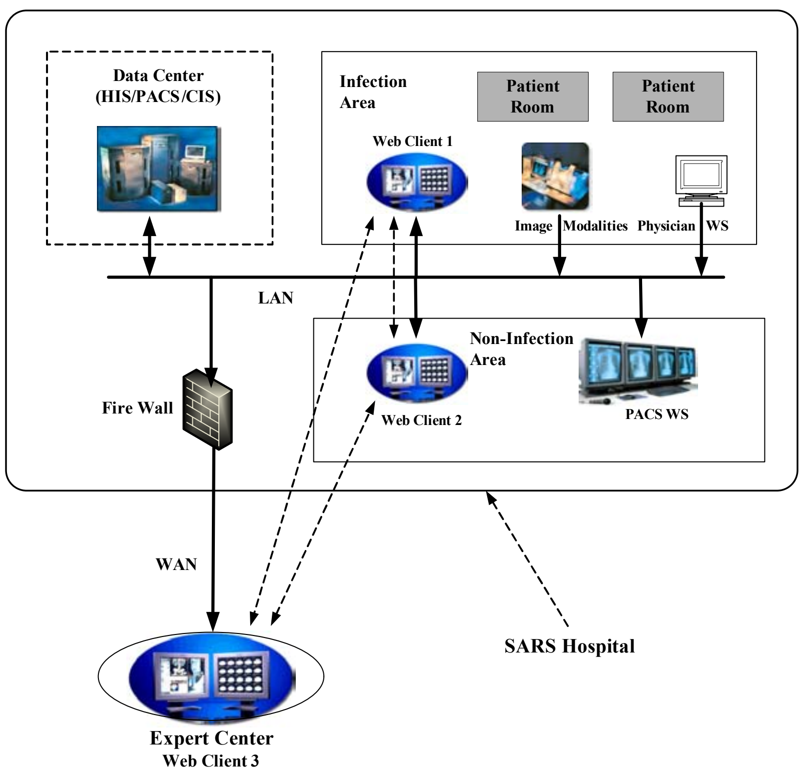

Figure 2. The network connections inside and out side of SARS hospital for SARS teleconsultation.

4. IMAGE ACQUISITION AND TRANSMISSION

Since even the medical records of SARS patients, such as paper record and films, were not allowed to bring out of infection area according to the infection control mechanism, the digital image acquisition and transmission were absolutely demanded in the diagnosis and consultation procedures. Although most images of SARS patients could be gotten from CT and CR modalities, there were still a lot of film images, which were transferred from other hospitals accompanying with patients. We used a laser digitizer (Array 2905, Japan) to digitize these film images and sent the digitized film images together with direct digital images to the hospital mini-PACS for archiving. Figure 3 shows the digitized film images of a SARS patient in the infection area of the Shanghai Infection Hospital. The most film sizes were 14 x17 inch, and the image formats of digitized films were DICOM about 3560x4320x2 bytes (the grayscale was 12 bits). The size of one digitized film images was usually 29.3 Mbytes.

Figure 4. The film images of SARS patients were digitized by a laser digitizer for network delivering.

The image delivering inside SARS hospital was trivial with fast LAN network connection for daily diagnosis and consultation between infection area physicians and non-infection doctors. For the off-site consultation, all patient images had to be transmitted to the expert center, which was located in Shanghai Xinhua Hospital affiliated to the Second Shanghai Medical University, through WAN. The transmission of case images with total number usually exceeding to 10 or 20 film sheets (300-600 Mbytes) had to be done before the teleconsultation session starting. We used two WANs for image transmission, one was ATM network built by Shanghai local healthcare organization, and the other was ADSL owned by Shanghai Telecommunication Corp.. The bandwidth of the AMT site to site was about 10 MByte/sec. For the ADSL, the downloading bandwidth was 2 MByte, and uploading was 1 MByte/sec. Table I and II gives the transmission results of the digitized film images from Shanghai Infection Hospital to Shanghai Xinhua Hospital by using ADSL and ATM respectively.

Table I. Transmission results of the digitized film images from Shanghai Infection Hospital to Shanghai Xinhua Hospital by using ADSL network connection

No.	Image Type	Num. of Images	Total size （MBytes）	Transmission time （mm:ss）	Used Bandwidth （kbps）	Usage of Bandwidth for 1Mbps（%）
1	SC	11	322.3	85:21	515.58	50.35
2	SC	8	234.4	62:32	511.78	49.98
3	SC	10	293.5	78:04	513.31	50.13

Table II. Transmission results of the digitized film images from Shanghai Infection Hospital to Shanghai Xinhua Hospital by using ATM network connection

No.	Image Type	Num. of Images	Total size （MBytes）	Transmission time （mm:ss）	Used Bandwidth （kbps）	Usage of Bandwidth for 10Mbps （%）
1	SC	20	561	14:48	5.08	50.8
2	SC	20	558	14: 35	5.10	51.0
3	SC	15	437	11:23	5.12	51.2
4	SC	11	320	15:03	2.83	28.3

5. INTERACTIVE TELECONSULTATION FOR SARS DIAGNOSIS

Since the diagnosis and treatment procedures were complicated, the physicians, radiologists and experts usually had to review all the medical records of a patient to make final decisions. So, the other clinical information was integrated into the teleradiology system to support EPR-based image diagnosis and consultation. The architecture of the EPR was presented in the paper [5371-20] of this proceeding. Figure 5 shows the GUI of the image-based EPR in a Web-based teleradiology display workstation.

Since the interactive remote control functionality was implemented in the teleradiology system, and both local and remote users can manipulate the images and medical records with dual cursors, as indicated in the righ image of the Figure 5, the clinical SARS physicians can online consult the remote radiologists or experts, located in non-infection area or off-site expert center, with the interactive teleradiology system. Figure 6 shows an expert in the remote expert center, which was located in Xinhua Hospital, talking to the SARS physician about SARS patient images with our teleradiology system, who was working in the infection area of the Shanghai Infection Hospital.

We installed the interactive teleradiology system in Shanghai Infection Hospital and Xinhua Hospital respectively in the May of 2003. The SARS images including chest X-ray and CT were digitized and transferred to the mini-PACS in the Infection Hospital first, and then transmitted to Xinhua Hospital if consultation was required for specific patient. There were 8 SARS patients consulted from the remote expert center, and total 2.73 GB image data were transmitted from the

Infection Hospital to Xinhua Hospital in the consultation activities. During the consultation meeting, the interactive teleradiology system provided bi-directional remote control functionality to both sides on image processing and manipulation and synchronized their operations on the image display, and it could also provided patient other examination reports and medical records to help the remote expert on case analysis and management.

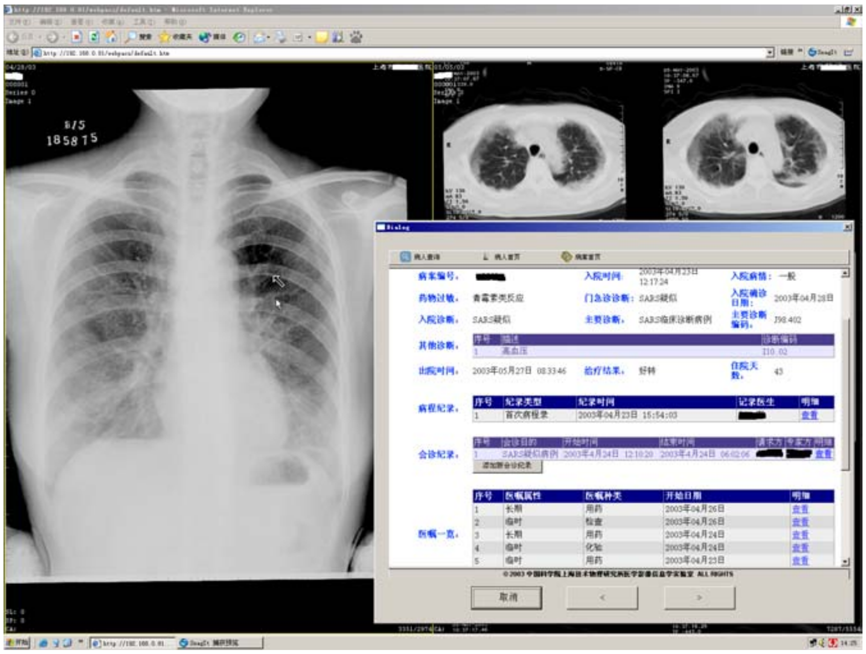

Figure 5. The GUI of the EPR-based teleradiology display workstation with dual cursors

Figure 6. An expert in the off-site expert center talking to the clinical SARS physician located in the infection area of the SARS hospital about a SARS patient images.

The consultation results showed that our interactive teleradiology system has better consultation capabilities comparing to point-to-point teleradiology system in SARS teleconsultation application, and the central mode operation simplifies the consultation procedures on image delivering and display. Also, the architecture and configuration shows that is easier to be used in intranet and Internet collaborative applications.

6. CONCLUSIONS

This presentation gave a new approach to develop a Web-based interactive teleradiology system for radiologists in infection control image diagnosis, and also presented a way to use Web technology and DICOM standard to build an open architecture for collaborative image applications. The new Web-based interactive teleradiology system provides new tool for radiologists, physicians and experts to study interactively and collaboratively on SARS images without SARS infection. The on-time interactive communication features of the system on manipulated images can improve the efficiency and the quality of collaborative diagnosis and consultation. The system can be used for both intranet and Internet infection control image applications such as tele-diagnosis, teleconsultation, and distant learning of infection diseases.

7. ACKNOWLEDGEMENT

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A RIS/PACS Simulator with Web-based Image Distribution and Display System for Education

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ABSTRACT

As PACS and related imaging technologies become more common in the healthcare setting, better methods are needed for training radiologists, allied healthcare providers and IT personnel to understand and use them effectively. We presented an educational PACS Simulator in 2002 and a RIS integrated PACS Simulator in 2003. In this presentation we integrate a web-based image distribution and display system with the Simulator to complete the simulation of clinical PACS workflow. The Simulator consists of RIS Simulator, modality Simulator, DICOM gateway, PACS controller, clinical viewing workstations, PACS monitor system and a web server. The addition web server distributes images to browser-based display clients for display and manipulation using web technology. Using this Simulator, trainees can:

1. Observe clinical RIS/PACS operation with web image distribution, component by component,
2. Trace image data flow through each component,
3. Query, retrieve and review images at web display clients,
4. Induce failure in a component to observe its impact on the entire RIS/PACS operation.

The Simulator has been developed as a stand-alone tool for trainees to understand RIS/PACS concept and appreciate RIS/PACS workflow with hands-on experience. The core Simulator has been applied in many training classes, and the addition of web server will significantly improve its training value.

Key words: RIS, PACS Training, DICOM, Simulator, Web distribution, Web Display

1. INTRODUCTION

A picture archiving and communication system (PACS) [1] is a medical imaging management system widely used in the healthcare enterprise now. It is a system integration of various imaging modalities (such as CT, CR, MR, and US), and storage and display subsystems connected by digital networks. The workflow of PACS is completely different than the modality workflow radiologists are used to. Therefore, to learn and master how to use and manage PACS becomes an important process for radiologists and other healthcare providers. Many educational courses have been designed for training radiologists and physicians in learning PACS concepts or how to operate PACS workstations, such as, online PACS training offered by the vendors [2] and the refresher courses offered at the RSNA (Radiological Society of North America) annual meeting. However, these courses are either in text format or focus only on the end-user workstations, from which trainees cannot learn the workflow of PACS with hands-on experience. Some other trainings in the clinical environment [3] do offer PACS workflow training and analysis. However, these courses are designed only for system engineers or PACS administrators. Besides, it is difficult to use a clinical PACS to offer such a training course, because PACS is in a 24/7 operation. There is yet a tool available for training of PACS concept and workflow analysis for most of healthcare and IT personnel. Therefore, to develop a stand-alone educational PACS Simulator, without interrupting the workflow of clinical PACS, becomes relevant.

We have developed a stand-alone educational RIS (Radiology Information System)/PACS Simulator for this purpose during last three years [4][5]. The RIS/PACS Simulator consists of six key components: RIS Simulator, acquisition modality Simulator (AMS), DICOM gateway, PACS server (UNIX-based), clinical viewing workstations, and a monitoring system connected by a 100 Mbits/sec local area network (LAN). A generic DICOM compliant PACS software package and a RIS are running on these components to simulate a typical clinical RIS/PACS workflow. The AMS is connected to a clinical PACS and contains thousands of CT, MR, US, CR, and digitized film examinations. These images are replenished continuously through the clinical PACS connection with patient name and ID removed. The images are pushed to DICOM gateway from the AMS, and automatically forwarded from the DICOM gateway to the PACS server for archive, and distributed to workstations for review. This paper adds a Web-based distribution and display system to the above Simulator to complete the clinical PACS workflow. Because of its low cost and wide availability, Web technology and Web server has become a new way in clinical PACS to distribute the image exams to common viewing and other application workstations during the last several years. A generic Web server simulating the clinical PACS Web server is connected to the above PACS server and the images are automatically pushed from the PACS server to the Web server. A Web client uses a Web browser (e.g., Internet Explorer) to query/retrieve the images from the Web server, and display and manipulate the images at the Web browser.

This Simulator has been used in many training classes. This paper discusses a few successful examples. In addition, the Simulator, as a standalone system, is also used as a test bed for evaluation of medical imaging applications at Image Processing & Informatics (IPI) laboratory, e.g., ASP off-site backup archive [6] and Medical Imaging Security [7] application. Therefore, we have successfully developed a standalone RIS/PACS Simulator for education and testing.

2. SYSTEM DESIGN AND IMPLEMENTATION

The system design concept of RIS/PACS Simulator with a Web-based image distribution and display system is to have separate components to simulate the function of modalities, DICOM gateway or workstations, PACS archive server, clinical viewing workstations and Web server and Web display client in a clinical PACS. Therefore, the workflow of clinical RIS/PACS can be simulated in this Simulator. As shown in Figure 1, the typical workflow of clinical RIS/PACS is:

1. Patients come to radiology front desk for registration and exam ordering through a RIS. RIS sends patient demographic information and exam information through a RIS/PACS interface to Modalities, e.g. CT modality here. Because RIS uses HL7 standard and PACS uses DICOM standard, a RIS/PACS interface is used here to perform a format conversion.
2. These information forms a work list at CT modality. CT modality performs a scanning based on the work list, and generates an image exam.
3. CT modality sends the exam to the Workstations, or DICOM gateway.
4. The Workstations automatically forwards the exam to PACS archive server for archiving. The Workstations can also query/retrieve the previous exams from the PACS archive server for review.
5. The physician reviews the exams, creates a Diagnostic report, and sends the report back to RIS through the RIS/PACS interface.
6. PACS archive server distributes the exams to a Web Server either by automatically push or through manually query/retrieve from the Web Server.
7. The Web Client query/retrieve exams from Web Server, and display and manipulate the images at web browser.

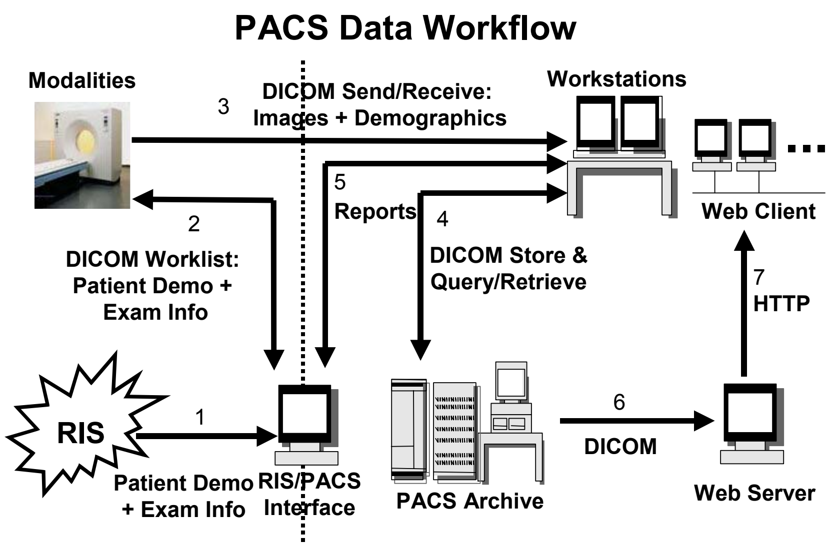

Figure 1. An example of clinical PACS data workflow

To simulate above clinical RIS/PACS workflow, a design criteria of the Simulator is set as follows:

1) Follow DICOM standard and IHE integration profiles.
2) Simulate the above key components (such as modality and DICOM gateway) in separate machines running independent software so that trainees can easily observe and understand the function and workflow of the components.
3) Make each software component configurable so that trainees can have hands-on experience in the Simulator and do some troubleshooting as well.
4) Make the Simulator standalone so that it will not interrupt the clinical workflow.

Based on the design criteria, the RIS/PACS is designed to consist of following components: RIS Simulator, acquisition modality Simulator (AMS), DICOM gateway, PACS controller (UNIX-based), a clinical viewing workstation, a PACS monitoring system, a Web Server and a Web display client. All these components is connected by a 100 Mbit/sec LAN. Figure 2 shows the system and workflow design of the RIS/PACS Simulator with a web-based distribution and display system.

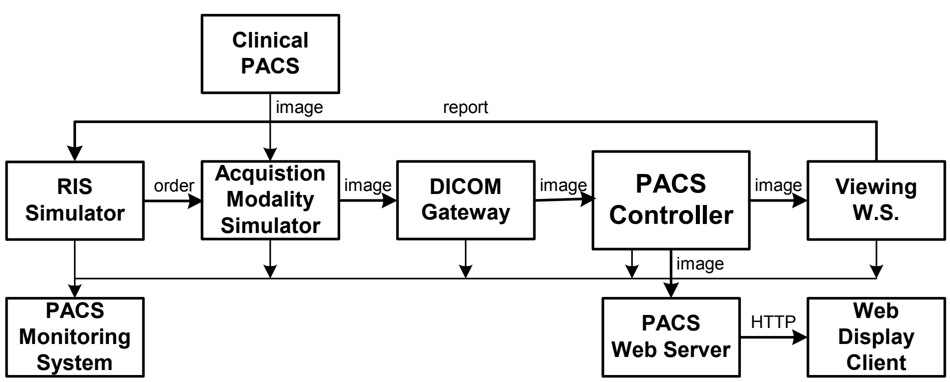

Figure 2. The system and workflow design of RIS/PACS Simulator

All the components in this Simulator are implemented by software program running on PCs and UNIX machines. The AMS is connected to a clinical PACS, from where the clinical exams are continuously fed into the AMS. The patient information in the header of these DICOM exams is scrambled and the pseudo patient information from the RIS Simulator is put into the DICOM header. These exams are then used as the simulated exams in the Simulator.

2.1 Radiology information system (RIS) Simulator

A generic RIS manages radiology patient demographical information and patient registration, examination order scheduling, and diagnostic reporting. RIS is usually a client-server system and has workstations at the radiology front desk.

We developed a web-based generic RIS software to simulate the functions and workflow of a clinical RIS. This Simulator runs in a PC with Windows system and requires a Web browser (e.g. Internet Explorer) to run the user interface. Trainees can perform patient registration, exam order scheduling, historical report query/retrieve, diagnostic report input, and workflow management through the interface of the RIS Simulator. Figure 3 shows an example of a patient registration at the RIS Simulator.

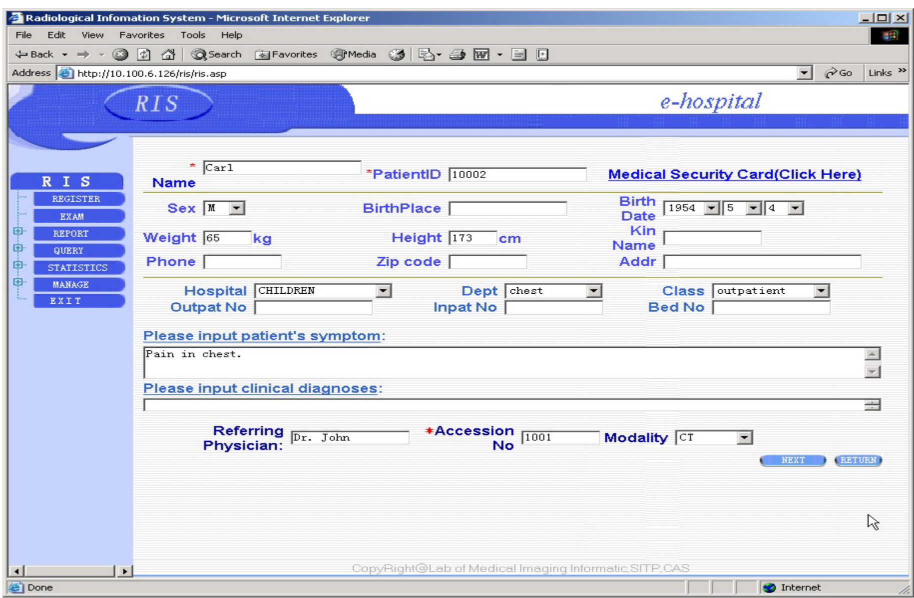

Figure 3. An example of patient registration at the RIS Simulator.

2.2 Acquisition modality Simulator (AMS)

AMS is developed to simulate the workflow of exam generation at the clinical modalities (e.g., CT, MR, CR and US). AMS is connected to a clinical PACS and contains thousands of CT, MR, US, CR, and digitized films examinations in its local hard disk. The images are replenished continuously through the clinical PACS connection and the patient information in their DICOM header are scrambled. AMS gets the simulated work list from the RIS Simulator (Figure 4) and randomly selects the exams based on the exam order information, and then adds the pseudo patient information to the header of the exams to simulate the exam generation. For example, AMS can select several CT exams of Chest from the replenished clinical exams if the exam order is a CT chest scan, and add the pseudo patient information to replace the original information in the DICOM header. After exams are simulated, AMS sends the exams to the DICOM gateway. Trainees observe the workflow in the AMS and understand the clinical workflow at various types of modalities without interrupting the clinical modality operation. Trainees can also perform the AMS configuration through the user interface and induce some failure to observe the impact in PACS workflow.

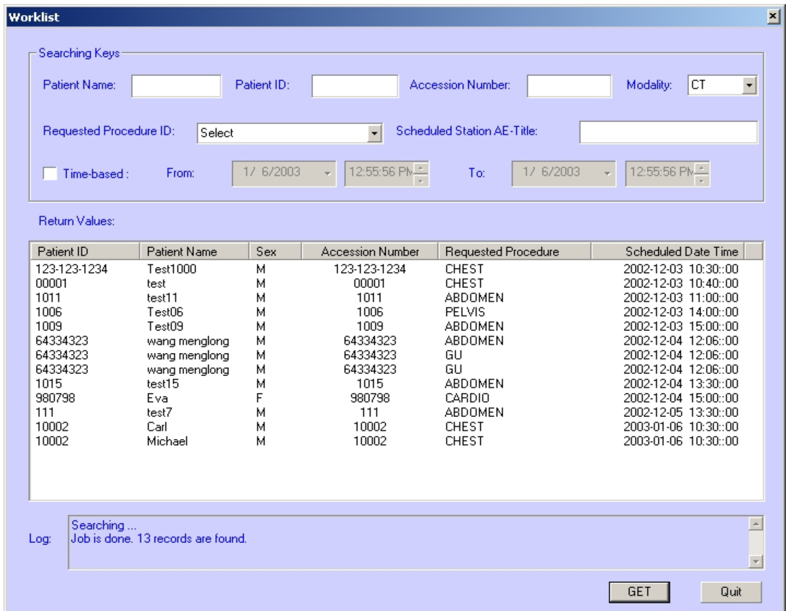

Figure 4. An example of the simulated work list at AMS.

2.3 DICOM gateway

A DICOM gateway performs two functions in clinical PACS: First, it receives images from different imaging modalities and takes care of various types of image format. There are some legacy modalities in the hospital without DICOM output. DIÇOM gateway has to receive these exams and convert them to DICOM format. Even for the modalities with DICOM output, they might be different because of different conformance from different vendors. The DICOM gateway must communicate with all these different modalities and re-format them to a standard DICOM format that the PACS archive server supports. Second, it performs quality control (QC) in PACS. It assures the format and pixel of the exams is good for archive and review. DICOM gateway has a software process running in the background that it can automatically send the exams to PACS archive server.

We developed DICOM gateway software in the Simulator that can receive most of the DICOM compliant modality exams and also some non-DICOM format, like JPEG and Tiff. It can also reformat the non-DICOM compliant modality exams to standard DICOM format. The software runs in Windows system and has a user interface for configuration and management. The DICOM gateway receives a DICOM exam from AMS and automatically sends the exam to the PACS archive server for archiving. Trainees can observe this image flow through the user interface, and manually induce failures to the DICOM gateway to observe its impact on the PACS workflow.

2.4 PACS controller

The PACS controller, or PACS archive server, is the engine of the clinical PACS [1]. It receives various modality types of DICOM exams and archives them in short-term and long-term archiving devices. It also distributes exams to the viewing workstations by automatic push or manual query/retrieve.

We developed a generic UNIX-based PACS controller software in the Simulator that supports the DICOM Storage and Query/Retrieve functions. It receives exams from the DICOM gateway and stores them in the local hard disk. It also automatically sends the exams to the viewing workstations based on a simple routing mechanism. Trainees at the viewing workstation can query/retrieve exams from the PACS controller too. Because of the importance and complexity of the PACS controller, most of the PACS training courses only provide training of the PACS controller to PACS administrators or system engineers only. We provide a standalone PACS controller for trainees to observe its workflow and do configuration and setup as well as troubleshooting.

2.5 Clinical viewing workstation

The viewing workstation is the place where the exams are reviewed and diagnostic reports are created. It receives exams either automatically, or on-demand through query/retrieval from the PACS controller. After the image is reviewed, radiologists dictate the diagnostic report and send it back to RIS. There are two types of viewing workstation: clinical diagnostic workstation and common viewing workstation. The common viewing workstation is for referring physician or other physicians to review and it usually runs in a desktop with a regular display monitor. The common viewing workstation can also be a web display client running on a web browser. The clinical diagnostic workstation needs very high-resolution dual monitors for diagnosis.

We used a dual 2K×2K digital flat panel (FP) display system [8] in the Simulator for the clinical viewing workstation with user-friendly viewing software [9], additional workstations can be added in the PACS Simulator. Figure 5 is a screen shot of CR chest image in the viewing workstation. Trainees can query/retrieve images from PACS controller through the viewing software and view the images.

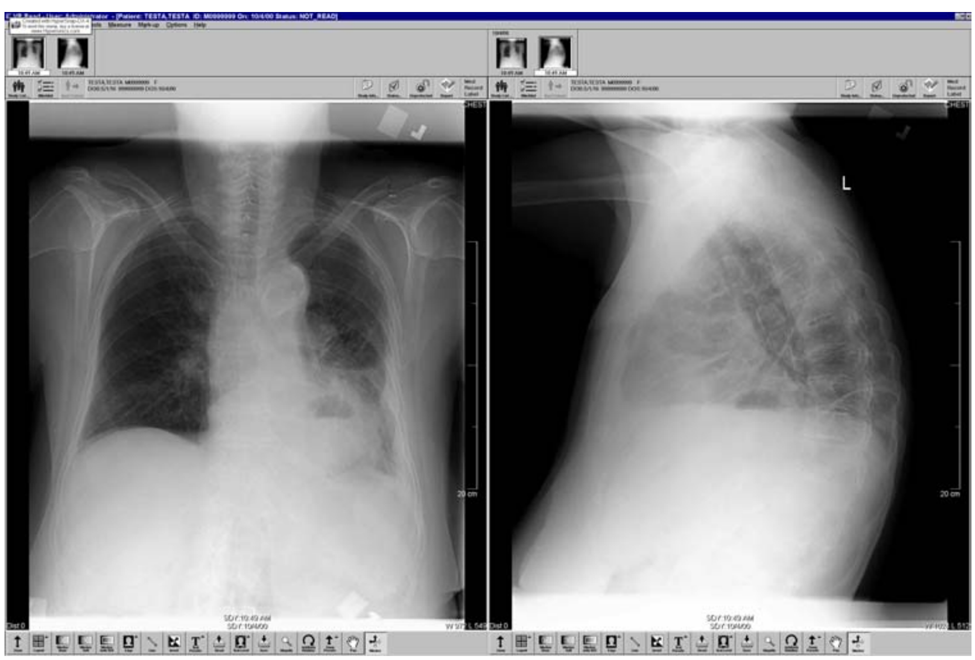

Figure 5. A Chest X-ray exams at the viewing workstation.

2.6 PACS Monitoring System

PACS monitoring system is a unique feature in the RIS/PACS Simulator. It is a software package developed to monitor all the workflow going through each component of the Simulator. It logs the image transaction in PACS and displays the logs in a user interface so that the trainees or PACS administrators can easily observe the system workflow and trace every exam transaction in each component.

2.7 Web server and web display client

Because of its low cost distribution and wide availability, Web server and Web display are extensively used in clinical PACS recently. Using HTTP (Hypertext Transfer Protocol) and TCP/IP (Transmission Control Protocol/Internet Protocol), Web server can easily distribute the image to a display client within Intranet or through Internet. The client can be any computer running with any operating system, as long as it has a web browser. Comparing to the viewing workstation running DICOM viewing software, the cost of web browser is much lower. Because HTTP supports multiple image formats and multimedia, it is very flexible to send exams in different type of quality and size based on the network condition. However, because the Web server uses image compression, the quality of the images may not be good enough for clinical diagnosis. There are different ways to integrate the Web server and display system with PACS together now. A typical architecture of Web-based PACS distribution and display system is shown in Figure 6 [10].

1. PACS archive server automatically pushes the new coming DICOM images to Web Server through a DICOM C-Store Service.
2. Web Server stores the received images in its local hard disk and converts the DICOM images to JPEG images or other common type image formats.
3. The JPEG images are then ready to distribute to the web clients (browsers) for display through a HTTP protocol.
4. Web clients can also send a query/retrieve request to Web Server in a HTTP protocol.
5. In this case, the web server translates these HTTP request to a DICOM Query/Retrieve request and sends it to PACS archive server.
6. PACS archive server sends the retrieval exams to the web server.
7. The exams are converted to JPEG format, and ready for browse by the web client.

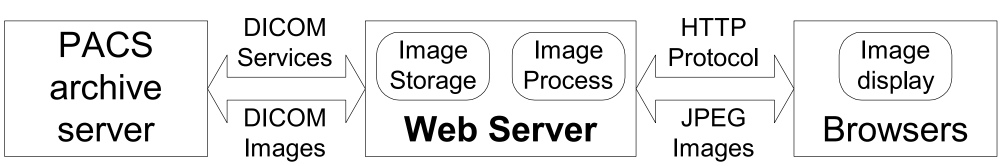

Figure 6. A typical architecture of web-based PACS image distribution and display.

We used a generic web distribution and display system, Stentor web system [11], to integrate with the RIS/PACS Simulator. After receiving the new image exams, the PACS controller automatically pushed the exams to the web server. The Web client then uses the web browser (e.g. Internet Explorer) to query/retrieve the images from Web server and display the images. Figure 7 is an example of MR images displayed at the web browser in the Simulator.

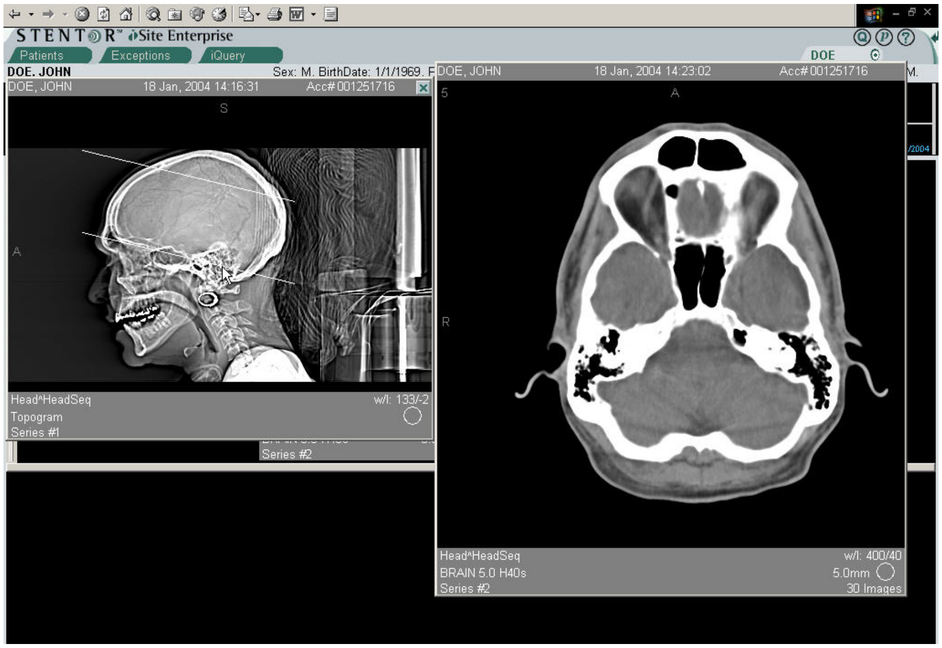

Figure 7. An example of MRI images at the Web browser.

3. RESULTS AND DISCUSSION

3.1 Examples of training classes using RIS/PACS Simulator

The RIS/PACS Simulator has been successfully installed in two sites (IPI and Hong Kong Polytechnic University), and been used in different types of training courses. Following are a few examples:

3.1.1 PACS training workshop at IPI Laboratory, USC

The training workshop was offered to a group of trainees from Hong Kong on May 6-19, 2002. The workshop included the lectures and tutorials on concept and workflow of PACS, and a hands-on workshop using the RIS/PACS Simulator as well as a clinical site visits. During the hands-on workshop, the trainees were asked to do software configuration and troubleshooting at the Simulator components. The course evaluation from the trainees was very good.

3.1.2 PACS training programs in the Hong Kong Polytechnic University [12]

The same RIS/PACS Simulator has been setup in the Department of Optometry and Radiography, Hong Kong Polytechnic University. The Simulator has been used as a training tool for the undergraduate and postgraduate programs. The trainees were asked to have a hands-on workshop and laboratory study in the Simulator. The workshops and courses have been found to be useful to help trainees understand the concept and workflow of PACS and related their learning to their clinical situation.

3.1.3 Imaging Informatics Program at the Biomedical Engineering Department, USC

A new Master of Science Program, Medical Imaging & Imaging Informatics, is initiated at Biomedical Engineering Department, USC this year. Leading to a Ph.D. degree, this program aims to prepare students for further graduate training or professional career in Biomedical imaging & image processing, and medical imaging informatics (including PACS). Two of its core courses, BME 527 and 528 use the RIS/PACS Simulator as the training tool in the class.

3.1.4 A PACS course at the College of Medicine, Chang Gung University, Taiwan

College of Medicine, Chang Gung University, Taiwan is going to open a new PACS course and is in the process of installing the same RIS/PACS Simulator in the College this year. The Simulator is going to be used as a training tool for students to learn PACS with hands-on experience.

The feedbacks from these courses have been very good. Trainees do feel this is a good tool that helps them to learn the concept and workflow of PACS and to get the hands-on experience for their daily clinical work.

3.2 A test bed for medical imaging applications

Medical imaging application needs to be evaluated in clinical PACS environment before it is applied in clinical settings. However, clinical PACS has to be in 24/7 duty and is very difficult to schedule time for such an evaluation. A standalone PACS Simulator is a good solution to this problem, since it will not interrupt the clinical workflow. We have successfully performed laboratory evaluations for two medical imaging applications: ASP off-site PACS backup archive and medical imaging security.

3.2.1 ASP off-site PACS backup archive [6]

ASP (Application Service Provider) off-site PACS backup archive provides storage of a clinical PACS data at a secondary site and recovers this PACS data to the clinical PACS in the event of a disaster. The data flow of ASP is: the clinical images are automatically sent from clinical PACS server to a DICOM gateway or workstation. The DICOM gateway also sends the data to a backup archive PACS server at a remote site through the wide area network (WAN) for remote off-site backup. The backup data can be fed back to clinical PACS through the network or a data migrator in the event of a disaster.

The RIS/PACS Simulator was applied to evaluate the data flow of ASP. Using the Simulator, we simply replaced the AMS in RIS/PACS Simulator with the Clinical PACS Server, moved the DICOM gateway to remote site, and connected the DICOM gateway to the local PACS controller through T1 connection. Here the PACS controller acts as a backup archive PACS server for the ASP application. Figure 8 shows the laboratory evaluation of the workflow of ASP application. Since all components and the image data are DICOM compliant, there is no need to change any software. This evaluation has been successfully performed for one year between St. John healthcare center, Santa Monica, CA and IPI laboratory, USC. The ASP off-site backup archive is going to be put in clinical usage this year.

Figure 8. Evaluation of the workflow of ASP off-site backup application

3.2.2 Medical imaging security – Digital Signature Embedding (DSE) method for protecting data integrity of medical images [7][13]

As medical imaging becomes digital, the security issue of medical images becomes very important. All the security problems that digital information faces will happen to medical images too. Security includes privacy, authenticity and data integrity. Data integrity refers to the data has not been compromised since its acquisition. Conventional security methods, such as firewall and user password, are not sufficient to protect the data integrity of the medical image data. We have developed a digital signature embedding (DSE) method to assure image data integrity during its transmission through public networks and in storage. Since digital signature (an encryption of the hash value of the image) can detect the change of any single pixel of the image, this method can assure that the data has not been compromised. The workflow of DSE method for image transmission [7] is: the *sender* embeds the digital signature of the image into the image and sends the embedded image to the *receiver*. The *receiver* then extracts the digital signature, computes the digital signature of the received image again, and compares these two signatures to verify whether the data has been changed.

The RIS/PACS Simulator was applied to evaluate this workflow in laboratory. As shown in Figure 9, the DICOM gateway was selected as the *sender,* and the PACS controller as the *receiver*. The DSE software was installed in these two components to perform digital signature embedding and extraction as well as verification. After receiving the image from AMS, DICOM gateway embeds the digital signature to the image and sends the embedded image to PACS controller. PACS controller then extracts the embedded digital signature from the received image, and verifies the signature.

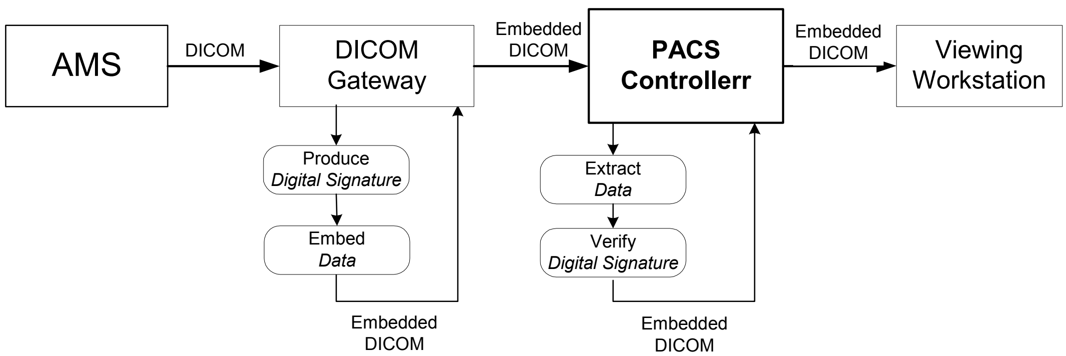

Figure 9. Laboratory evaluation of the imaging security method by using the RIS/PACS Simulator

From these two clinical application evaluations, we believe the Simulator is a very good test bed for the laboratory evaluation of medical image applications. Since the workflow of the Simulator is almost identical to the clinical PACS workflow, it would save the implementation time if the evaluation has been performed in the laboratory first. This is very important to the clinical PACS, because any new applications can be tested first at the Simulator without interfering with the 24/7 clinical PACS operation.

CONCLUSION

In summary, we have successfully developed a RIS/PACS Simulator with a web-based distribution and display system as a training tool for radiologists, new PACS administrators, other healthcare and IT providers. The Simulator provides trainees an excellent environment to learn and understand the concept and workflow of PACS with hands-on experience. It has been successfully applied in many training courses. It also has been successfully applied to the laboratory evaluation of several medical imaging applications.

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