IMAGE PROCESSING AND INFORMATICS LABORATORY

Department of Radiology
University of Southern California

2006 Annual Report

SUMMARY

Major emphases of the Image Processing and Informatics Laboratory (IPI) during year 2005 were in education, International liaisons, cultivation of new research directions, and industrial collaboration. Some of the accomplishments are detailed:

1. Education

We received a five year T32 Training Grant from the National Institute of Biomedical Imaging and Bioengineering (NIBIB), National Institutes of Health (NIH), DHHS entitled: "Biomedical Imaging Informatics Training Program" effective September, 1, 2005 – August 31, 2010, totaling about US$1.6 million. The PI and Co-PI are Dr. H.K. Huang of Radiology and Dr. Michael Khoo of BME, respectively. The program considers candidates from the following four categories of applicants: USC Radiology residents and fellows, USC Biomedical Engineering Ph.D. students, USC MD/PhD Program students, and Post Doctoral fellows from other institutions. The available positions are: (Post Doctoral, Pre Doctoral) (2,2), (3,3), (3,3), (3,3), (3,3) for each year, respectively. Annual stipend and partial tuition/fees are provided for the successful candidate.

For the second year in a row, we were awarded the USC Summer Undergraduate Research Award for two undergraduate students to perform research. In addition, we participated for the first time in the USC BME Summer Internship Program to foster research training among BME undergraduate students across the country and received an additional BME undergraduate student who interned with IPI. This helps to foster future potential candidates interested in entering Medical Imaging and Informatics Training in the BME Graduate Program.

Milestones for our staff members: Zheng Zhou received his Ph.D. degree from the BME Department, and has continued as a Post-Doc fellow at IPI. Aifeng Zhang passed her BME Ph.D. qualifying exam and became a BME Ph.D. candidate. Tao Chan, M.D. and Heston Kwong, M.D. both passed their Ph.D. candidate confirmation exams in Medical Imaging Informatics at the Hong Kong Polytechnic University.

2. International Liaisons

The following three professors from Germany, Hong Kong, and Brazil have joined IPI: 1) Heinz U. Lemke, Professor, Technical University Berlin as a Visiting Professor of Radiology; 2) Maria YY Law,

MPhil, BRS, Ph.D., Associate Professor, The Hong Kong Polytechnic University as a Visiting Associate Professor of Radiology; and 3) Marco A. Gutierrez Ph.D., Invited Professor, Heart Institute of University of Sao Paulo as a Distinguished Research Fellow.

3. Research Projects

In addition to our existing long term research projects: Data Grid, wireless PDA Server, and bone age assessment of children, we have embarked on several new areas of research. These include Radiation Therapy information system (RTIS), HIPAA-compliant monitoring system, patient tracking and verification system, and image analysis of brain diseases. Three Scientific infoRAD Exhibits showcasing research in wireless PDA server, patient tracking, and image analysis have received RSNA Certificate of Merit awards.

4. Industrial Collaborations

Anticipating the dwindling NIH research support in the near future, IPI has ventured into establishing Research and Development (R & D) collaborations with the private industry. We have successfully transferred the RTIS technology to an Electronic Medical Record (EMR) manufacturer. In addition, at least five other manufacturers are under negotiations with IPI for long term R & D collaborations.

As described in the Table of Contents, this 2005 Annual Report includes materials related to IPI developmental plans and results, 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) in Medical Imaging*, San Diego, California, February 11-16, 2006.

Our research has been supported by:

- NIH R01 EB 00298
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- USC Undergraduate Research Award No. 22-2149-6044
- Wright Foundation Research 23-5149-4292
- Array Corporation, Japan
- MI^2

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IMAGE PROCESSING AND INFORMATICS LABORATORY - STAFF AND COLLABORATORS

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Ph.D. Candidate, Hong Kong Polytechnic University

IMAGING EQUIPMENT LAYOUT at IPI and NETWORK CONFIGURATION

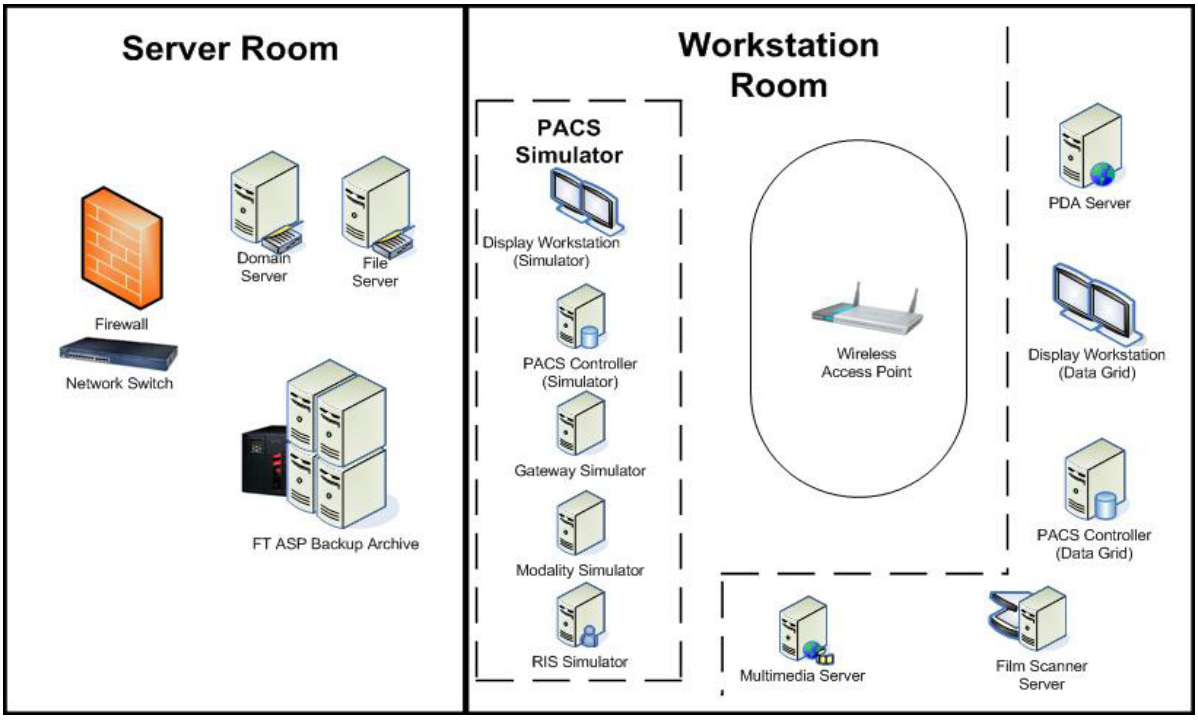


Figure 1. Equipment layout at IPI Lab.

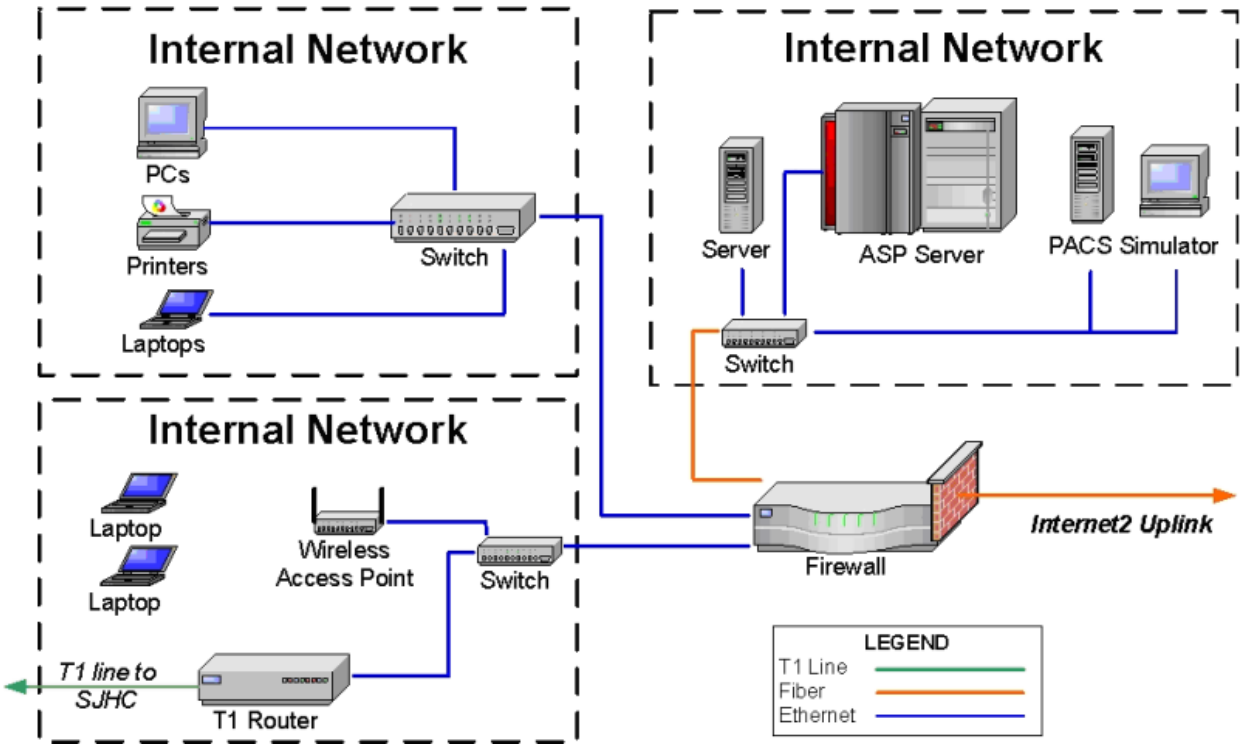


Figure 2. IPI Lab network configuration.

NATIONAL and INTERNATIONAL COLLABORATING SITES
IPI WEBSITE

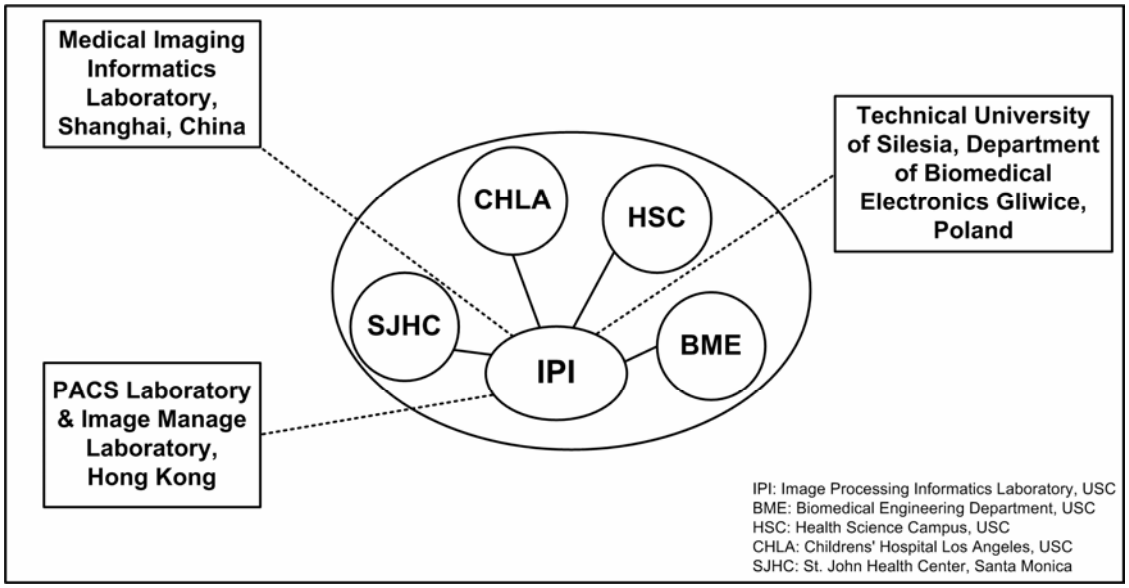


Figure 3. IPI collaborating sites.

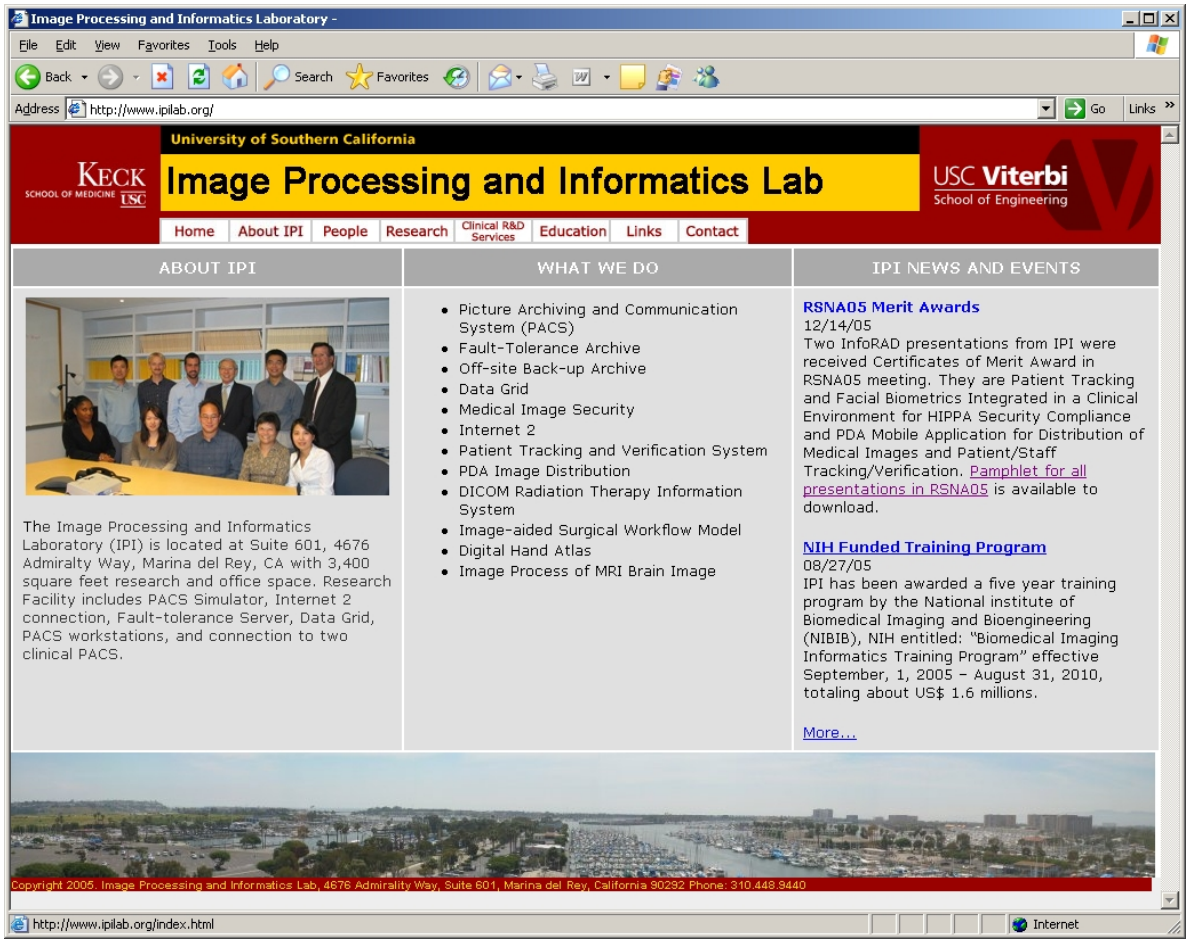
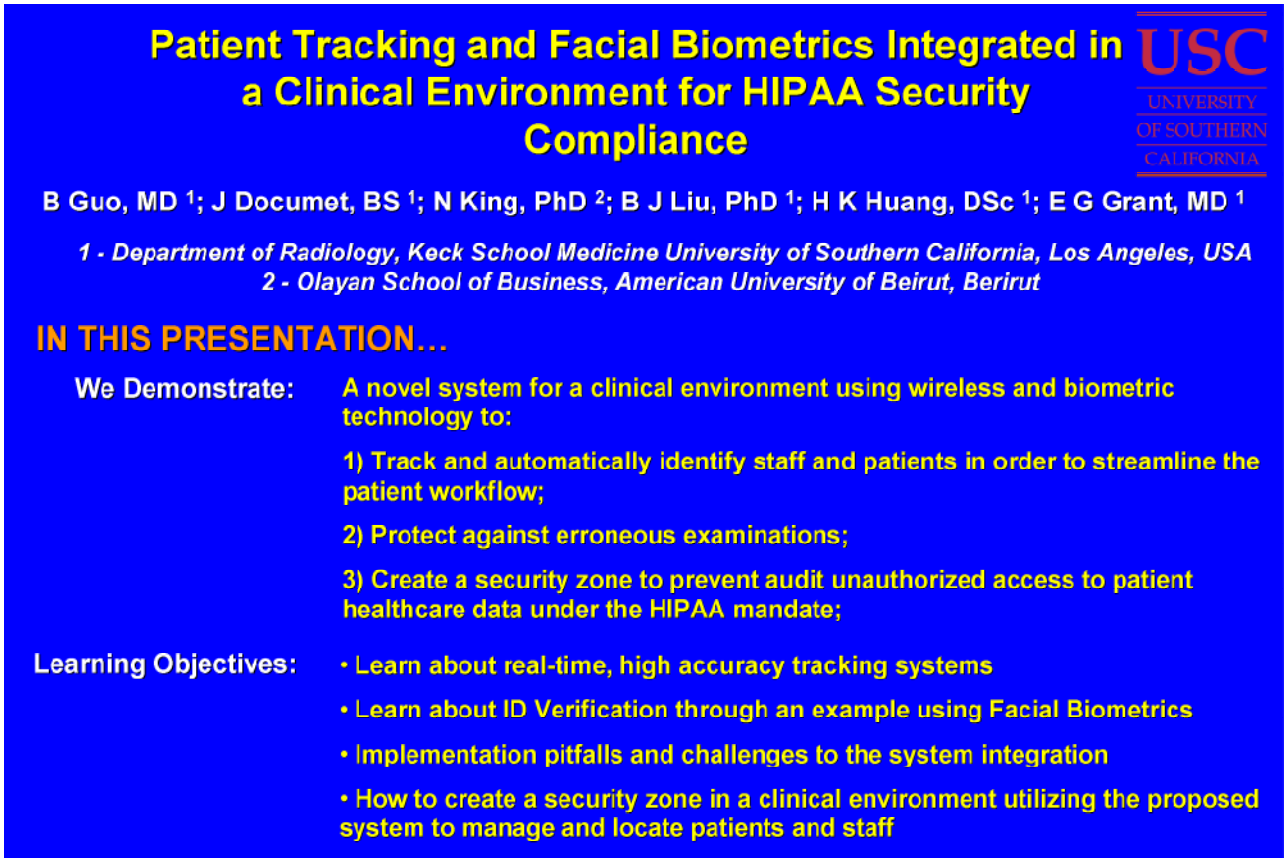


Figure 4. IPI website screen shot.

RSNA 2005 InfoRad POSTERS



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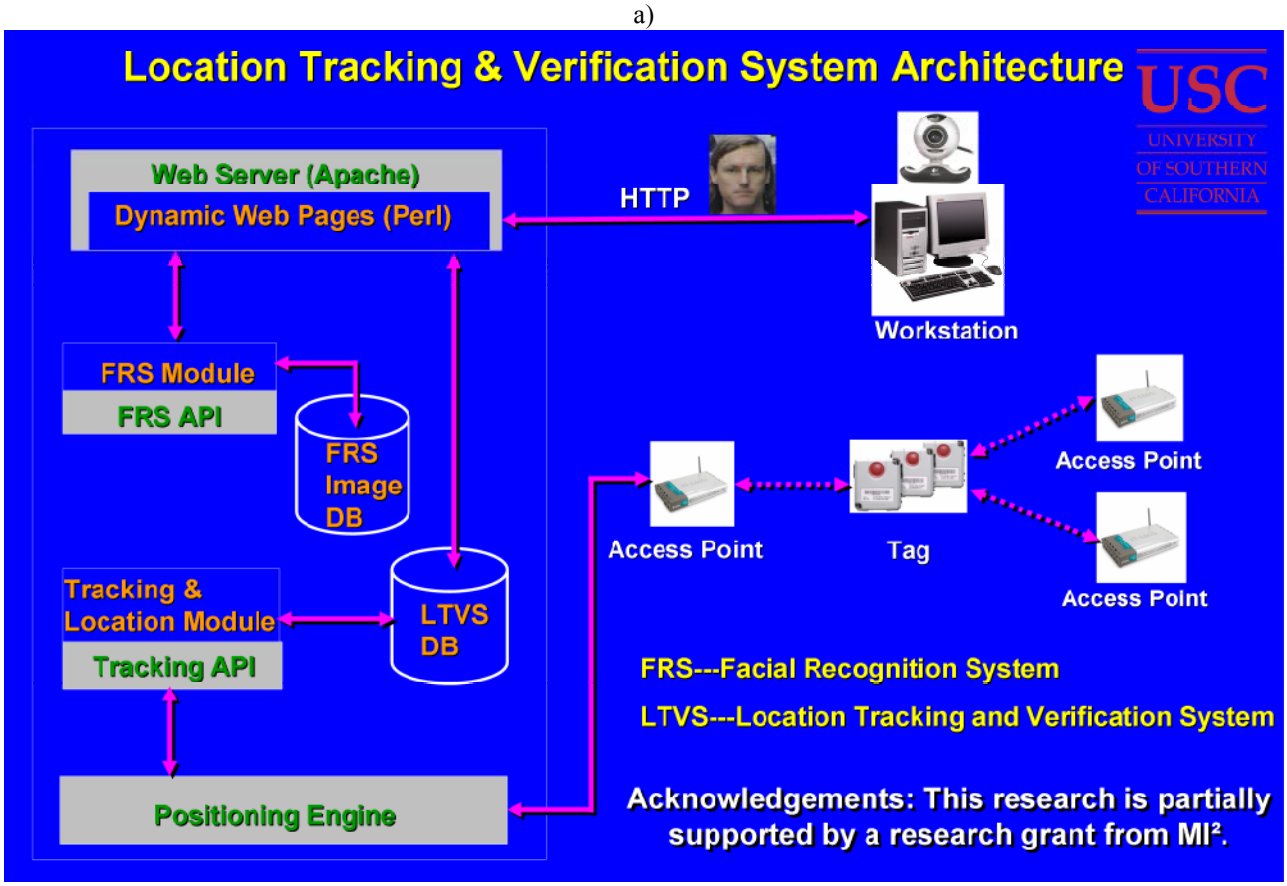

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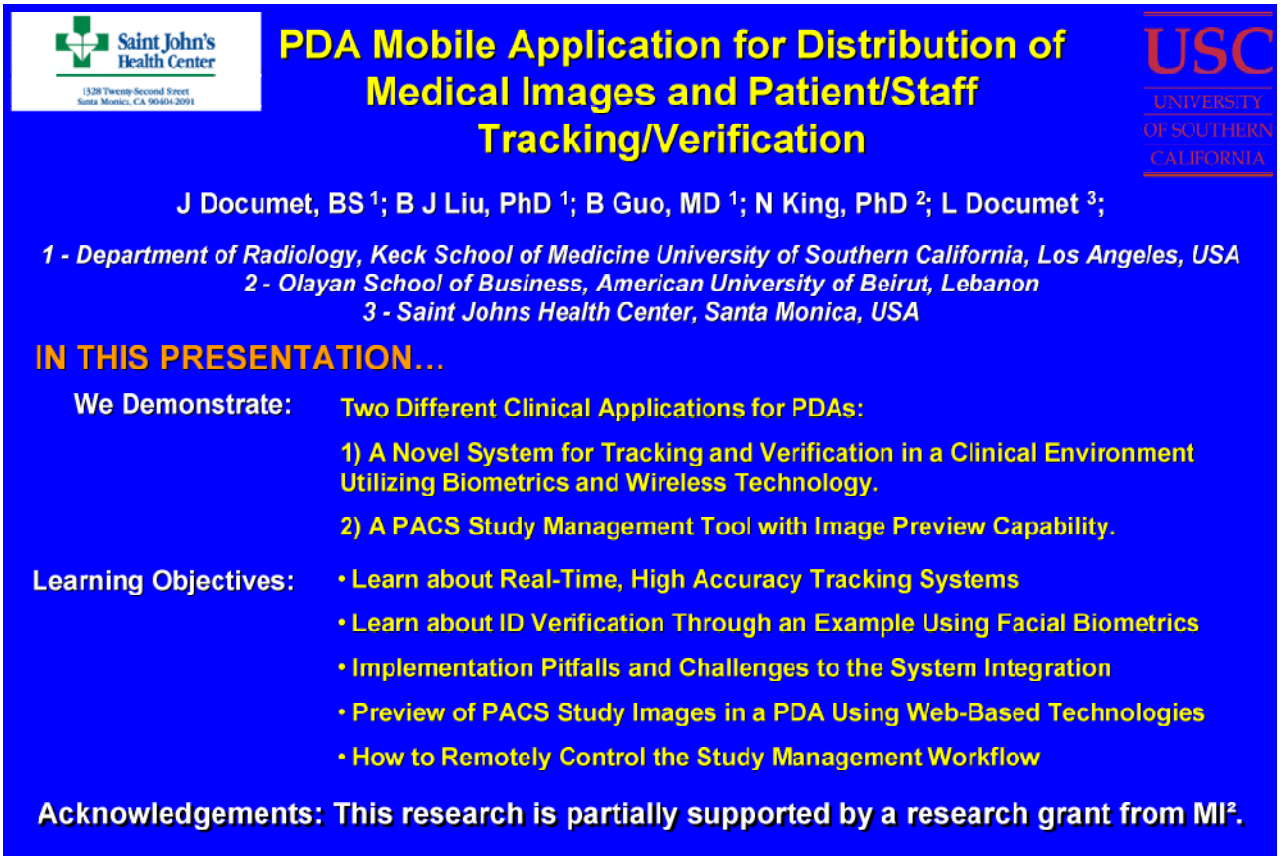

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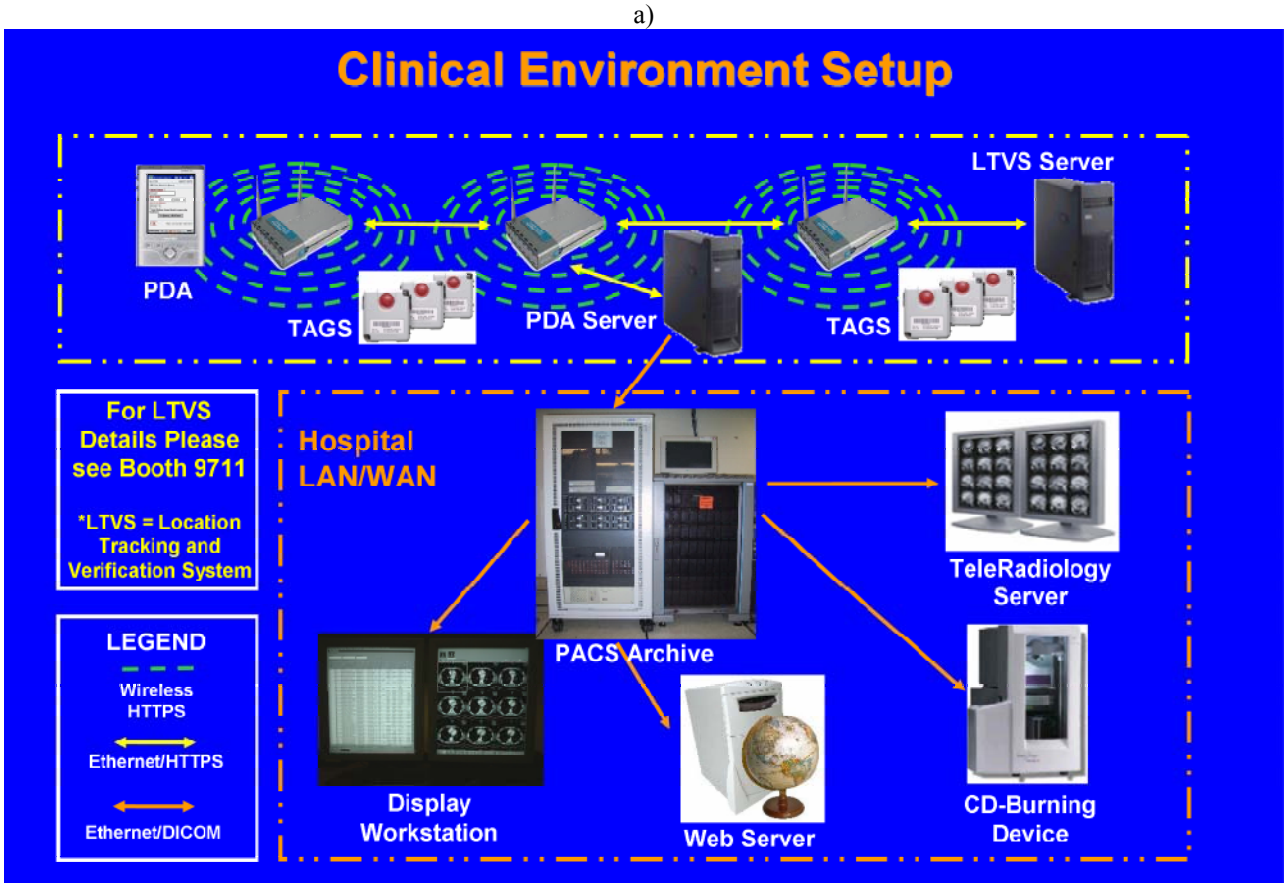

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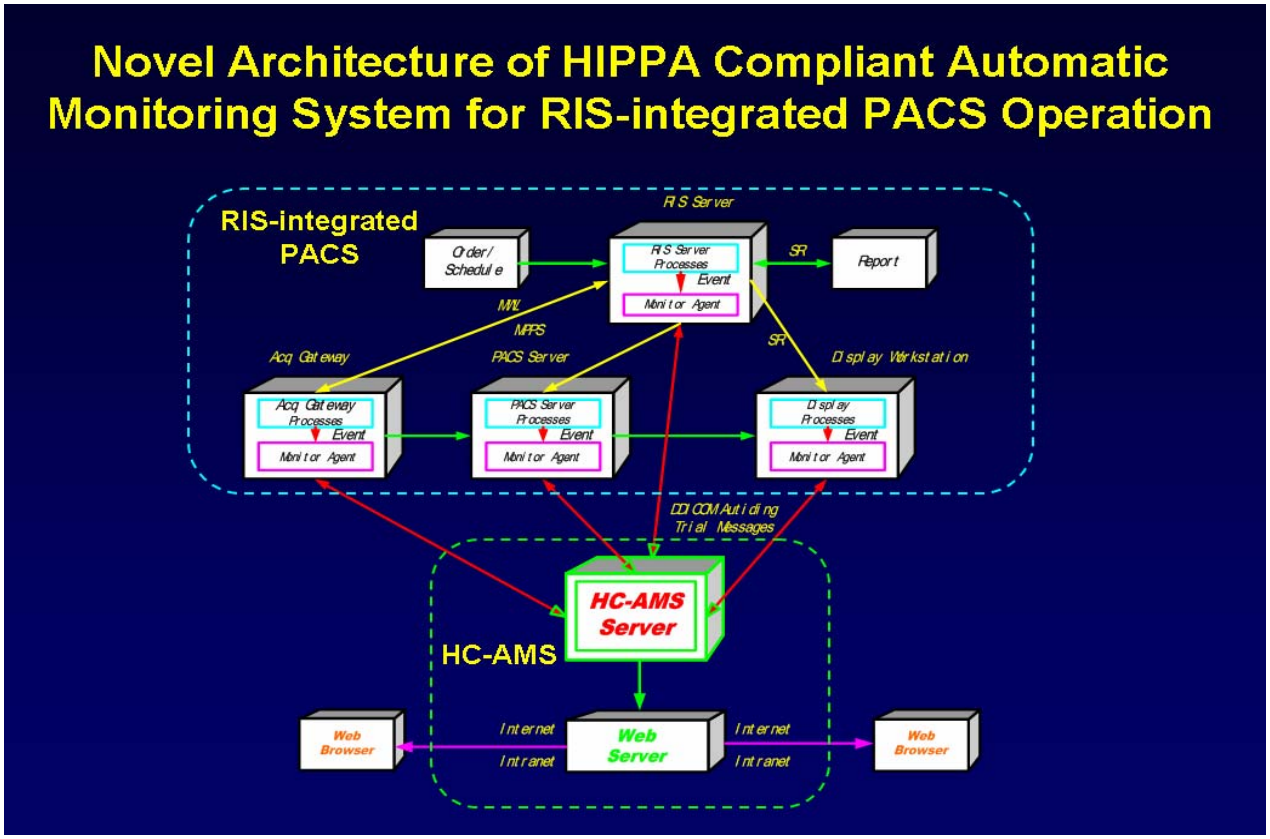

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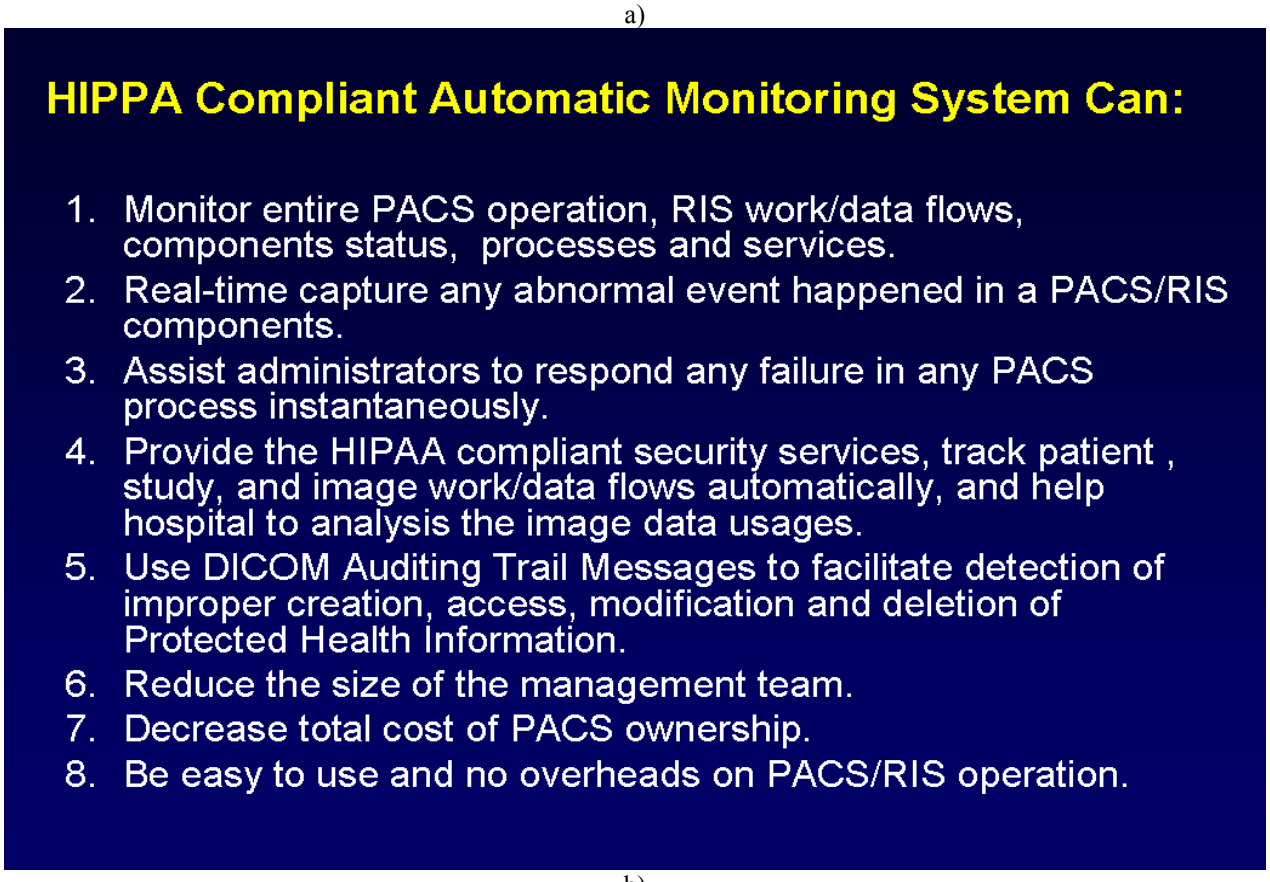

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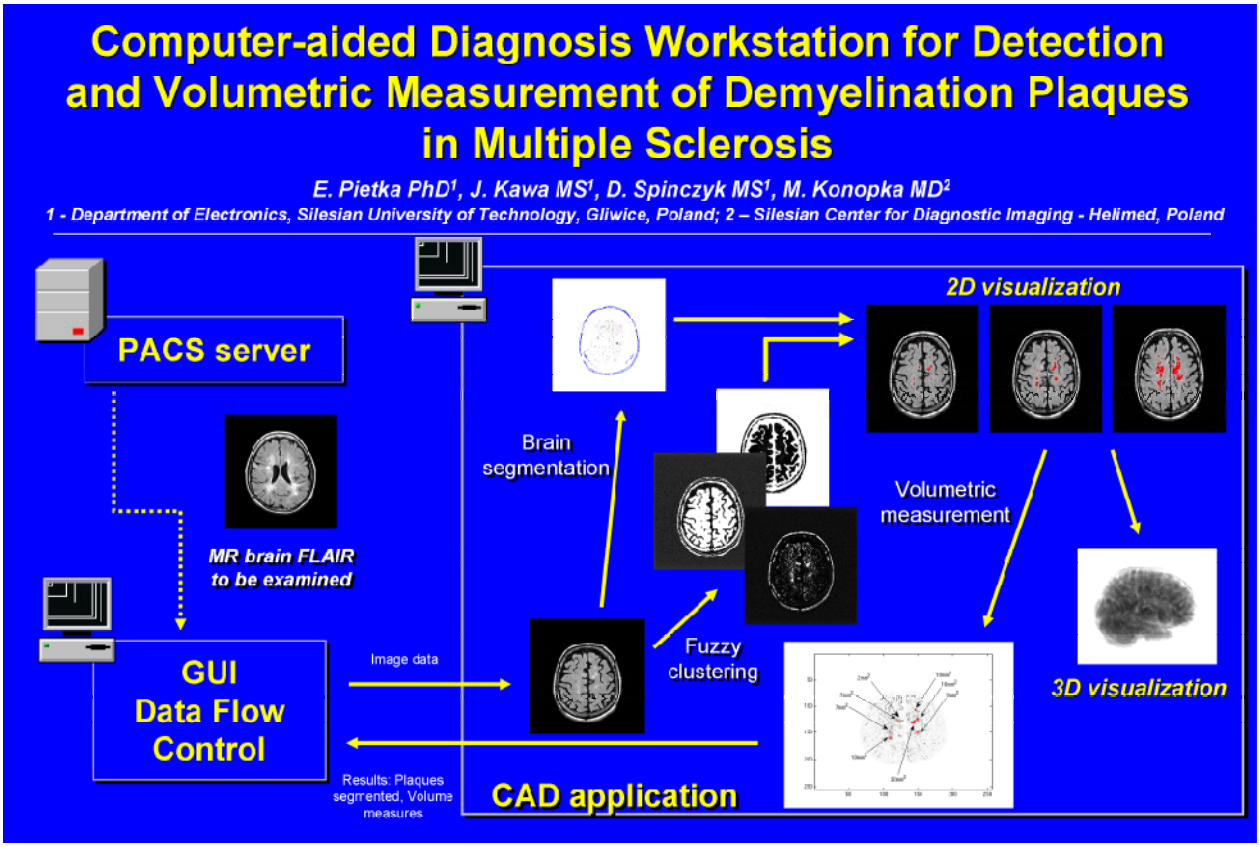

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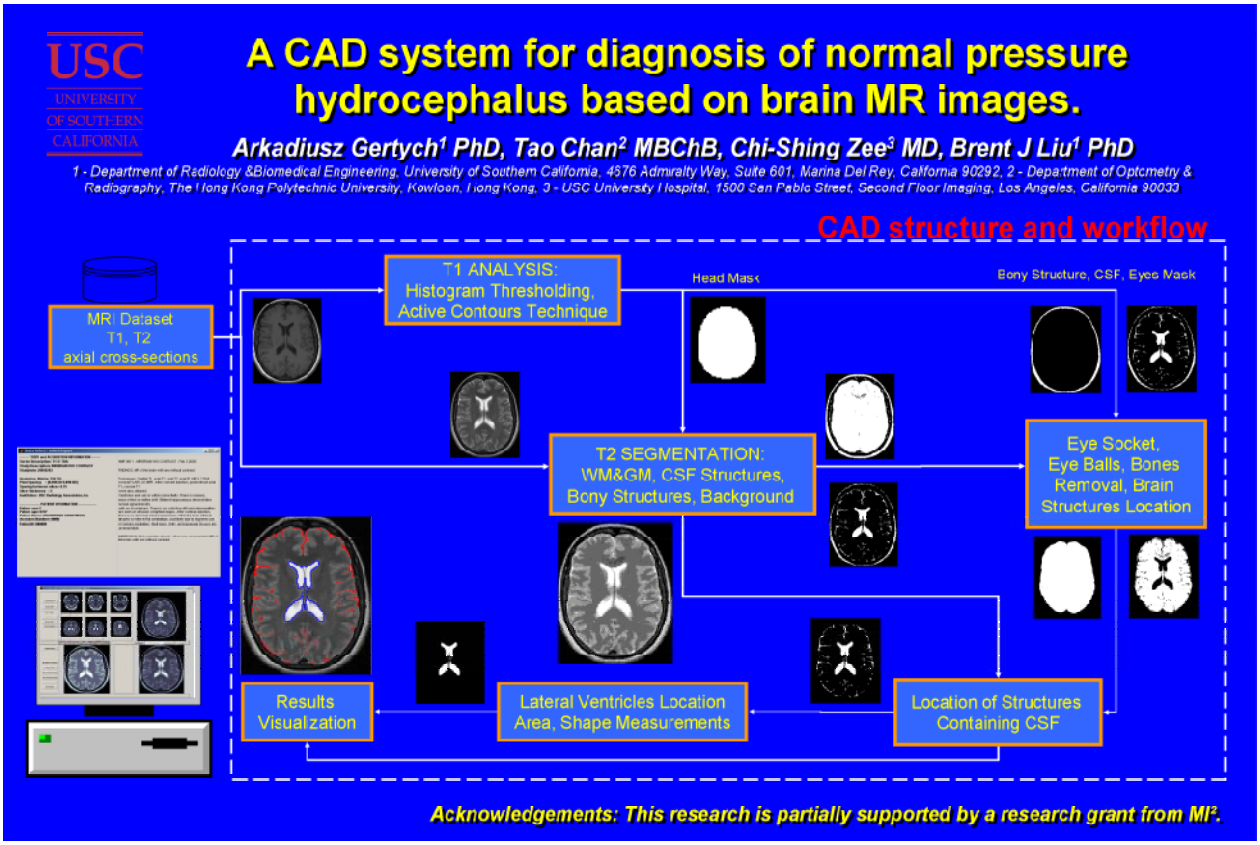

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Computer Aided Diagnosis of Acute Intracranial Hemorrhage on CT

T Chan, MBChB; H K Huang, DSc
Department of Health Technology and Informatics, The Polytechnic University of Hong Kong

Introduction

Detection of acute intracranial hemorrhage (ICH) is a major task for triage of patients suffering from acute neurological disturbance or head injury. The evidence of acute ICH often dictates different immediate management strategies. Failure to detect blood may result in delayed treatment or, even worse, do harm to the patient. Computed Tomography (CT) of brain has been the modality of choice for imaging because of its availability, speed, and high sensitivity for acute ICH. Acute ICH is depicted as bright or hyperdense materials on CT, relative to the other normal structures. The visualization is usually straightforward; however, interpretation may be obscured especially when the abnormality is small or the observer is inexperienced.
Therefore, we have developed a computer aided detection (CAD) system that reliably identifies acute ICH as small as 3mm across.

Materials

All images were conventional axial CT images of the brain performed on an urgent basis, retrieved from the CT archive of a 1200 bed acute hospital in Hong Kong.

Performance

The CAD achieves sensitivity of 92% and specificity of 89% on the 114 tested cases. On a regular Pentium IV based PC, the system spends no more than 3 minutes to perform CAD on a set of CT brain images.
MRMC ROC study performed on 7 emergency physicians showed statistically significant increase in the area under ROC from 0.91 to 0.97, from unaided to CAD assisted reading.

Conclusion

Our CAD of acute ICH on CT improves reading accuracy of emergency physicians.

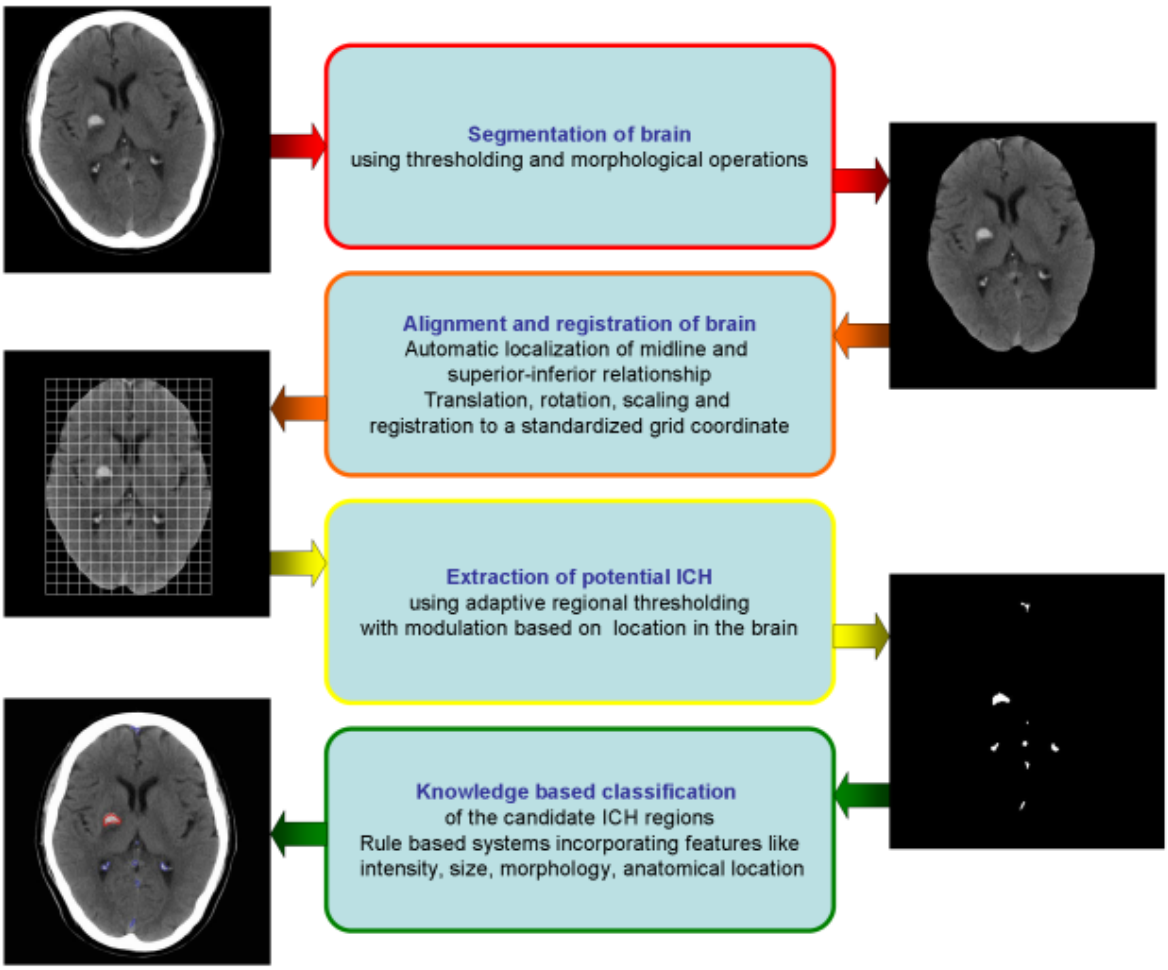

Figure 10. Computer aided diagnosis of intracranial hemorrhage on CT.nosis of intracranial hemorrhage on CT.

PREPRINTS FROM SPIE 2006

An Ultrasound Image-Guided Surgical Workflow Model

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[1]Department of Radiology, USC, USA, [2]Technical University of Berlin, Germany

ABSTRACT TEXT

A 2003 report in the Journal of Annual Surgery predicted an increase in demand for surgical services to be as high as 14 to 47% in the workload of all surgical fields by 2020. Medical difficulties which are already now apparent in the surgical OR (Operation Room) will be amplified in the near future and it is necessary to address this problem and develop strategies to handle the workload. Since the OR is the most cost-intensive sector in the hospital, the optimization of the workflow processes is of particular concern for healthcare providers, managers, and administrators. Appropriate use of ICT (Information and Communication Technology) as part of a reengineered workflow is considered by many experts a significant contribution to solve the problem. Workflow issues are central to the efficiency of the OR and in response to today's continuing workforce shortages and escalating costs. A number of special workshops and seminars which addressed these and related problems have taken place in recent years in Europe and USA. In general, these workshops and seminars identified OR workflow issues, and possible solutions. Among them include: Inefficient and redundant processes, System Inflexibility, Ergonomic deficiencies, Scattered Data, Lack of Guidelines, Standards, and Organization. Some possible solutions suggested were to improve awareness, ensure real-time data availability, and seamless integration of ICT system. The objective of this research is to validate the hypothesis that a workflow model does improve the efficiency and quality of surgical procedure. We chose to study the image-guided surgical workflow for US as a first proof of concept by minimizing the OR workflow issues. We developed, and implemented deformable workflow models using existing and projected future clinical environment data as well as a customized ICT system with seamless integration and real-time availability. We then compared the model data with the baseline data obtained before the implementation of the model. An ultrasound (US) image-guided surgical workflow (IG SWF) for a specific surgical procedure, the US IG Liver Biopsy, was researched to find out the inefficient and redundant processes, scattered data in clinical systems, and improve the overall quality of surgical procedures to the patient.

KEYWORDS: image-guided surgical workflow, Operating Room, Information and Communication Technology

1. INTRODUCTION

A 2003 report in the Journal of Annual Surgery predicted an increase in demand for surgical services to be as high as 14 to 47% in the workload of all surgical fields by 2020. However, the processes are of particular importance in response to the continuing workforce shortages and operational inefficiencies that are being experienced throughout the healthcare industry. Since the OR is the most cost-intensive sector in the hospital, the optimization of the workflow processes is of particular concern for healthcare providers, managers, and administrators. Appropriate use of ICT (Information and Communication Technology) as part of a reengineered workflow is considered by many experts a significant contribution to solve the problem. Workflow issues are central to the efficiency of the OR and in response to today's continuing workforce shortages and escalating costs, among them include: Inefficient and redundant processes, System Inflexibility, Ergonomic deficiencies, Scattered Data, Lack of Guidelines, Standards, and Organization. In order to address these issues, as a first step, we developed an ultrasound (US) image-guided surgical workflow (IG SWF) for a specific surgical procedure, the US IG Liver Biopsy to find out the inefficient and redundant processes, scattered data in clinical systems, and to validate the hypothesis that a workflow model does improve the efficiency and quality of surgical procedure.

An ultrasound (US) image-guided surgical workflow (IG SWF) for a specific surgical procedure, the US IG Liver Biopsy, is studied to find out the inefficient and redundant processes, scattered data in clinical systems, and improve the overall quality of surgical procedures to the patient. The significance of selecting US image-guided surgical workflow as a first model is that US IG is relatively noninvasive and involves a minimal number of personnel. Taking a biopsy (tissue sample) of the liver under ultrasound image-guided can help diagnose abnormalities, including hepatitis, inflammation or malignancy. The procedure is performed with an ultrasound scanner by a team of experts, including an US radiologist specialist and a diagnostic medical sonographer, as well as a registered nurse. The support staff may vary from institutions, however, the core group would always include a radiologist and a medical sonographer. The general workflow of the operation begins with the

patient laying on the examination table so that prior to the biopsy procedure, ultrasound images of the abdomen can be performed to locate the precise area. A gel is applied to the abdomen to help sound waves travel more readily through the body. It is usually warmed to comfort to the patient. A transducer (small, microphone-like device) is placed over the abdominal area. There is no pain and only mild pressure from the transducer. Once the biopsy area is identified, the radiologist cleans the abdomen and places sterile drapes over the work area. The radiologist numbs the biopsy site by administering a local anesthetic, which may cause a slight stinging sensation as the medication is injected. As the medication takes effect, the radiologist will explain how to breathe during the actual biopsy. After the procedure, the patient is observed and monitored for six hours. The ultrasound (US) image-guided surgical workflow (IG SWF) model is studied and developed based on the current baseline workflow within the Imaging Department of an outpatient facility, at the Healthcare Consultation Center II (HCCII), an outpatient imaging facility located on the USC Health Science Campus. HCCII was a good clinical site to study an IG SWF since it is within a controlled environment and there are clinical information systems implemented within a fully digital environment which has integrated HIS/RIS/PACS/VR (voice recognition). This paper describes the methodology for the development and implementation of an US IG SWF model. With these components, a workflow study was first performed on a specific image-guided US surgical procedure. Based on the workflow, twenty-four workflow steps including readying the patient, preparing tools, and performing the procedure, were identified and researched. The inefficient and redundant processes were addressed and a better understanding was obtained on how the operational processes can be performed efficiently in the future.

2. METHODS AND MATERIALS

2.1 Major components in the Workflow Modeling

Before we studied the US IG workflow, one of the most important first steps for workflow modeling is to identify the major components in the developmental process of workflow model. Since the focus of this research will be on patients with liver biopsy, the workflow related to these particular treatment cases will be studied.

We have identified the major components in the workflow modeling for US IG liver biopsy for the Departments of Radiology, which are shown in Figure 1. This is a general process to develop a workflow model in a clinical environment which could be applied to the intra-operative workflow for the ultrasound biopsy as well as any other systems such as the surgical robotics. There are six major components in the SWF modeling, including real-world workflow data collection through observation period, modeling, presentation of the SWF model, analysis, implementation, validation and evaluation.

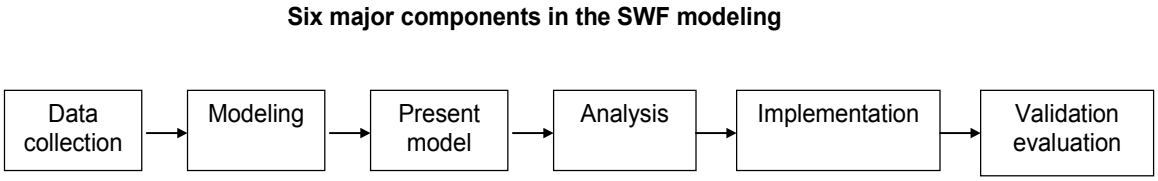

Figure 1. Six major components in workflow modeling for US IG liver biopsy for the Departments of Radiology at HCC II are shown above.

2.2 Data Collection

An observation period of total 4 weeks, 5 workdays a week was performed to observe the workflow of US IG liver biopsy cases at HCC II. The US IG Liver biopsy cases from HCCII were studied. From these US IG liver biopsy cases, a total of 10 cases operated by the same personnel were studied and all the steps beginning from patient preparation are recorded. This included readying the patient, personnel, preparing tools, and performing the procedure. The results were implemented into the clinical workflow model. During the observation period, the major steps of the workflow were first collected within the outpatient imaging facility and are shown in Figure 2. A total of twenty-four workflow steps were identified and will be described later.

2.3 Data Modeling

Dr. Steven Horii from the University of Pennsylvania Medical Center, has already performed some intra-operative ultrasound process and model researches, and developed an general intra-operative ultrasound processes and modeling. Under the guidance of Dr. Steven's research, and based on the workflow data that we have collected from the US IG liver biopsy cases we developed an outpatient intra-operative ultrasound workflow. The major components in the workflow are shown in Figure

2: 1) As an outpatient imaging center, the patients of HCC II are scheduled in the RIS (Radiology Information System). The ultrasound supervisor is notified ahead of time about an Ultrasound Image-Guided Liver Biopsy operation to be performed as well as the estimated time of the procedure. 2) Patient enters the facility based on the scheduled time and patient preparation prior to undertaking a liver biopsy is essential. 3) One sonographer will perform the regular liver US survey before the radiologist begins the operation. 4) The Radiologist was informed that the patient has entered the operating room, (the number of the radiologists are determined by the complexity of the liver biopsy examination). 5) Radiologist locates a suitable site for the liver biopsy from the initial US Liver survey. 6) Radiologist and the sonographer perform the biopsy surgery together. 7) The liver biopsy procedure is completed and tissues samples are obtained. 8) Patient is sent to ETC (Emergency Treatment Center) for post-procedure monitoring. 9) The sonographer transfers the US images recorded before and during the procedure to the PACS (Picture Archive and Communication System) for future reviewing.

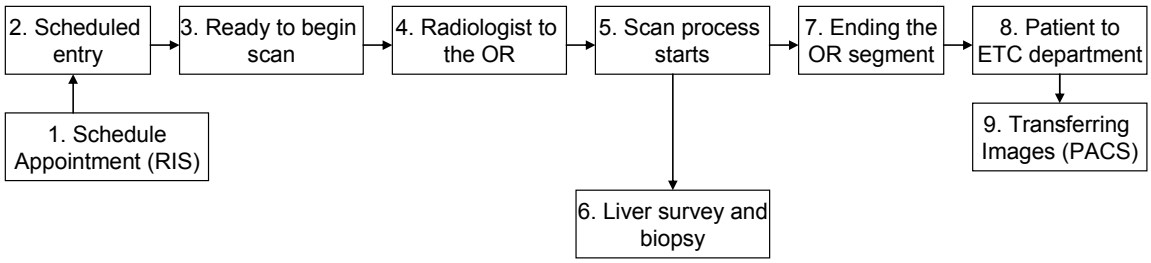

Figure 2. Outpatient Intra-operative ultrasound workflow including 9 steps at HCC II.

2.4 Current Model

With the successful development of the outpatient intra-operative ultrasound workflow, we were able to clearly examine detailed steps contained in each of the components. There are a total of twenty four steps in the workflow modeling for US IG liver biopsy for the Departments of Radiology and the full workflow model is presented in Figure 3:

1) Patient preparation prior to undertaking a liver biopsy. For example, discontinue aspirin 1 week prior to the procedure. Nonsteroidal anti-inflammatory drugs should be stopped 3 days prior to the biopsy procedure.
2) RIS (Radiology Information System) Tracking status is activated after the patient checks into the radiology department of HCCII.
3) The sonographer prepares operating room for liver biopsy procedure, including cleans up the bed, and preparing forms of informed consent.
4) After clean up and preparation of the operation room, sonographer will bring patient into the OR and ask patient to change clothes in the dressing room. At the same time, sonographer will review recent laboratory evaluation of prothrombin time and complete blood count of the patient, including platelets.
5) After sonographer has evaluated the patient condition whether he or she should continue the biopsy procedure, the sonographer will page radiologist to inform the radiologist that the patient has entered the OR.
6) While waiting for the radiologist, the sonographer will search medical history of the patient through RIS, ultrasound or CT imaging with report may be useful, particularly if obtaining a biopsy of a particular region or mass within the liver is desired.
7) The sonographer will perform a regular US liver survey for the patient first, locate the biopsy area, and record the image.
8) After the radiologist arrives, the radiologist will repeat a regular US liver survey for the patient. Once a suitable site has been identified, he or she will mark this location with a surgical pen.
9) The radiologist will continue to explain the whole process of the liver biopsy procedure and the risks during and after the procedure to the patient.
10) If the patient agrees to continue the procedure, patient will sign the informed consent form.
11) The patient will be given 250ML 0.99% Sodium Chloride Injection, USP for safety reason.
12) Radiologist based on the biopsy position marked location, carefully measures the distance from skin surface to the node on the US image.
13) Radiologist and sonographer put on gown and gloves.
14) The radiologist covers the US probe with sterile covers.
15) The sonographer will place sterile drapes for the patient on the abdomen.
16) The radiologist operate local anesthesia with 1% lidocaine in both superficial and deep planes, waiting several minutes for anesthesia to be effective.
17) Based on the distance from the skin surface to the node on the US image and depending upon the approach and physician experience, radiologist selects suitable size of the biopsy needle for the procedure.
18) One or two radiologists, (the number of the radiologist are determined by the complexity of the liver biopsy

examination, one might hold the US probe, the other one might hold the biopsy needle) operate the liver biopsy.

19) Once the radiologist obtains the liver tissue by using the biopsy needle, the liver tissue will be stored in a bottle filled with Formalin.
20) Steps 18 and 19 are repeated 3 times repeated to obtain different angles of the mass of the liver.
21) After the liver biopsy procedure is complete, radiologist and sonographer take off gown and gloves. Radiologist leaves the OR.
22) The sonographer sends the patient to ETC (Emergency Treatment Center) to monitor post-procedure condition of the patient for at least 6 hours as a precaution.
23) The sonographer sends liver tissue samples to the pathology department for liver tissue assay and cleans up the OR.
24) The sonographer transfers US images recorded before and during the procedure to the PACS (Picture Archive and Communication System) for future reviewing.

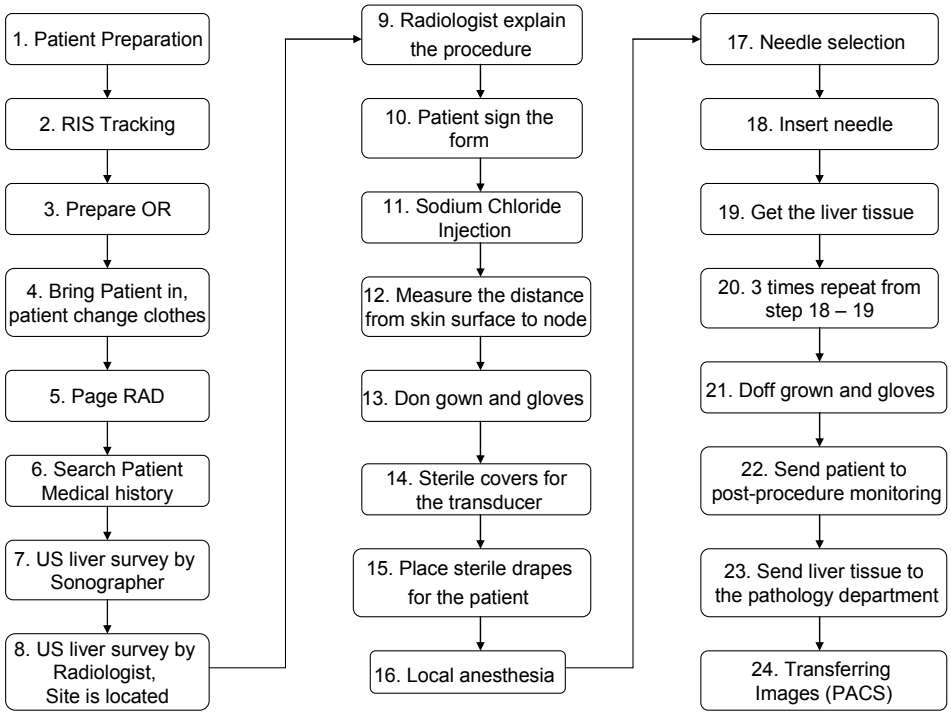

Figure 3. Ultrasound Image-guided Liver Biopsy workflow at HCC II.

2.5 Data Analysis of Current Workflow

The objective of a detailed workflow analysis is to model and visualize the procedure in order. For instance, allowing a correlation between workflows of different types of surgical procedures in future research, (e.g. to obtain a measure of similarity between workflows). Data analysis of the workflow model assists in identifying those parts of the same and different workflows where a process redesign with automated activities may prove to be of a clinical and economic advantage. It also provides concepts and data to assist in the specification, design, implementation and in-vivo usage of new information and communication technology. By carefully analyzing the twenty-four US IG liver biopsy workflow steps, the inefficient and redundant processes were addressed as follows: 1) Data (text and images) presentations at HCCII for the liver biopsy procedure are not adequate since patient medical history reports or images available only if stored in information system of the same healthcare center. The need for enterprise availability of RIS and PACS are extremely beneficial. 2) Patient data analysis and strategic decision-support tools to assist in the presentation system are not available. The needle selection for liver biopsy, usually depends upon the approach and physician experience. With a strategic assistant presentation system, the decision-support application could be used during a more complicated Ultrasound image guided surgery process. 3) It is difficult to locate an available radiologist timely which results in extending the patient wait time unnecessarily. These three processes are highlighted in orange in Figure 4.

3. RESULTS AND DISCUSSION

An US IG SWF model including a formalized description of a coordinated set of surgical activities that are connected in a specific order has been recorded and developed at HCCII specifically for the US image-guided liver biopsy procedure. The inefficient and redundant processes were addressed and shown in orange in Figure 4, and a better understanding was obtained on how the operational processes can be performed efficiently in the future. For example, in Step 6, data (text and images) presentations at HCCII for the liver biopsy procedure are not adequate since patient medical history reports or images available only if stored in the information systems within the same healthcare center and not available enterprise-wide across the entire health campus. For Step 17, patient data analysis and strategic assistant presentation system for decision-support are not available. One area where decision-support applications can be beneficial is in the needle selection for liver biopsy, which is usually depending upon the approach and physician experience. With the strategic assistant presentation system, the decision-support application could be used during a more complicated Ultrasound image guided surgery process. For Step 5. it is difficult to locate an available radiologist timely, which lengthens patient wait time.

The next step would be to use computer modeling tools to model the recorded workflows and develop and implement a new US IG SWF model for liver biopsy in a clinical environment. Then, compare the model data with baseline data obtained before the implementation of the model. Future work could include focusing research on the three areas defined in the current workflow to improve and streamline the processes.

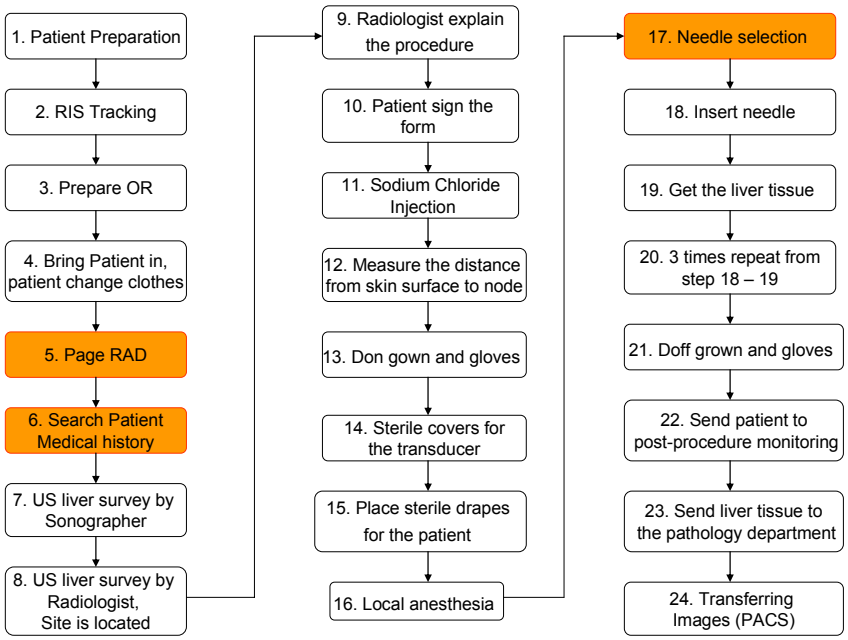

Figure 4. Inefficient and redundant processes are shown in orange boxes (Step 5, 6, 17).

4. CONCLUSION

As a result of studying the US IG SWF and using a workflow modeling method to derive from data obtained from the real-world surgical environment, we have determined that among several major US surgical procedures, the US IG Liver Biopsy requires several interwoven intra- and inter- workflow steps which can be resolved during the initial phase. Three areas of improvements have been identified as future research work. We have identified 24 steps with some requiring fluidity. It is seen that even in a single surgical procedure, there are certain fluid steps which will require the consideration of a deformable model. A workflow model of US IG SWF was successfully developed for the US IG Liver Biopsy procedure. The success of this model is a first step towards developing more US IG SWF models which would in turn provide the healthcare service with a portable, scalable, and a more efficient and cost-effective operational environment. Appropriate use of information systems and communication systems as part of a re-engineered workflow is considered by many experts a significant contribution to solve this problem.

To summarize, we will take lessons learned form the US model and extend it to an IG WSF deformable model for a selected healthcare facility. The success of this project will have a potential impact to the long-term benefit in terms of a more efficient and cost-effective healthcare services.

REFERENCES

1. Etzioni, DA.A., et al: The aging population and its impact on the surgery workforce. Ann Surg, 2003, 238(2): p. 170-177
2. Pentacost M.: Review of the operating room of the future, OR-2020, UCLA Seminar on Imaging and Informatics, October 4-6, 2004
3. Sandberg W.: Workflow in a digital operating rooms of the future, UCLA Seminar on Imaging and Informatics, October 4-6, 2004
4. Horii, S.: Workflow of intra-operative ultrasound procedure, UCLA Seminar on Imaging and Informatics, October 4-6, 2004
5. Lemke HU.: Surgical Workflow and Surgical PACS, UCLA Seminar on Imaging and Informatics, October 4-6, 2004
6. Sandberg W.: Review of the operating room of the future, OR-2020, UCLA Seminar on Imaging and Informatics, October 4-6, 2004
7. Siegel E.: Interventional radiology and image based procedures in radiology. UCLA Seminar on Imaging and Informatics, October 4-6, 2004

A Design Methodology for Fault-Tolerance in A DICOM-COMPLAINT Data Storage Grid

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ABSTRACT

With the increasing demand of PAC systems, more and more examinations are acquired by healthcare institutions which results in an enormous amount of image data and metadata information that needs to be archived and retrieved especially during disaster recovery. Last year we presented a Data Storage Grid (DSG) architecture based on the five-layer architecture design for Grid technology that provides 99.999% up time. The proposed solution was implemented as a three-site testbed and was developed using Globus 3.2 Toolkit. A grid architecture built on Globus middleware achieves reliability and availability through the distribution of hardware components and services. However, a DICOM-compliant DSG requires a Metadata Catalog to provide the DICOM header information available to DSG clients. For this reason, this paper describes the continued development of the DSG utilizing DICOM and IHE standards including the development of a fault-tolerant Metadata Catalog for a DICOM-compliant data grid environment.

Keywords: Metadata Catalog, Fault-Tolerance, Grid Architecture, Data Storage Grid, PACS

1. INTRODUCTION

PACS has become more prevalent in hospitals and medical imaging centers. According to Frost and Sullivan the penetration of PACS in hospitals in the year 2003 was only 17.7% with an expected growth of 59.6% by the year 2010[1]. On the other hand, imaging centers had an 8.9% penetration in the year 2003 and an expected penetration of only 25.0% by 2010[1]. This indicator shows that more hospitals than medical imaging centers will become filmless environments in the near future. With the arrival of a digital clinical environment that will support the daily workflow of a Radiology department, a cost-effective and fault-tolerant technology for storage of PACS data should also be considered. Because of the various shortcomings of current backup and recovery solutions[2] for PACS data, the Data Storage Grid represents a new approach to storage utilizing Grid Computing Technology.

Last year we presented a paper that described a Fault-Tolerant Data Grid storage model for backup and disaster recovery[3]. This model was based on Globus Toolkit 3.2 (GT3)[4] and designed specifically to store and retrieve medical image data. During the last year, the Globus Consortium upgraded Globus toolkit version to GT4 (Globus version 4) to enhance to functionality of the toolkit, with limited support for previous versions of their toolkit. Currently the DSG utilizes Globus Toolkit 3.95. In our architecture we provide the basic components for a fully-implemented DICOM (Digital Imaging and Communications on Medicine)-compliant Data Grid for PACS. Our Data Storage Grid (DSG) can be implemented seamlessly into an existing PACS network, without requiring installation of any special protocol or software at the servers or clients. It only requires the clients to add standard DICOM connectivity configurations such as IP address, Application Entity Title (AET), and port number in order to access the DSG. The DICOM C-Store and Query/Retrieve commands which are part of the DICOM standard[9] are utilized for accessing the DSG to store and retrieve clinical images. Within the DSG, all the components are assigned with specific tasks to successfully support the needs for the DICOM-compliant PACS data. The main goal of the DSG is to provide a continuous available solution for PACS, with 99.999% service availability and minimized number of single points of failure. To achieve those requirements some components are redundant and distributed, introducing new challenges in order to maintain synchronous data exchange, transfers, and catalogs, while being continuously available to users. Fault-tolerance (FT) is one of the inherent characteristics of the Grid environment. However, Grid Fault-tolerance is limited when providing data storage for medical images in DICOM format because of the lack of a distributed Metadata Catalog. In this paper, we present the methodology for utilizing the most available Globus Toolkit components to implement services to specifically address the needs of a DICOM-compliant Data Grid. In particular our focus is on Globus Toolkit services that provide access to the information regarding PACS image data. This key area that requires FT is the metadata of clinical images in the DSG, which is crucial to a DICOM standard environment like PACS. Also, this catalog is the source for providing DICOM-compliance when utilizing the functionality of the DICOM services such DICOM Query and Retrieve. We have researched and developed a DICOM tailored Metadata Catalog that reflects the needs of the

DICOM services in a grid environment. To avoid a single point of failure of the service, the design methodology must provide redundancy, consistency, and continuous availability of the Metadata Catalog.

Our proposed design for the DSG is a three-site configuration where the clinical images are stored. However the design is not limited to three sites and can easily be extended to an n-site DSG. It was determined in a previous paper that SAN technology was a cost-effective and robust storage solution for the DSG[3]. Figure 1 shows a three-site configuration used as the clinical testbed, which includes Saint Johns Health Center (SJHC) at Santa Monica, HealthCare Consultation II (HCCII) at USC/Health Sciences Campus, and the IPI Laboratory (IPILab) facility at Marina del Rey.

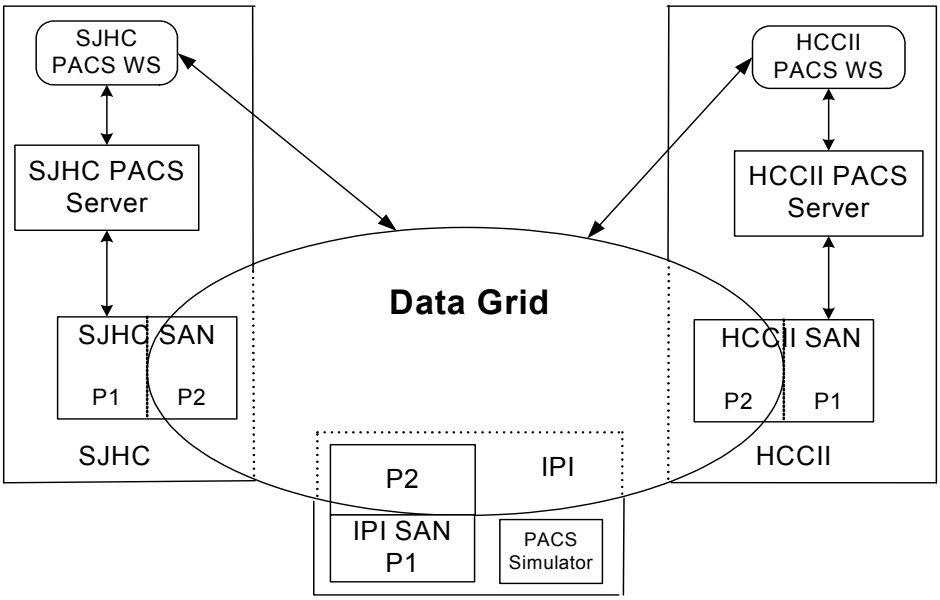

Figure 1 - three-site testbed for the Data Storage Grid

In Figure 1 we see that local PACS in HCCII and SJHC do not need additional software or hardware. Only the Workstations in these sites access the DSG vs DICOM clients to obtain the medical imaging data. In the figure SJHC and HCCII have SAN solutions with two partitions, the first one for their local PACS data and the other partition for the DSG. IPILab's SAN is also divided into two partitions, one for Local IPI activity and the other for the storage of the DSG.

In the following sections we will be discussing design methodology that will provide Fault-Tolerance within a DSG with special attention to the Metadata Catalog Service. In addition, an update to the current status of our implementation, the results we have obtained in our testbed configuration and the conclusions from our work including the plan for next tasks will be discussed.

2. METHODS AND MATERIALS

2.1 Current available solutions for Metadata Catalog Services

Some previous efforts have been made to integrate a Metadata Catalog Service into the Grid architecture which demonstrates the importance of such a service in the overall architecture within the Data Grid. The list of solutions includes:

1) Metadata Catalog Service[5]: A general purpose service for data intensive applications known as MCS.
2) Metadata service[6]: Developed in the Lightweight Data Replicator effort for managing replication of data in a medium-sized Grid environment.
3) Grid Metadata Catalog Service-Based OGC Web Registry Service[7]: A domain-specific extension of the MCS for the Open Geospation Consortium (OGC).

The solutions mentioned above are good candidates for their field area; however, they do not address a Metadata Catalog Service for a DICOM-compliant Grid, which is the case for our DSG. In the same methodology that the OGC developed a domain-specific extension from the MCS, a tailored solution was required for our DICOM-compliant DSG. The importance of including a DICOM tailored Metadata Catalog Service within the DSG architecture is to provide a Query service for

DICOM clients. The DSG stores both the DICOM header information as well as the DICOM files, which forms the basis for the DICOM Query and Retrieve services. Once the file is stored in the DSG, its DICOM contents is extracted and stored within the DICOM-tailored MCS. This is shown in Figure 2. A logical filename is associated to each image and the physical location of the files is managed by the Replica Location Service (RLS). The number of copies for the DSG is defined in the Data Storage Policies. The physical location of the files ultimately will reside in storage media. In the design of the DSG each site belonging to the DSG will provide space from its own SAN reserved for the DSG. When a request from a client enters the DSG to search for a given examination, the Query result is provided by the MCS and the retrieve/store services are provided by the other DSG services, such as Reliable File Transfer (RFL), RLS and the GridFTP[8].

Figure 2 shows the general structure of a DICOM store within our DSG. The workflow is as follows:

Step 1: The clinical images are received by the GAP (Grid Access Point) component. GAP shown with intermittent lines indicate redundant ones.

Step 2: The medical images are parsed and the DICOM information is extracted from the headers.

Step 3: The images are then sent to the Metadata Catalog Service; and this service will update its database to reflect the new information. In the DSG there are more than one MCS

Step 4: Once the previous step is finished the GAP will coordinate with the Replica Location Service (RLS) and the Reliable File Transfer (RFT) Service to make the necessary copies of the DICOM image. Multiple RLS and RFT services are available on the DSG.

Step 5: The RFT service relies on the Gridftp service to store the images in the final destination. For final destination we have the SAN from the 3 sites as shown in Figure 1.

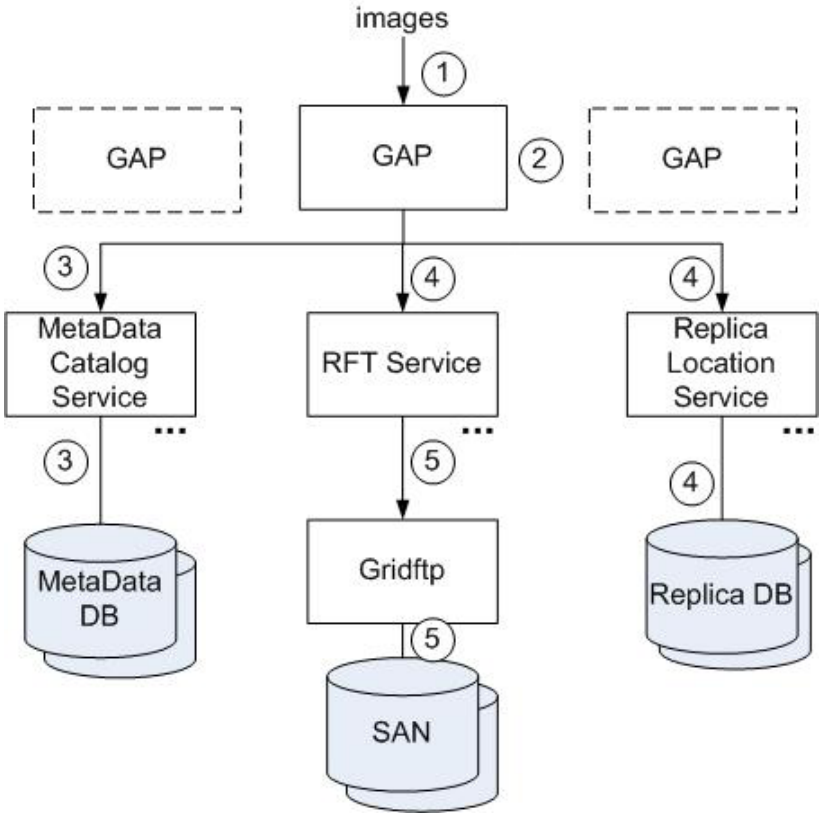

Figure 11 - General Architecture for DICOM Store in DGS

In this context the GAP is the door entrance for DSG clients to the DSG. It converts all the DICOM requests to proper DSG activity. The Metadata Catalog Service is in charge of keeping the Metadata, or information about the clinical images, in the

corresponding database. The RFT Service makes sure the copies of the clinical images are copied fast and successfully, while the RLS keeps information about the final locations of the copied files.

2.2 Metadata Schema Design and Development

The metadata schema designed and developed for the DSG follows the schema of the DICOM standard version 3.0[9]. In addition, the metadata schema also follows the DICOM model of the real world, which includes Patient, Study, Series, and Images. We have initially extracted key data fields from the DICOM data model considered crucial. The schema design is object-oriented as well as modular so that it can be easily extended to accommodate both IHE and HL7 standards as well as any additional DICOM fields required such as DICOM-RT (DICOM-Radiation Therapy). The scope of DICOM fields can be widened in case the need arises. Our Metadata Catalog Service utilizes PostgreSQL 8.0.2 as a database, a cross platform open source database and also used by the Globus Toolkit. The figure below shows the current fields included within the schema for the Metadata Catalog Service and its relationships. As it is shown, the tables include Patient, Study, Series and Image which follow the DICOM real world model. This is also the data model used by the DICOM standard, which makes a good choice for the DSG. For Patient we include the ID, the name, date of birth and other demographic values. For the study we have the modality, the date of the study, and the Study Instance UID, which uniquely identifies a study in PACS. For the series table, the date is stored, as well as the number of images and it's Instance UID. Finally, the Image table has information about the logical name of the image, the size of the image and it's Instance UID. Also, the figure below shows the relationships among tables. Each arrow describes that the table corresponding to the starting point has a dependency from the table where the arrow ends. In this fashion, all the table depend on the table Patient; the Series and Image tables depend on the Study table and the Image table has a dependency on the Series table.

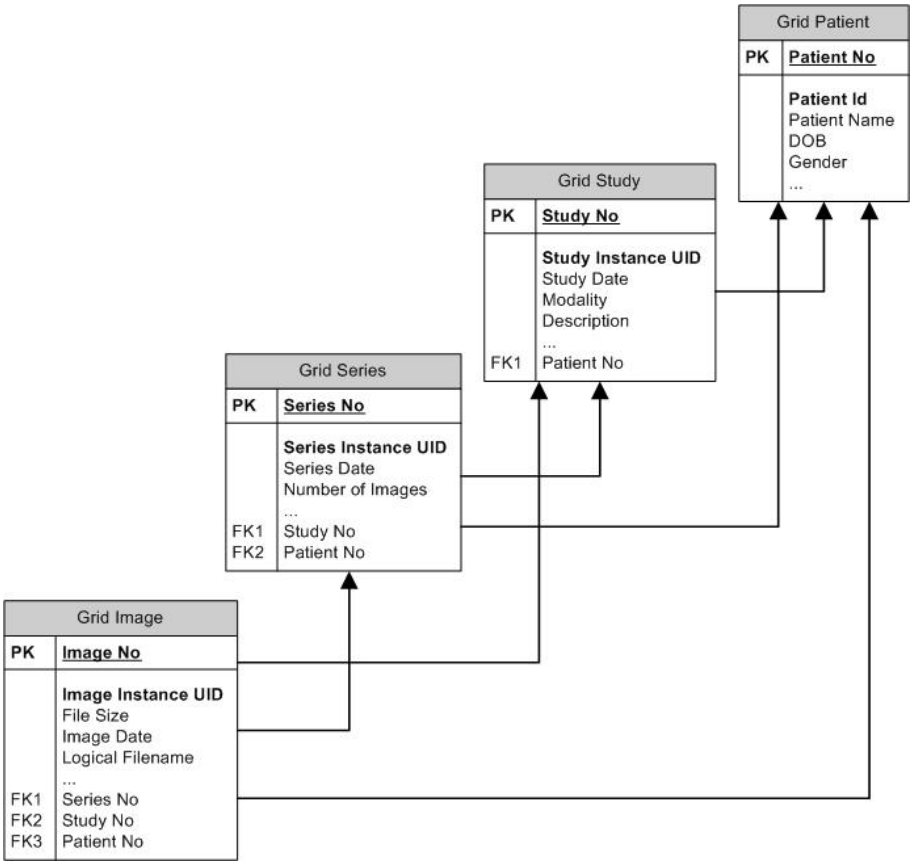

Figure 3- Entity-Relationship diagram for the MCS Schema

2.3 Two Proposed Models for Achieving Fault Tolerance in the Metadata Catalog Service

Two Models have been designed and developed to provide Fault-Tolerance to the MCS. In order to achieve FT within the DSG for the metadata, multiple MCS must be developed to avoid a single point of failure and provide high reliability. To provide this Fault-Tolerance we have to deal with location of the MCS, network latency, performance on keeping the Metadata Catalog up to date, and the behavior of the MCS itself. For these reason we are proposing two models for the DSG. The following models were designed for our three-site testbed configuration in order to provide multiple MCS for continuous availability, the design and methodology can be easily expanded to multiple sites if necessary. Both models provide redundant copies but the manner they handle the DICOM C-Store and Query/Retrieve functionality makes them different.

The DSG architecture design allows for multiple sites to share the same Metadata Catalog Services through its security policies. But the metadata information regarding clinical examinations for a given hospital is only available to authorized users associated to that particular hospital. This feature is important because it keeps the integrity of the information stored in the MCS and complies with HIPAA and hospitals want to keep their data private. This design reduces the need to have any special MCS for a particular site and makes the solution scalable whenever a new site is incorporated to the DSG. These security policies are enforced for every DICOM request made to the DSG. In the proposed models, the Metadata Catalog Service (MCS) and the Metadata Catalog Database (MCD) are considered a single piece for easier management within DSG.

Model A

The design of both models is based on the three-site configuration discussed and shown in Figure 1. Figure 4 shows the workflow of Model A which includes three MCS components distributed within the DSG, one for each of the three clinical sites. The workflow for DICOM C-Store is as follows:

Step 1: The DSG stores a new image thru any of the available GAPs.

Step 2: The GAP extracts the DICOM information.

Step 3: The GAP then performs three separate copies of the same data in each MCS in the DSG. If any of the MCS are not available at this time, the GAP is responsible for synchronizing the data after the particular MCS becomes available again.

This workflow also works for DICOM Query/Retrieve as follows:

Step 1: The request is made and an available GAP is contacted by the DSG client.

Step 2: The GAP processes the request from the DSG client.

Step 3: The GAP forwards the request to any of the MCS within the DSG. In this case, the DSG also provides status information about the available services so that the GAP does not need to be preconfigured to access a specific MCS but whichever one is available and has the best performance statistics.

The main disadvantage for this model is that overloads the GAP with extra tasks, such as synchronizing the metadata database.

This model also provides redundancy at the GAP level, thus, if the GAP executing the DICOM request from a DSG client goes down, the DSG will be intelligent enough to re-route that request to another GAP. But the newly contacted GAP will have to start over to perform the same request as the other GAP. Now, this GAP will be responsible for making the necessary copies to the MCSs and not the first contacted GAP. Alternative GAPs are shown with intermittent lines in Figure 4.

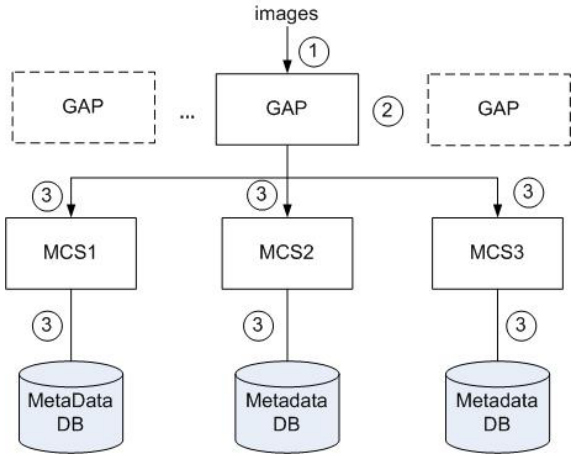

Figure 4 - Model A for MCS design

Model B

Figure 5 shows the workflow of Model B which includes three MCS components distributed within the DSG, one for each of the three clinical sites. In this case, the workflow for the DICOM C-Store is as follows:

Step 1: The DSG stores a new image thru any of the available GAPs.

Step 2: The GAP extracts the DICOM information.

Step 3: The GAP then sends this data to the best available MCS, which is provided by the DSG in real time.

Step 4: Once the most available MCS is contacted and the data has been successfully stored, this MCS is responsible for providing proper redundancy and fault tolerance by managing the other redundant metadata databases. In this case, the other MCS's will receive an update from the initial MCS to keep all the MCS's in synchronization.

In this model, the GAP is freed from the synchronization task, which now lies at the MCS level. The same workflow as in Model A happens for the DICOM Query/Retrieve. The main drawback for this model is the extra overhead in time generated by first contacting one single MCS for update and then only at this time the update can be simultaneous to the other MCS peers.

This model also provides redundant GAP access, thus, if the GAP executing the DICOM request from a DSG client goes down, the DSG client will then need to switch to another GAP. But the newly contacted GAP will have to start over to perform the same request as the other GAP. Now, the steps described above are executed from the recent GAP. Alternative GAPs are shown with intermittent lines in Figure 5.

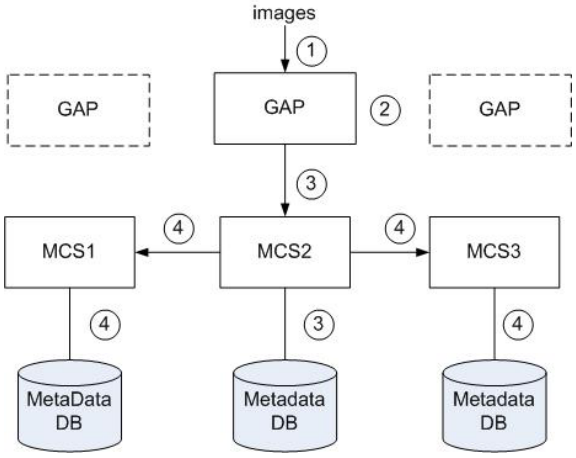

Figure 5 - Model B for MCS design

3. RESULTS AND DISCUSSION

The design methodology for a FT MCS has been proposed for a three-site DSG. We are still in the process of acquiring all the required hardware and planning for configuring the network sites to support the DSG. An initial laboratory prototype has been developed to test the functionality of the MCS. This version contains a single Database and its contents are directly stored from the GAP. This prototype will serve as a starting point for implementing the two models described above. We have been able to perform successful C-Store and Query/Retrieve from DSG clients. For a DICOM C-Store client tools were developed to configure and send the PACS examinations to the DSG. The DICOM information was successfully extracted from the DICOM files and stored within the MCS Metadata database. For Query/Retrieve we used a DICOM diagnostic display workstation to perform and test the successful Query/Retrieval of PACS exams. All that was required to access the DSG was to add DICOM AET, IP address, and port number information to the client workstation and we were able to perform DICOM services from the DSG immediately. In addition, the query mechanism is not case sensitive which minimizes time spent performing DICOM Query/Retrieve from clients. The next step is to expand the number of MCS and the metadata database to three instances based on the two models designed and developed. We will implement both MCS models in the laboratory prototype as well as the three-site clinical testbed and measure their performance to determine the best solution for the DSG. Table 1 shows some of the criteria developed for the testing and evaluation portion:

DICOM command: C-Store. Manually performed by a DICOM client accessing the DSG.	
Criteria	**Testing Scenario Description**
Time measurements will be performed during a normal DICOM C-Store from the client to the DSG.	Normal operations scenario. DSG continuously records statistics of time performance for DICOM commands. Both models will provide statistical measurements.
Time measurements will be performed during failover of a MCS when the DICOM client is performing a C-Store.	**Model A:** The MCS that is receiving the DICOM info from the GAP will be disconnected from the network to simulate a failure. The time measured will be the total time required by the GAP to finish the C-Store transaction **Model B:** The MCS that is receiving the DICOM info from the GAP will be disconnected to simulate the downtime. The total time for the C-Store transaction for the GAP is measured.

DICOM command: C-Store. Manually performed by a DICOM client accessing the DSG.	
Criteria	**Testing Scenario Description**
Time measurements for Metadata synchronization.	**Model A:** Measurements come from the GAP and is referred to the time it takes to synchronize the MCS metadata databases after downtime. **Model B:** Measurements come from the MCS and is defined as the time it takes for the MCS to synchronize among peers.
DICOM command: Query. Manually performed by a DICOM client accessing the DSG.	
Criteria	**Testing Scenario Description**
Time measurements will be performed during a normal DICOM Query from the client to the DSG.	This is normal operations scenario. The DSG continuously records the statistics of time performance for DICOM commands. Both models will provide statistical measurements.
Time measurements will be performed during failover of a MCS when the DICOM client is performing a Query.	Both models measurements come from the same testing scenario. This failure is simulated by disconnecting the MCS from the network. The total time required by the GAP to finish the Query will be measured.
DICOM command: Retrieve. Manually performed by a DICOM client accessing the DSG.	
Criteria	**Testing Scenario Description**
Time measurements will be performed during a normal DICOM Retrieve from the client to the DSG.	This is normal operations scenario. The DSG continuously records the statistics of time performance for DICOM commands. Both models will provide statistical measurements.
Time measurements will be performed during failover of a MCS when the DICOM client is performing a Retrieve.	Both models measurements come from the same scenario. This failure is simulated by disconnecting the MCS from the network. The total time that takes the GAP to retrieve the queried PACS exam from the MCS will be measured.

Table 1 - Testing Criteria and Scenario Description for the proposed models of the MCS

As we can see from the table above, the scenarios for failure are similar in both models except for the failover scenario while performing a C-Store. While the C-Store requires a DICOM SCP (Service Class Provider) from the DSG, the Query/Retrieve assumes the DSG is an SCU (Service Class User). For the SCU model, the GAP only requires a read-only respond and does not involve any update of the data. For this reason, any available MCS can reply, and the DSG provides real-time information about the best available MCS. On the other hand, when the GAP is performing a C-Store, the MCS needs to update its databases and also keep all three of them in synchronization. While Model A handles this from the GAP, Model B performs it from an MCS. The measurements of how this command is implemented in these models will allow us to statistically infer which model better suits the DSG.

We also are considering expanding the DSG laboratory prototype to sites very far in distance. For example, Grid Services and clients will be integrated with the DSG laboratory prototype at sites in both Hong Kong and Brazil utilizing Internet2. Once the infrastructure of this new configuration is established more evaluation will be performed measuring the performance of the DSG in general and the MCS in particular. This will also further enhance the performance evaluations of the two models developed.

4. CONCLUSION

In summary, by presenting the FT Design Methodology for the Metadata Catalog Service and the Metadata database of a DICOM compliant data storage grid, the inherent FT design of a grid environment is enhanced even further by providing the data schema infrastructure to support the storage and retrieval of DICOM images as well as incorporating future HL7 and IHE workflow standards. As a first step, two models were designed and developed for an FT Metadata Catalog service with the DSG providing the storage and cataloging of DICOM header and image information integrated with open standards of the Globus Toolkit platform. In addition, we have successfully implemented an initial laboratory prototype to provide metadata catalog capabilities to the DSG. Future work will include implementing, testing, and evaluating the two proposed models to determine which is best-suited for the DICOM-compliant DSG while still providing continuous availability to the DSG clients. Once the best model has been identified, the DSG will be extended and evaluated in a three-site clinical environment. This research development will allow for a Data Storage Grid to take advantage of both open source Globus Toolkit Grid Services and the additional FT for the MCS all integrated with DICOM, HL7, and IHE standards in order to provide the Medical Imaging community with a robust, scalable, and easy-to-use solution for clinical image storage and disaster recovery.

REFERENCES

1. Frost and Sullivan. North American Turnkey Radiology Picture Archiving and Communications Systems (PACS) Markets, June 2004.
2. Huang, HK, 2004. PACS and Image Informatics: Basic Principles and Applications. 703 pages, Cloth. John Wiley & Sons, Hoboken, NJ
3. King N., Liu B., Zhou Z., Documet J., Huang HK. The Data Storage Grid: The Next Generation of Fault-Tolerant Storage for Backup and Disaster Recovery of Clinical Images. Proceedings of the SPIE, Medical Imaging 2005
4. Globus Toolkit http://www.globus.org
5. Metadata Catalog Service http://gaul.isi.edu/mcs/v3/
6. LDR Metadata Service: http://www.lsc-group.phys.uwm.edu/LDR/overview.html
7. Grid Metadata Catalog Service-Based http://laits.gmu.edu/Papers/Peisheng_Aijun.pdf
8. Liu B., Zhou Z., Documet J., Utilizing data grid architecture for the backup and recovery of clinical image data. Computerized Medical Imaging and Graphics 29 (2005) 95-102.
9. DICOM Standard 2003, http://medical.nema.org/dicom/2003.html

Three-Dimensional Lossless Digital Signature Embedding for the Integrity of Volumetric Images

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ABSTRACT

Our previous study presented a lossless digital signature embedding (LDSE) method for assuring the integrity of 2D medical images in network transit or during archival. With the advent of multi-detector CT scanners and volume acquisition technologies, a PACS exam can now potentially generate hundreds, even thousands, of images. To perform the 2D LDSE method on each individual image in the volume would be extremely time consuming and inefficient. For this reason, a novel 3D LDSE method has been investigated for 3D image volumes. The method begins with generating a single digital signature (DS) of the entire volume. Embedding of the DS is performed first by identifying a bit stream from the image volume based on the correlation of 3D pixel values. The bit stream is compressed using lossless compression methods and the DS is concatenated with the compressed bit stream. This concatenated bit stream is then embedded within the image volume. During the verification process, the embedded bit stream is extracted and utilized to recover the original bit stream and the original DS. The original bit stream can be used to restore the image volume which in turn can be used in the verification of the DS. In addition, to 3D LDSE embedding methodology for image volumes, a new procedure is developed to address clinical workflow for 3D image volumes. Experimental results demonstrated that the 3D LDSE method can assure the integrity of 3D image volume efficiently and effectively; and a 3D clinical image workflow procedure was demonstrated.

Keywords: medical imaging, 3D, integrity, digital signature, data embedding

1. INTRODUCTION

Image security is a critical issue when medical images with pertinent patient information are transmitted over public networks [1-3]. With integrated medical imaging systems being extensively used in clinics for healthcare delivery, image security consideration is no longer limited to images in transit but also in storage. Medical image security, in general, can be characterized by three major issues: privacy (or confidentiality), authenticity, and integrity [4]. Privacy seeks to protect image data from being accessible or disclosed to unauthorized individuals. Authenticity verifies that the source of the image data is what it claims to be. Integrity assures that the image data is not altered or destroyed by unauthorized personnel.

With current information technology, it is easy to alter a medical image without detection when the image is in transit or in storage. Such alteration could affect the quality of healthcare services, and even worse, could cause clinical legal problems [5,6]. As a result, image integrity has become a crucial issue for current clinical imaging systems such as PACS. Traditional methods, such as encryption, firewall, and access control by user password, have been used to protect the privacy and authenticity of image data. These methods, however, are not effective for assuring the image integrity, because an image can still be altered or destroyed even without the knowledge of the content of the image.

We have developed a lossless digital signature embedding (LDSE) [7,8] method for assuring the integrity of two-dimensional (2D) medical images. Our experimental results show that the LDSE method is effective in assurance of medical image integrity. With the advent of multi-detectors and volume acquisition technologies, a CT, MR or US exam can generate a three-dimensional (3D) volume containing hundreds, even thousands of, images. To perform the LDSE methods on each individual image in the volume would be extremely time consuming and inefficient. Currently, there are no methods available for assuring the integrity of 3D medical images. For these reasons, we have developed a novel 3D LDSE method for the 3D volumes.

2. METHODS

The 3D LDSE method consists of two processes: Signing & Embedding process and Extracting & Verifying process. A CT volume with n ($n \geq 3$) images will be used as an example to illustrate the method in following sections.

2.1 Signing & Embedding

In order to make it difficult for unauthorized users to extract the embedded digital signature, randomization is utilized to arrange the image order in the CT volume before actual embedding. The random order is generated based on a set of pseudo-random numbers r_k computed by the random number generator. After the arrangement, all the pixels are read into a buffer starting from the first pixel of the 3rd image to the last pixel of the 1st image shown in Figure 2.7. The n is the random order. A hash value is computed for all pixels using cryptography hash functions such as SHA1 [9]. The hash value is then encrypted and becomes a digital signature (DS) of the whole volume using public-key encryption method such as RSA public-key encryption method.

The DS is embedded in pixels of images within the volume using a 3D LDSERS (Regular/Singular Groups) embedding algorithm. The 3D LDSERS algorithm is basically an extension of 2D LDSERS [7]. The embedding starts by searching R and S groups in the images of the CT volume. A Z-shape walking pattern [7] is utilized to search the R and S groups, which consist of 4 voxels each group, in the CT volume. A voxel is defined as $p_{x,y,z}$, where x represents the horizontal line (or row), y the vertical line (or column), and z the image number in the randomized volume. For example, $p_{1,1,1}$ represents the voxel in the first row and the first column of the first image. After the Z-shape walking, a group of this 4 voxel group is extracted. The correlation coefficient of each group is then computed. Based on the coefficients, the extracted groups can be separated into R or S groups, which are converted to an RS bit stream. The RS bit steam is then lossless compressed. The walking and compressing processes end until there is sufficient space to embed the DS. The compressed bit stream and the DS are then embedded in the volume replacing the original R and S groups. After embedding, the 3D volume is re-arranged in the original order. The result of embedding is a signature embedded image volume.

2.2 Extracting & Verifying

When extracting and verifying, the 3D volume is arranged in the same random order in the embedding processes. The R and S groups are then found based on the same Z-shape walking pattern. The found R and S groups are converted to an R and S bit stream which consists of the compressed original R and S bit stream and the bit stream of the DS. The original CT volume is recovered based on the original R and S bit stream. The extracted DS is then verified with the recovered volume. The verified volume is re-arranged into the original order for clinical usages.

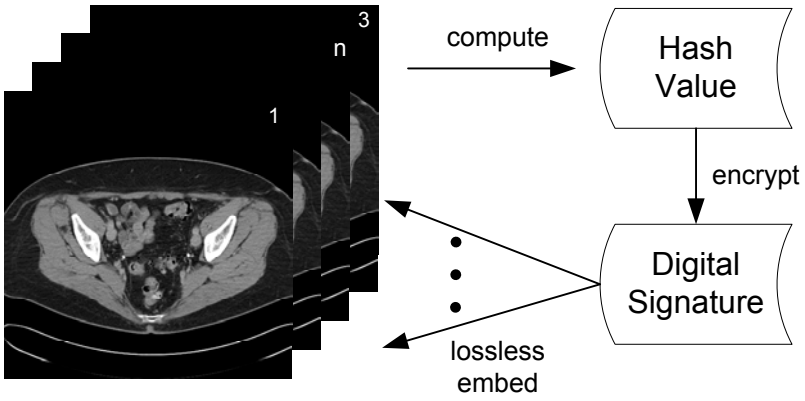


Figure 1 The 3D lossless digital signature embedding (LDSE) method. A single image digital signature is generated for a CT volume for assuring the integrity of the volume.

3. RESULTS

3.1 Data Collection

Twenty-four image sets generated by the three most common 3D imaging modalities used in clinical practice, CT, US, and MR, were gathered. Table 1 shows the number of images, total size of the images, and the average size per image in these image sets. The maximum number of images in these image sets was 176, while the minimum number was 10.

All 3D image sets were collected from three clinical institutes: Healthcare Consultation Center II (USC), St. John Healthcare Center (Santa Monica), and Childrens Hospital Los Angeles (USC). Patient demographic information has been de-identified and cannot be traced back.

Table 1 Twenty-four Image Sets Collected for Testing

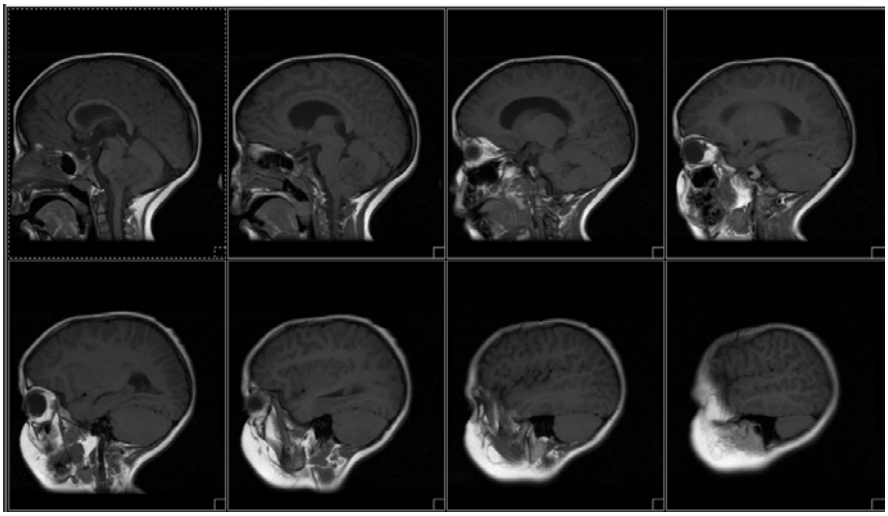
3D Image Modalities	Number of images	Total Size of the images (MB)	Average size per image (MB)
10 MR sets	886	352.69	0.39
4 US sets	164	47.84	0.29
10 CT sets	567	287.83	0.50

3.2 Results of Evaluation

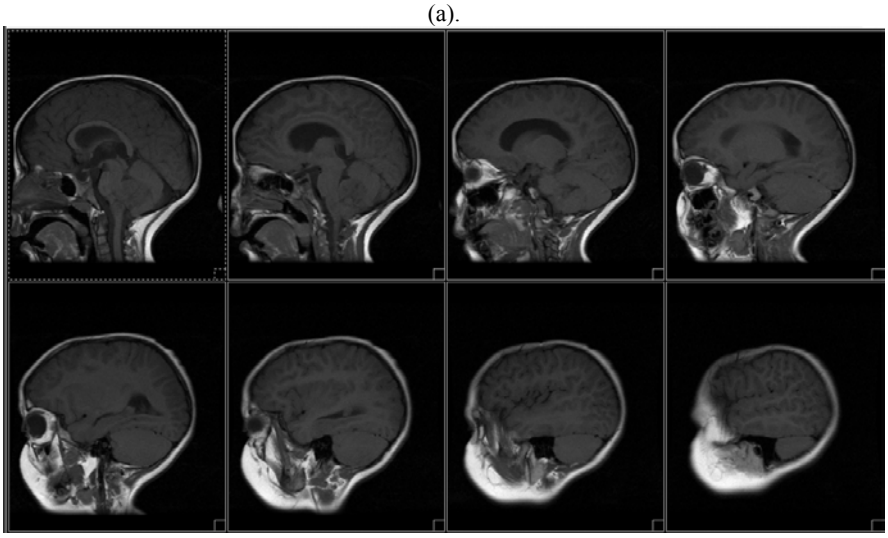
3.2.1 Examples

Figures 2 and 3 show the examples of an MR brain volume set and a CT coronal chest volume set from the results. The examples show a part of the images from these three volumes sets, the corresponding signature embedded images, and the subtracted images acquired by individually subtracting the original image from the corresponding signature embedded image. There was no visual quality degradation in the signature embedded images (e.g., Figure 2(b)) compared to the original images (e.g., Figure 2(a)). This is because the digital signature was embedded in the bit planes (e.g., least significant bit plane) containing most of noises.

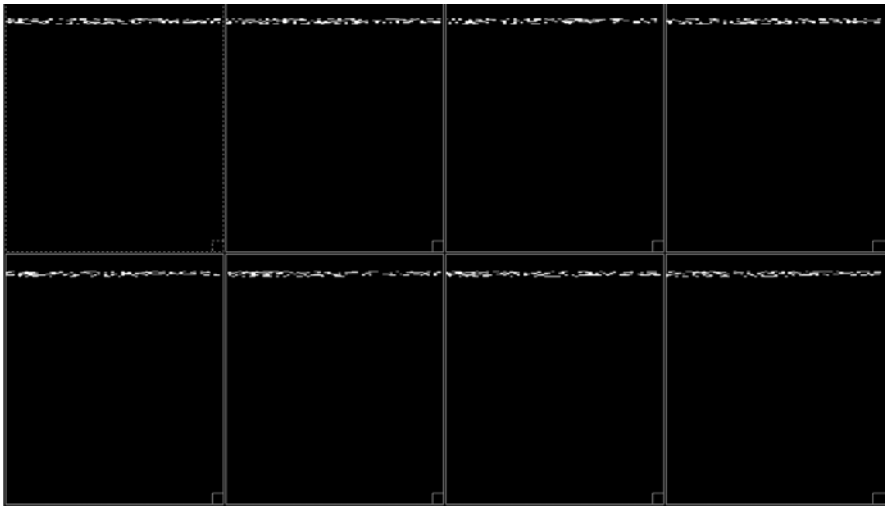
An intuitive view of the pixels being changed during the data embedding process can be observed from the subtracted images in Figures 2 and 3. A horizontal strip shape pattern can be observed in every subtracted image of the volume set (e.g., Figure 2(c)). The strip shape shows that every bit embedding changed four adjacent pixels in the 3D LDSERS algorithm.



(a).

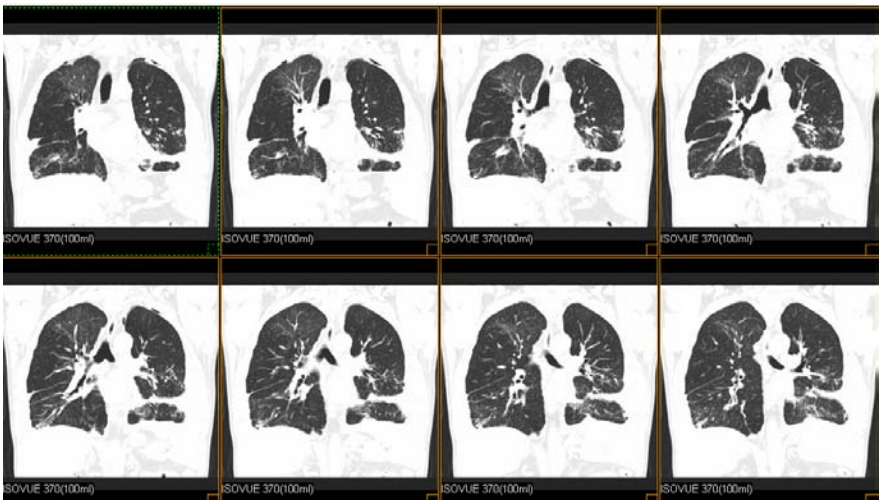


(b)

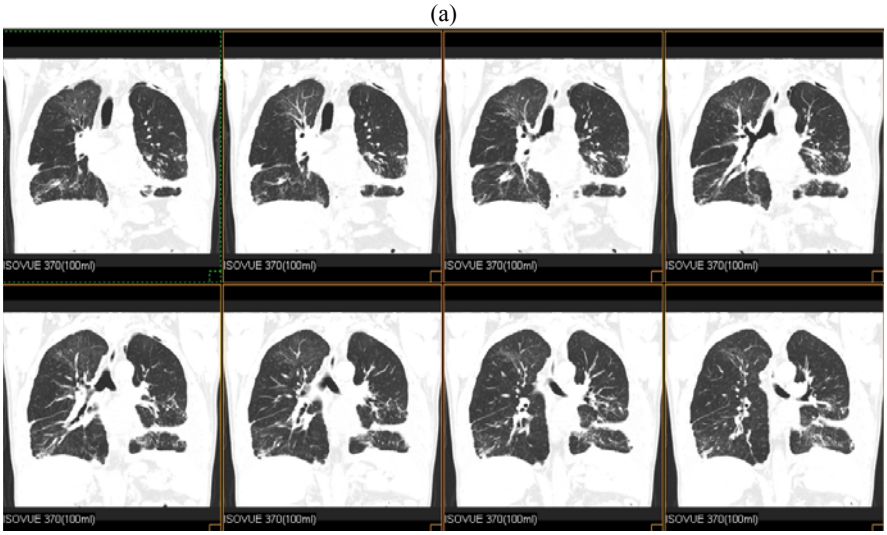


(c)

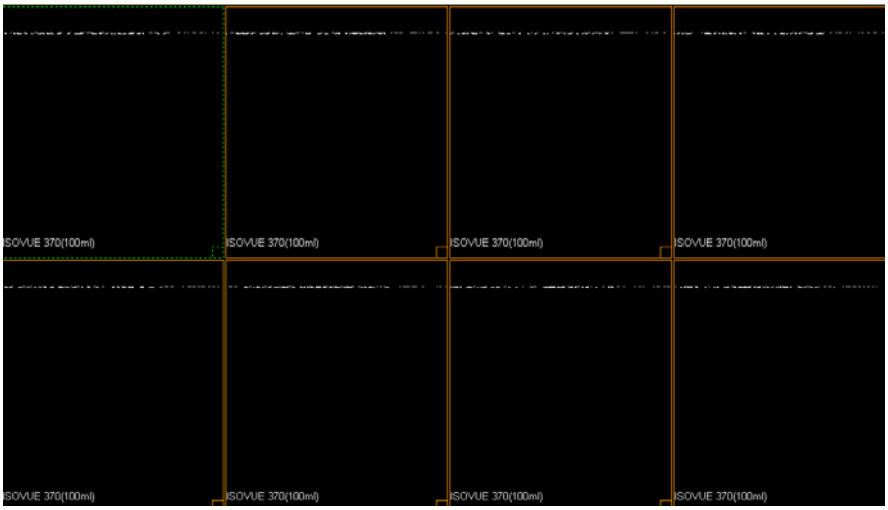
Figure 2 Example of the results of MR Brain volume. (a) Eight consecutive images of the original MR volume. (b) The same images as in (a) with a partial digital signature embedded. (c) The subtracted images between (b) and (a) showing where the digital signature is embedded.



(a)



(b)



(c)

Figure 3 Example of the results of reformatted CT Coronal Chest volume. (a) Eight consecutive images of the original CT volume. (b) The same images as in (a) with a partial digital signature embedded. (c) The subtracted images between (b) and (a) showing where the digital signature is embedded.

3.2.2 Time Performance of the 3D LDSE Method

The time performance of the 3D LDSERS has been recorded and some of the results tabulated in Table 2. In order to compare these results to 2D LDSERS for every image in the volume, the process time of 2D LDSERS has been computed by multiplying the process time of individual image [7] with the number of images in the same volume sets and the computed results are tabulated in Table 3. The process time of "Sign" or "Verify" of every volume set using 3D LDSERS is faster than 2D LDSERS by about 0.3 seconds. This is because only one digital signature was generated for a volume set in 3D LDSERS resulting in a faster performance time for public key encryption required in digital signature. For example, to generate 10 digital signatures for 10 images in the volume would need ten times public key encryption, whereas it only needs one encryption using 3D LDSERS. This reduction saved process time, since the public-key encryption was a relatively slow process [9].

A more significant improvement in time performance happened in the "Embed" or "Extract" processes. The process time for most exams using 3D LDSERS was about 10 times less than 2D LDSERS correspondingly. The maximum difference was about 60 times less for CT set 2 by using the 3D than by the 2D LDSERS method. Also, the time of "Embed" or "Extract" process was shorter than the time of "Sign" or "Verify". When the number of images in the volume set became larger, the former was only about a tenth of the latter. These results show that the time of "Embed" or "Extract" process becomes almost ignorable when the number of images increases in the volume. This indicates that using the 3D LDSERS method for 3D volumes was far more efficient than using the 2D LDSERS method.

3D Volume sets (number of images)	Sign (seconds)	Embed (seconds)	Extract (seconds)	Verify (seconds)
MR set1 (25)	0.125	0.062	0.063	0.125
MR set2 (49)	0.218	0.063	0.063	0.203
MR set3 (40)	0.59	0.063	0.047	0.61
MR set4 (160)	1.734	1.11	1.26	1.67
US set1 (30)	0.281	1.1	0.531	0.282
US set4 (42)	0.391	0.047	0.047	0.375
CT set 1 (69)	1.156	0.157	0.175	1.047
CT set 2 (97)	1.375	**0.062**	0.047	1.328

Table 2 Time performance of the volume sets using 3D LDSERS

3D Volume sets (number of images)	Sign (seconds)	Embed (seconds)	Extract (seconds)	Verify (seconds)
MR set1 (25)	0.381	0.529	0.475	0.325
MR set2 (49)	0.698	0.943	0.881	0.773
MR set3 (40)	0.72	0.72	0.76	0.72
MR set4 (160)	2.515	4.298	3.04	2.4
US set1 (30)	0.42	0.99	1.26	0.39
US set4 (42)	0.588	1.386	1.764	0.546
CT set1 (69)	1.311	2.829	2.001	1.104
CT set2 (97)	1.843	**3.977**	2.813	1.552

Table 3 Time performance of the volume sets computed by multiplying the number of images in the set with the time of individual image using 2D LDSE

4. INTEGRATE 3D LDSE WITH CLINICAL 3D IMAGE WORKFLOW

Integration of the 3D LDSE method with a typical clinical 3D image workflow [10] is focused on how to protect the integrity of all images involved in the workflow profiles anytime at anywhere without interrupt the clinical data flow.

As shown in Figure 4, the integration of the 3D LDSE method with the 3D image workflow is as follows:

1. The original exam is generated in a 3D imaging modality. Before the exam is stored in the archive, a signature of each series of the exam is embedded in the image set of the series using the 3D LDSE method. The signature embedded exam is then sent to the image server for archiving. Thus, the integrity of the original image exam is assured when the exam is in transit and in archive.
2. The signature embedded exam is sent to a 3D post-processing workstation.
3. When a series of reformatted images (e.g., a CT coronal reformatted series) is generated in the 3D post-processing workstation, a signature of this image set is also generated and embedded in the image set using the 3D LDSE method that has been installed in the workstation.
4. The signature embedded series of reformatted images is sent to the image server for archiving. It is important to notice that no changes are made to the signature embedded original exam because the new signature is only embedded in the reformatted image series.

5 & 6. Once the exam is retrieved to the diagnosis workstation or the review workstation, the integrity of the exam can be verified anytime on demand.

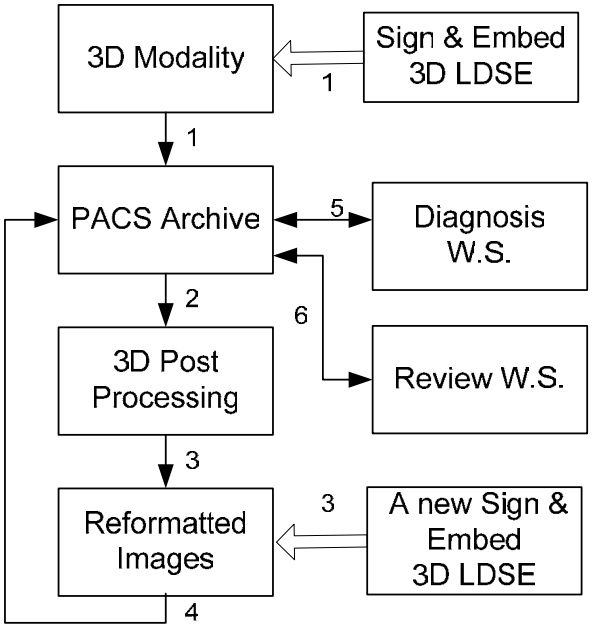


Figure 4 Integration of 3D LDSE with clinical 3D image workflow.

5. CONCLUSION

With the advent of 3D imaging modalities, a clinical CT or MR exam can contain hundreds, or even thousands of, images. We have developed a 3D LDSE method specifically for assuring the integrity of 3D image volumes in order to improve the efficiency and time performance of 2D LDSE method [7] applied in 3D image volumes. Our experimental results demonstrate that the 3D LDSE method is effective for assuring the integrity of 3D image volumes and is far more efficient for 3D image volumes than the 2D LDSE method. The integration of 3D LDSE method with the clinical 3D image workflow furthermore demonstrates that the 3D LDSE method can be seamlessly integrated with clinical imaging systems like a PACS for assuring the clinical 3D image volumes.

REFERENCES

1. S.B. Berger and B.B. Cepelewicz, "Medical-legal issues in tele-radiology," *Am. J. Roentgenoloy*, vol. 166, pp. 505-510, 1996.
2. L. Berlin, "Malpractice issue in radiology-teleradiology," *Am. J. Roentgenoloy*, vol. 170, pp. 1417-1422, 1998.
3. G.H. Kamp, "Medical-legal issues in teleradiology: a commentary," *Am. J. Roentgenoloy*, vol. 166, pp. 511-512, 1996.
4. Information processing systems, Open systems Interconnection, Basic Reference Model-Part 2: Security Architecture, *ISO* 7498-2, 1989.
5. J.G. Hodge Jr., G.O. Lawrence, and P.D. Jacobson, "Legal issues concerning electronic health information: privacy, quality, and liability," *J American Medical Association*, vol. 282(15), pp. 1466-1471, 1999.
6. A.E. James Jr., E. James III, B. Johnson, and J. James, "Legal considerations of medical imaging," *J Legal Medicine*, pp. 87-113, 1993.
7. Z. Zhou, "Lossless digital signature embedding for medical image integrity assurance", *Ph.D. dissertation Chapter 2*, Univ. of Southern California, Los Angeles, CA, Aug. 2005.
8. Z. Zhou, H.K. Huang, B.J. Liu, Digital signature embedding for medical image integrity in a data grid off-site backup archive, *Proc. SPIE Medical Imaging*, vol. 6, pp. 306-317, 2005.
9. A.J. Menezes, P.C. Oorschot, and S.A. Vanstone, *Handbook of Applied Cryptography*, CRC Press, 1997.
10. Integrating the Healthcare Enterprise (IHE) Technical Framework Volume I: Integration Profiles, 2005.

A DICOM-RT Based ePR Radiation Therapy Information System for Decision-Support of Brain Tumor Patients

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ABSTRACT

The need for comprehensive clinical image data and relevant information in image-guided Radiation Therapy (RT) is becoming steadily apparent. Multiple standalone systems utilizing the most technological advancements in imaging, therapeutic radiation, and computerized treatment planning systems acquire key data during the RT treatment course of a patient. One example are patients treated for brain tumors of greater sizes and irregular shapes that utilize state-of-the-art RT technology to deliver pinpoint accurate radiation doses. Various treatment options are available to the patient from Radiation Therapy to Stereotactic Radiosurgery and utilize different RT modalities. The disparate and complex data generated by the RT modalities along with related data scattered throughout the RT department in RT Information/Management systems, Record & Verify systems, and Treatment Planning Systems (TPS) compromise an efficient clinical workflow since the data crucial for a clinical decision may be time-consuming to retrieve, temporarily missing, or even lost. To address these shortcomings, the ACR-NEMA Standards Committee extended its DICOM (Digital Imaging & Communications in Medicine) Standard from Radiology to RT by ratifying seven DICOM RT objects starting in 1997. However, they are rarely used by the RT community in daily clinical operations. In the past, the research focus of an RT department has primarily been developing new protocols and devices to improve treatment process and outcomes of cancer patients with minimal effort dedicated to integration of imaging and information systems. By combining our past experience in medical imaging informatics research, DICOM-RT expertise, and system integration, our research involves using a brain tumor case model to show proof-of-concept that a DICOM-Standard electronic patient record (ePR) system can be developed as a foundation to perform medical imaging informatics research in developing decision-support tools and knowledge base for future data mining applications. As an initial first step, we will develop a methodology to perform medical imaging informatics research on a clinical scenario where brain tumor patients undergo treatment planning for either radiosurgery or radiation therapy. Specifically, we will research the "inverse treatment planning" process that is used for those types of treatments and integrate decision-support knowledge and tools designed to assist in the decision-making process, thus introducing an improved "*knowledge-enhanced* treatment planning" approach.

Keywords: DICOM-RT, ePR, Inverse Treatment Planning, Brain Tumors

1. INTRODUCTION

Stereotactic radiosurgery is the use of high intensity radiation to ablate a targeted area without much damage to its surrounding normal tissue. It has been used for over 30 years for treating brain tumors and other disorders. Throughout the years, different equipment has been invented to facilitate such treatment, ranging from the Gamma Knife to X-knife to Cyberknife. Though accurate, the design of the Gamma Knife limits its use to brain only and requires an invasive immobilization device for framing. The X-knife operates using conventional linear accelerator with modifications making it less accurate to treat tumors. Both the Gamma Knife and the X-knife have been utilized by the RT department for many years now. The Cyberknife system is a newer radiosurgery system that utilizes two distinct innovative technologies. First, it tracks and verifies tumor location to enable automatic compensation for tumor movement utilizing a proprietary image-guidance system. This image-guidance system eliminates the need for an invasive immobilizing device making it frameless. Second, it utilizes a multi-jointed robotic arm with six degrees of freedom to deliver radiation to previously unreachable tumors, reducing damage to surrounding critical structures [1]. This allows for treatment of brain tumors greater than 3.5 cm, irregular shaped tumors, and multiple lesions in the same treatment session with minimal damage to surrounding tissue. For both the Gamma Knife and the Cyberknife treatment planning systems, currently CT studies are utilized to plot the treatment plan with MR studies to help delineate critical structures and tumor volumes.

For radiation therapy, Intensity-modulated radiation therapy (IMRT) is an advanced mode of high-precision image-guided radiotherapy that utilizes a computer-controlled x-ray linear accelerator along with dynamic multi-leaf collimators which are

devices that use up to 120 movable "leaves" to deliver precise radiation doses to a malignant tumor or specific areas within the tumor. The radiation dose is designed to conform to the three-dimensional (3-D) shape of the tumor by modulating the intensity of the radiation beam to focus a higher radiation dose to the tumor while minimizing radiation exposure to surrounding normal tissues. Treatment is carefully planned by using computed tomography (CT) images of the patient in conjunction with computerized dose calculations to determine the dose intensity pattern that will best conform to the tumor shape. Typically, combinations of several intensity-modulated fields coming from different beam directions produce a custom tailored radiation dose that maximizes tumor dose while also protecting adjacent normal tissues. Because the ratio of normal tissue dose to tumor dose is reduced to a minimum with the IMRT approach, higher and more effective radiation doses can safely be delivered to tumors with fewer side effects compared with conventional radiotherapy techniques. IMRT also has the potential to reduce treatment toxicity, even when doses are not increased. Currently, IMRT is being used to treat cancers including patients with brain tumors.

In planning treatment either utilizing the TPS for Cyberknife or the TPS for IMRT treatment, the physician designates specific doses of radiation that the tumor and normal surrounding tissues should receive. The physics team then uses sophisticated computer programs to develop an individualized plan to meet the constraints. This process is termed "inverse treatment planning." Due to this "inverse treatment planning" characteristic, expert *a priori* knowledge is required before treatment planning. Therefore, decision-support can potentially improve *a priori* knowledge with historical knowledge as well as quantification and visualization tools to assist in the development of the treatment plan and shorten the learning cycle.

In order to perform treatment planning and to track the progress of the treatment of brain lesions of patients, clinically relevant data needs to be retrieved from various sources. For example, treatment records for a single RT session would either be stored on paper or within an RT information management system. Most of these systems can receive DICOM PACS studies which are used to perform treatment planning. However, the treatment planning systems (TPS) generate image-related data such as isodose curves and structure contours overlaid on diagnostic images. RT image data such as reference images either come from a simulator or from the TPS (eg, DRR's). Finally, each RT modality may have verification images (eg, portal images) acquired for a treatment session. In order to review a patient's case with brain tumors, the physician and physicist must interface with these various data sources which increase time and inefficiency in the RT department. Although some RT image data (eg, portal, simulator, DRR, etc) are already DICOM-RT compliant, there are still pertinent data from both the TPS and the record and verify systems (eg, critical structure curves, isodose lines, dose volume histogram (DVH) curves, etc) that have yet to be addressed. Each RT modality contains a separate proprietary treatment planning system with no standard for retrieving the pertinent clinical data. The two examples used in this paper, the Cyberknife TPS and the TPS for IMRT treatments reflect these inherent shortcomings

With the emergence of PACS as an imaging informatics tool, it has improved the workflow efficiency within the Radiology Department. [2] RT and the utilization of image-guided RT Systems to treat tumors have benefited from PACS and the DICOM standard by utilizing clinical images from Radiology. However, the real benefit to an RT department is to extend the experience and knowledge gained from system integration of PACS and modalities to the various sources of clinical data dispersed within the RT department. To date within the RT department, one of the biggest challenges towards an effective and efficient clinical workflow is integrating pertinent image and image informatics data into one source point for all clinical users. [3] These include a lack of formal methodology to define the clinical workflow of tumor cases, lack of system integration, and insufficient IT experts in RT-related applications. The need for an integrated solution utilizing a DICOM-based ePR server becomes apparent. In addition, the redesign of workflow to incorporate the information will help to enrich not only the electronic patient records but also provide a platform for researching and developing decision-support tools. Given this backdrop, the implementation of a DICOM ePR server would be an effective and efficient one-stop-shop source for tracking the treatment progress of patient's with brain tumors by merging the data from the various sources and present them in a user interface that will be designed for ease-of-use. In addition and more importantly, it provides a foundation of standardized data objects with which to build a knowledge base and data mining tools for clinical decision-support that would have been much more challenging to accomplish without standardization of this RT imaging and informatics data within the ePR system.

Various generic RT information/management systems feature the availability of necessary clinical data within the RT department. However, the most complete clinical data model is from the proposed DICOM-RT based ePR system of this research. Furthermore, the DICOM-RT based ePR system features open system integration based on the DICOM standard instead of proprietary like other RT information/management systems. In summary, the DICOM-RT based ePR system has the following superior features:

- Complies with DICOM-RT Object definitions
- Global data distribution
- Global Treatment Updates
- Open System Integration

This research aims to present a methodology to first standardize data into the DICOM-RT based data model, and then build a knowledge base and data mining tools for clinical decision-support. These tools can then be used within the ePR system as add-on features to improve the decision-making process of clinicians in the RT field.

2. METHODS AND MATERIALS

2.1 .Workflow Model for RT of Brain Tumors

One of the most important first steps for system integration of clinical image and information systems is to research the workflow model of the clinical operations. Since the focus of this research will be on patients with brain lesions, the workflow related to these particular treatment cases will be studied. A general clinical workflow model for radiation treatment of brain tumor cases was developed for the Departments of Radiology and Oncology as shown in Figure 1. The treatment begins with the patient diagnosed with brain lesion or multiple brain lesions. The Patient meets with the physician(s) and determines whether to treat the tumor(s) but also what type of radiotherapy will be performed. The patient is entered in an oncology information system and is scheduled for treatment. If conventional RT is prescribed, then a simulator image may be acquired. Otherwise, depending on the treatment type, a diagnostic CT will be acquired to plan the treatment. In both Cyberknife and IMRT treatment planning, a CT is used for treatment planning. The Radiologist and Radiation Oncologist review the patient's case and then the Radiation Oncologist defines the initial plan parameters such as dose limits and constraints, critical structures, and tumor volume to be treated. The physics team then computes the plan based on these dose constraints on the corresponding TPS. Once the initial plan is computed, the Oncologist reviews the results and makes any necessary changes. This process can be iterative and the feedback loop is defined in Figure 1 by a dashed line region. Once the treatment plan has been approved, the treatment session is executed by the Radiation Therapist, the corresponding RT plan data are stored in the treatment planning systems of the RT modalities and some results are also inputted into the oncology information system or a Record and Verify system. Since there are a variety of brain tumor types, and the treatment paths can differ, it is important to research and develop a more robust workflow model that can accommodate the various treatment paths and identify points within the workflow that can be improved. Not only would this enhance the design of the DICOM-based ePR System, but also serve as the foundation for a methodology to build quantification and visualization tools for decision-support. In this case, the iterative feedback loop is identified as a potential area of improvement. The feedback loop represents the inverse treatment planning process and can be quite tedious if much iteration is necessary. This becomes the area of focus where decision-support tools may benefit during the decision-making. If more *a priori* knowledge and robust quantification and visualization tools can be included during the decision-making process of the initial plan parameters, then it is possible to reduce the iterative process.

2.2 DICOM-RT Data Model Development

The DICOM (Digital Communication in Medicine) standard has been well established and widely successful for clinical imaging systems in Radiology, in particular PACS (Picture Archiving and Communication System). Image data acquired from equipment from different vendors can readily communicate with each other and integrate into a system through the DICOM standard. In 1997, the DICOM standard was extended to include radiotherapy information and further updated in the latest version released in 2003. [4,5] Seven DICOM radiotherapy (DICOM-RT) objects have been included by the DICOM standards committee for transmission and storage of radiotherapy

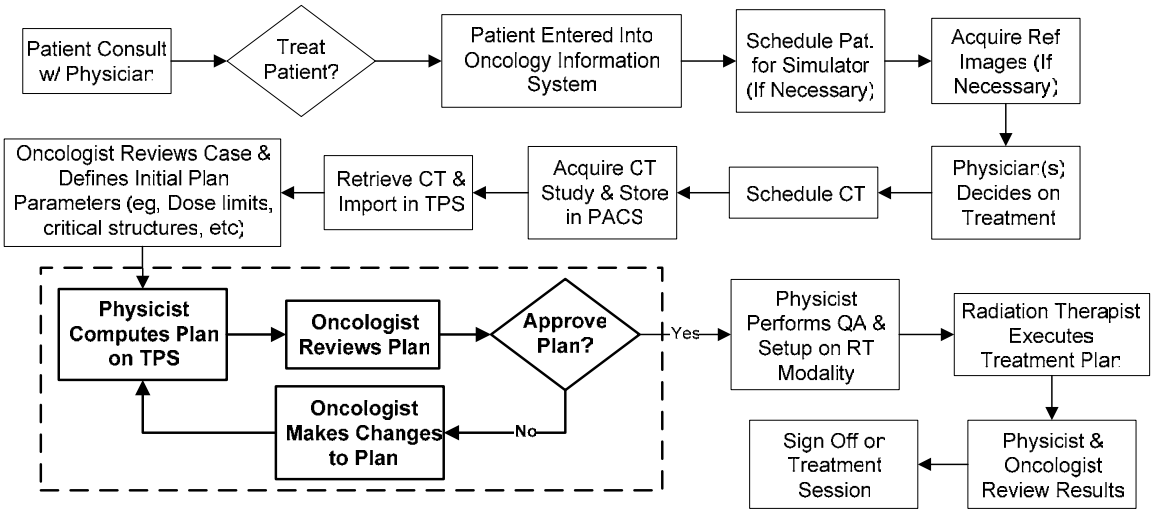

Figure 1: General Clinical Workflow for RT of Brain Tumors.

images and related information. These DICOM-RT objects are: 1) RT Image, 2) RT Plan, 3) RT Structure Set, 4) RT Dose, 5) RT Beams Treatment Record, 6) RT Brachy Treatment Record, and 7) RT Summary Record as shown in Figure 2. [6] Generally, the sources for these data comes from a treatment planning system (TPS), a RT information system, and both RT and Radiology modalities. The DICOM-RT object information models can be utilized to develop the data structure for the electronic patient record. To develop a conceptual data model, the RT workflow must be reviewed to define the data required. Additionally, clinical user input is needed as well. With these input sources, a conceptual model can be developed for an RT electronic patient record.

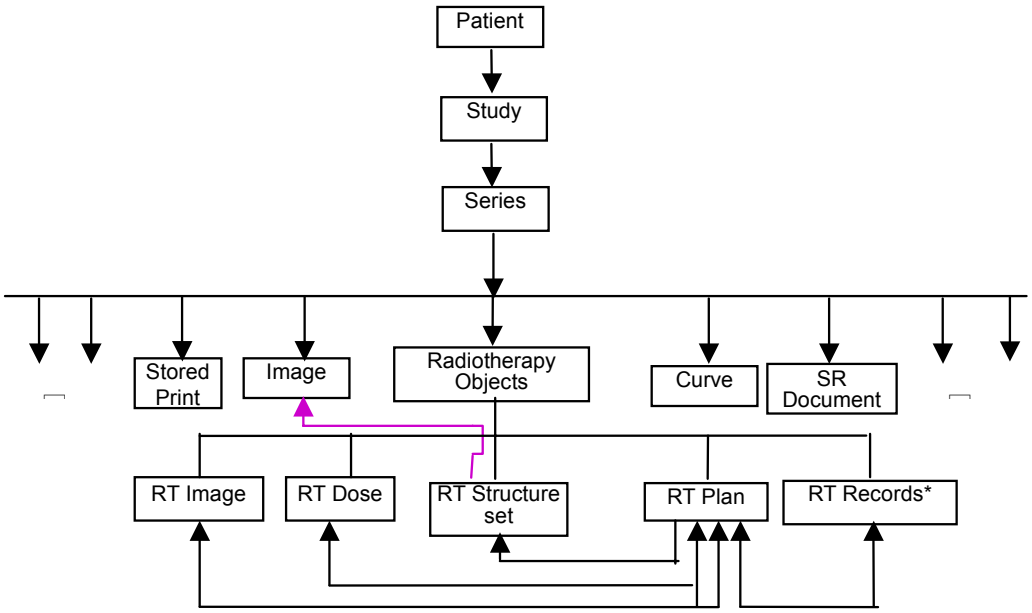

Figure 2: Portion of the DICOM Model of the real world. Note that the three records in DICOM-RT (Beam, Brachy, and Summary) are grouped under RT Records as denoted with the asterisk.

2.3 Data Collection

A data survey was performed to track patient cases utilizing the clinical information systems at USC/HSC. Patient cases that exhibit brain tumors were tracked to determine the treatment path and outcome. These results were implemented into the clinical workflow model. Brain tumor cases from the USC Oncology department will be tracked. From these brain tumor cases, a total of 50 cases treated by the Cyberknife will be extracted for a specific workflow model and later conversion into the DICOM-RT data model. In addition, 50 brain tumor cases of patients who are treated with IMRT will also be collected. The preliminary data collection survey was performed to determine the feasibility of data collection for the treatment of brain tumors at USC/HSC. The brief survey was performed using clinical information systems to track historical patients and their records. During the past 6 months, a total of ninety-four brain tumor cases were identified. The data survey was performed under the HIPAA Regulations and Compliance Guidelines set forth by USC. In addition, one sample data set each from the Cyberknife TPS as well as the IMRT TPS was reviewed and determined to be feasible to convert the non-DICOM data into DICOM-RT compliant objects. The results will be discussed in Section 3.

2.4 System Integration

In June 2004, a fully filmless and paperless environment was implemented at the Health Care Consultation Center II (HCCII) located on the Health Science Campus, University of Southern California. The PACS implemented at HCCII stores Radiology clinical images and was designed with long-term storage capable of supporting the entire Health Science Campus' clinical image data. The Radiation Oncology department features the latest state-of-the-art image-guided RT systems, including the Cyberknife, which was installed at the Norris Cancer Center and has been in clinical use since October 2002. [7] The entire HSC has connectivity to the two systems, which makes the integration of a DICOM ePR system possible. For the DICOM RT ePR system, a three-tier architecture was developed [8]: 1) The RT archive server manages, archives and distributes DICOM images and DICOM-RT objects, 2) The RT web-based application server processes patient planning and treatment data, and 3) the RT web-based client application presents the RT data. The database schema reflects this three-tiered system by physically representing the data as well as providing data structures, file organizations and mechanisms for system operation as well as data storage. In the design of the RT workflow, there are two database schemas developed; one for the RT archive server and the second for the RT web-based ePR application server. Because there is more RT data presentation at the web-based application server level, the latter database schema is much more complex as compared to the RT archive server. Based on the Data Model and the Clinical Workflow Model, the data workflow was designed based on Figure 3 for system integration [8].

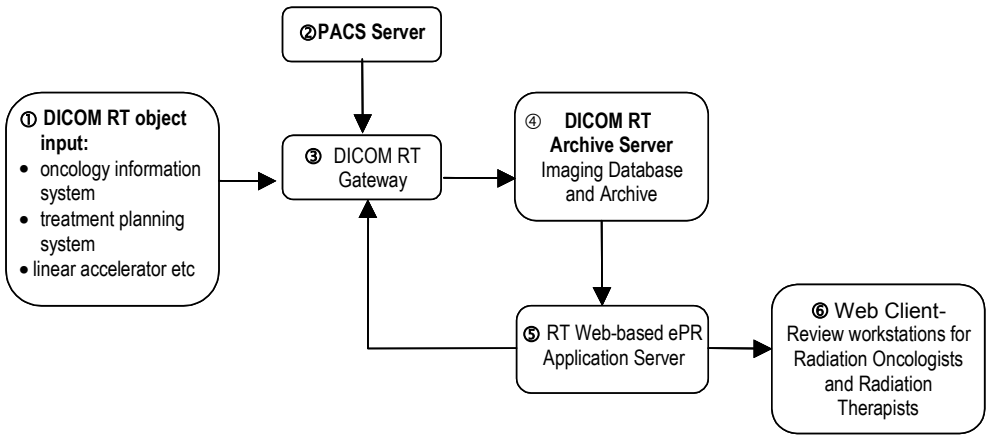

Figure 3: The RT Data Workflow. 1) RT data input from various different RT sources; 2) Diagnostic images from Radiology PACS; 3) Conversion into DICOM-RT objects by the DICOM-RT Gateway; 4) RT archive server stores, manages, and distributes RT data; 5) RT web-based ePR application server further manages and prepares patient planning and treatment information; 6) Web-based client review workstation displays RT-related data for clinician review.

Data from the Oncology Information System, Cyberknife TPS, and IMRT TPS will be converted into DICOM-RT objects and sent to the DICOM RT Gateway. The diagnostic images will be sent from the USC PACS Server into the DICOM RT Gateway as well. Once the DICOM-RT objects have been received by the DICOM RT gateway, they will be sent to the Archive server. A database schema will be developed for the archive server so that the DICOM RT objects can be archived and distributed to the web-based application server. This archive server is a Continuous Available (CA) server design with 99.999% uptime that has been utilized for a variety of clinical applications. [9,10]

Integration of the DICOM-RT ePR System within the clinical environment will include evaluating the target feedback loop shown in Figure 1 where the iterative process of inverse treatment planning to determine whether additional knowledge and decision-support tools improve the overall decision-making process. It is crucial for both the oncologists to have every available clinical imaging and information data to make as accurate a decision as possible. Because image-guided treatment planning systems data can be complex, the presentation of the image and information data may reflect that same level of complexity. Based on input from both Radiation Oncologists and Radiation Therapists at USC/HSC married with existing data and workflow models, a database schema and user interface design was developed to meet the clinical needs. This was implemented in the Web-based application server as well as the web client. [8]

2.5..Knowledge Base Development

Utilizing the clinical workflow model as a basis, a clinical scenario is identified where clinical decision-making is crucial from the physician and the tools to help this decision-making process are lacking. The first objective is to define the knowledge. The starting point for defining knowledge is based on the expert's ability, in this case, the oncologist and the physicist, to utilize data and other criteria in evaluating, grouping, and defining certain clinical characteristics that are extracted from the standardized DICOM-RT objects stored within the ePR system. This is achieved with expert guidance (eg, oncologist, physicist, etc), by defining the object classes, the class attributes and features, the class hierarchy, and the relationships between each of the classes. Query and search engine tools will be researched and developed to mine the knowledge base which can potentially assist in the clinician's decision-making process, such as when the oncologist needs to review a treatment plan and determine whether it should be approved or further modified and would like to reference previous treatment plans to gain an understanding of what criteria was used to approve previous plans. Additionally, quantification and visualization tools will be developed to extract and present pertinent knowledge for the clinician to review and utilize as a decision support tool. The knowledge base will be designed in an object-oriented and modular fashion so that additional knowledge and new object classes defined in the future can be easily integrated without affecting the overall design. This medical imaging informatics approach is a unique and novel approach towards development of clinical decision-making tools for the RT field. Although current manufacturers have the ability to develop such tools within the TPS, their primary focus has been in high-computational complex calculations and re-calculations of treatment plans. In addition, they have been slowed in part by the lack of availability of standardized DICOM-RT data objects.

2.6..Data Mining for Knowledge and the Development of Quantification and Visualization Tools

Once knowledge has been defined and identified, tools will be developed accordingly to mine the knowledge base. These tools serve as the foundation for building quantification and visualization features for the clinician end-user to utilize during the decision-making process. Data mining tools need to be developed in order to mine the knowledge base to automatically identify and extract the knowledge from the ePR system. This will be achieved through the guidance of an oncologist and

based on the current standard of practice. Tools will be developed accordingly to mine this knowledge which will eventually be utilized by the physician with appropriately developed quantification and visualization tools.

In the long term, as more knowledge data is collected from additional brain tumor patients treated, the knowledge base will be enriched. With data mining tools, knowledge data can be quickly extracted and presented to aid the oncologist and physicist for a new patient case to assess and determine the best treatment plan even before the very first plan is calculated. The following workflow steps show how data mining can provide decision-support based on our clinical scenario:

1) Oncologist or Physicist outlines a critical structure on a new brain tumor patient plan.
2) Critical structure converted to DICOM-RT object and sent through the ePR system and received at the web-based ePR application server.
3) Search engine tools in the web-based application server will automatically mine knowledge base for historic brain tumor cases with the critical structure.
4) Historic cases with critical structure knowledge is selected and corresponding DVH, isodose, critical structure curves, as well as the diagnostic image slices will be displayed using quantification and visualization tools.
5) Since historic cases are approved plans, the oncologist and physicist can utilize the tools to quickly review the automatically retrieved knowledge data to determine what acceptable dose plan constraints are as a guide to better plan the treatment of the new patient.
6) With these knowledge-enhanced dose constraints, the treatment plan is computed by the physicist.
7) TPS results are converted into DICOM-RT objects and sent to the ePR application server.
8) TPS results for the critical structure for the new treatment can be further assessed both with the tools as well as the already retrieved historic data and a final decision can be made.

Figure 4 shows the *knowledge-enhanced* inverse treatment planning workflow with the ePR system integrated with dashed lines. This knowledge-enhanced inverse treatment planning approach may eliminate the feedback loop and subsequent iterative steps of re-computing of a treatment plan since the first attempt was acceptable based on the prior knowledge. Because each plan is computationally complex and time-consuming, a best practice first computed plan aided by previous knowledge would greatly enhance the decision-making process and ultimately shorten the length of time before the patient is exactly treated as well as better preserve normal tissue and quality of care.

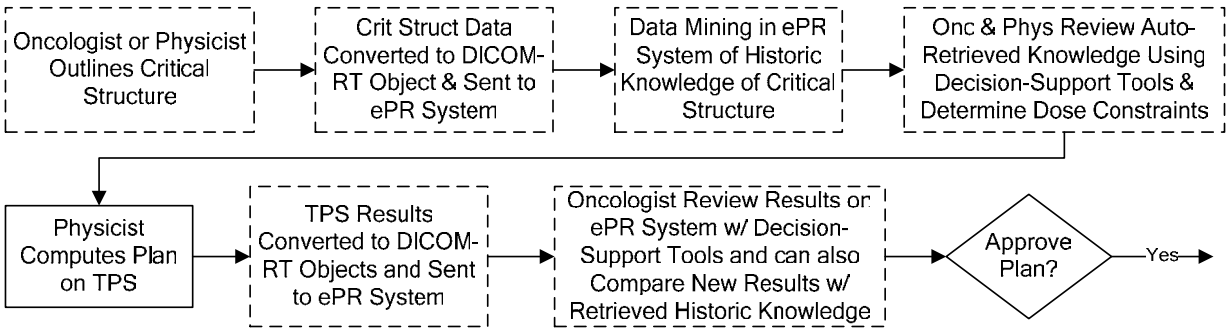

Figure 4: Knowledge-enhanced Inverse Treatment Planning. Dashed lines show where workflow steps would be performed in the ePR System as compared to the current feedback loop workflow shown in Figure 1.

Figure 5 shows a summary of the methodology for standardizing RT data into DICOM-RT objects and performing Medical Imaging and Informatics research to develop the knowledge base, the data mining, and quantification and visualization tools which ultimately become add-on features to the DICOM-RT based ePR system. With these decision-support tools, the end result is that clinicians can be assisted in their decision-making process for new brain tumor patient cases. This methodology can be applied to different lesion types as well as treatment types to quickly research and develop new decision-support tools.

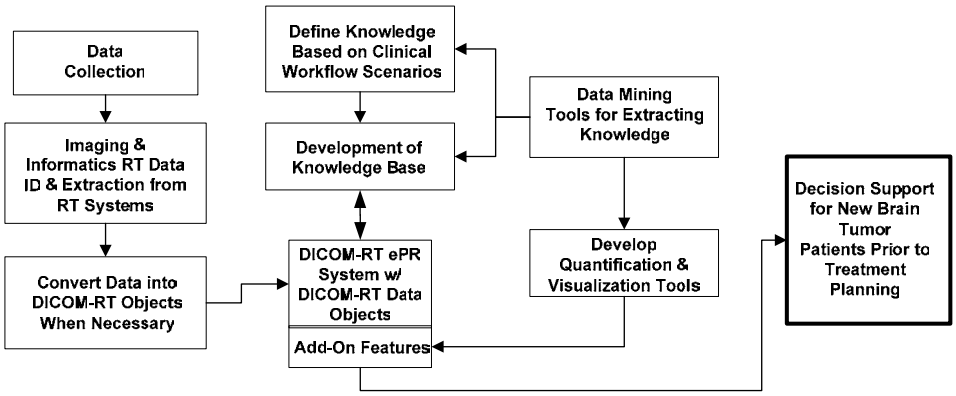

Figure 5: A Medical Imaging Informatics approach towards development of decision-support tools for the DICOM-RT based ePR system. The final results are add-on features for the ePR system to provide decision-support for new patient cases. This methodology can be applied to different lesion types as well as treatment types to quickly research and develop new decision-support tools.

3. RESULTS AND DISCUSSION

This section describes some of the results obtained from sample brain tumor cases treated by the Cyberknife TPSand IMRT TPS and integrated within the proposed DICOM-RT based ePR system. The end result is a comparison between what clinical information is displayed by a conventional RT information system provided by a manufacturer versus that of the richer database of the preliminary DICOM-RT based ePR system which can provide more information in the display. In addition, some preliminary knowledge base and quantification/visualization tools development has been performed based on a particular clinical scenario of assessing treatment plans of brain tumor patients.

Figures 6, 7, and 8 show initial results of sample data from brain tumor cases displayed by the GUI design of the web-based client of the ePR system. Figure 6 shows CT diagnostic images overlaid with the DICOM-RT structure set that was acquired within the Cyberknife treatment planning system.

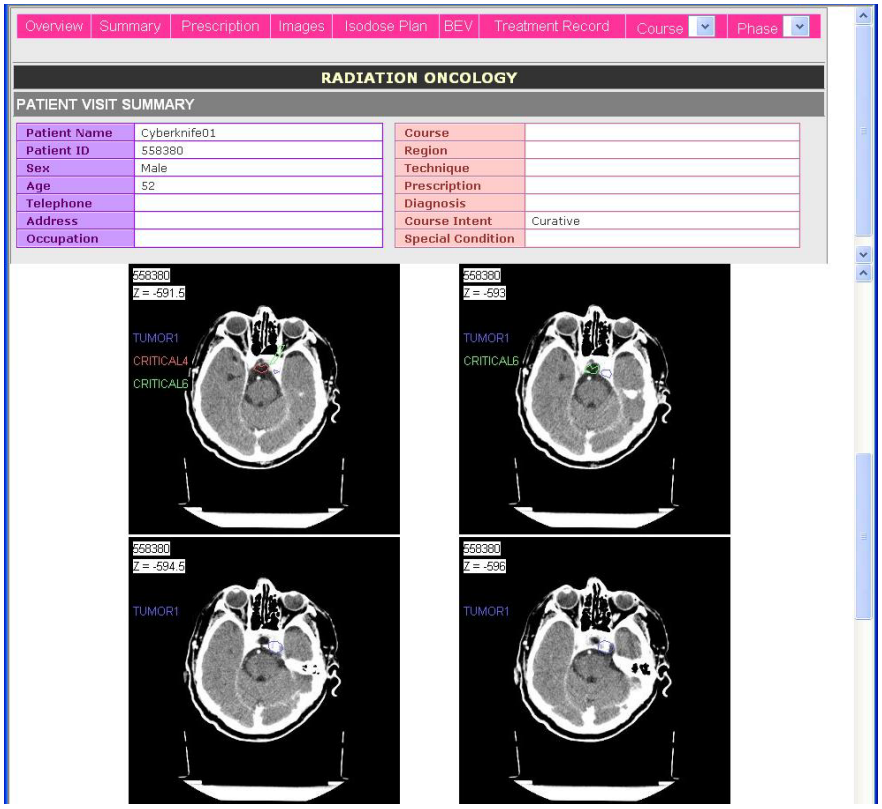

Figure 6: Display Window showing CT diagnostic images overlaid with critical structures obtained from the Cyberknife treatment system. The contours enclosing the tumor (TUMOR1, blue), the optic chiasm (CRITICAL4, red), and the left nerve (CRITICAL6, green) all happen to be displayed on this particular upper lefthand CT image slice.

These overlays represent the critical structures outlined within the Treatment Planning System for the Cyberknife. The blue colored contour encloses the tumor targeted for treatment. The red colored contour encloses the optic chiasm. The green colored contour encloses the left nerve. All three contours are displayed in the upper lefthand CT image slice. Figure 7 shows both critical structures as well as isodose curves representing percentage of dose values to the critical structures from an IMRT treatment of a brain tumor patient. These are also overlaid on the CT diagnostic images. Figure 8 is a timeline overview display showing that a CT and MR diagnostic exam was acquired. Since this particular case is an initial survey, some of the pertinent clinical data was missing, hence an incomplete patient overview. However, it is shown that clinical data from the RT systems can be integrated within the DICOM-RT based ePR system. Referring to Figure 8 (bottom), a conventional RT management information system or record & verify system only has the DICOM RT records but no DICOM RT plan, RT images, and DICOM images. On the other hand, the DICOM-RT based ePR system is able to display information extracted from all of the DICOM-RT objects and can be expanded for more detailed views from the icons on the timeline in the User Interface (both bottom & upper sections).

Data from the Cyberknife TPS and the IMRT TPS were reconstructed and displayed to show how the results are identical to that of the screenshot results of the same TPS. The differences being that data reconstructed in the DICOM-RT based ePR system are converted to DICOM-RT objects that can be further distributed to other clinical areas and DICOM-compliant clinical systems while the data from the Cyberknife TPS are proprietary and difficult to distribute throughout the healthcare enterprise. In addition, this standardized data can be used to develop knowledge based on clinical scenarios as well as data mining tools to extract this knowledge for decision-support.

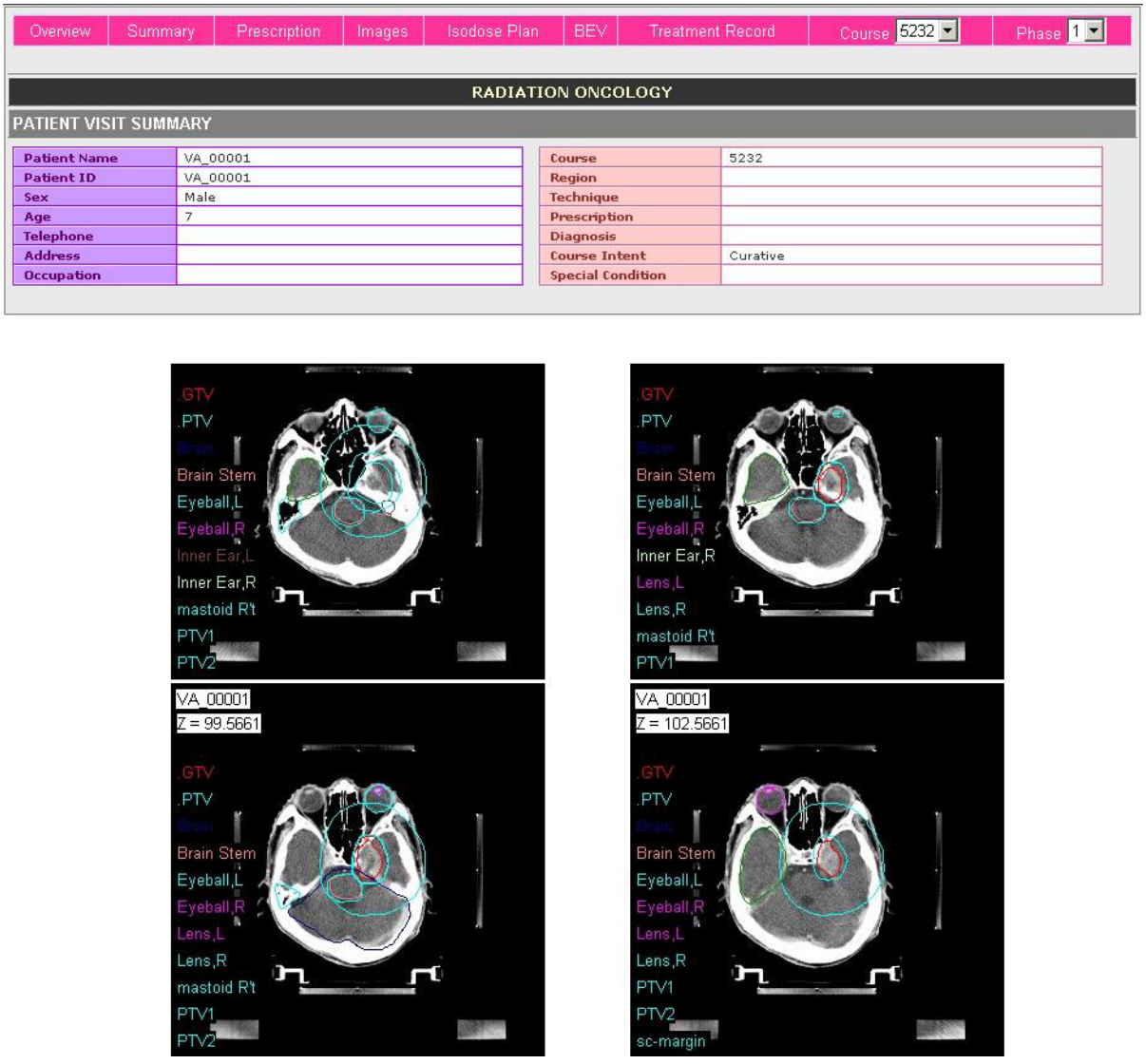

Figure 7: Display Window showing CT diagnostic images overlaid with isodose curves obtained from the IMRT TPS. The contours show percentage dose values calculated for critical structures that have been outlined prior to computing the treatment plan.

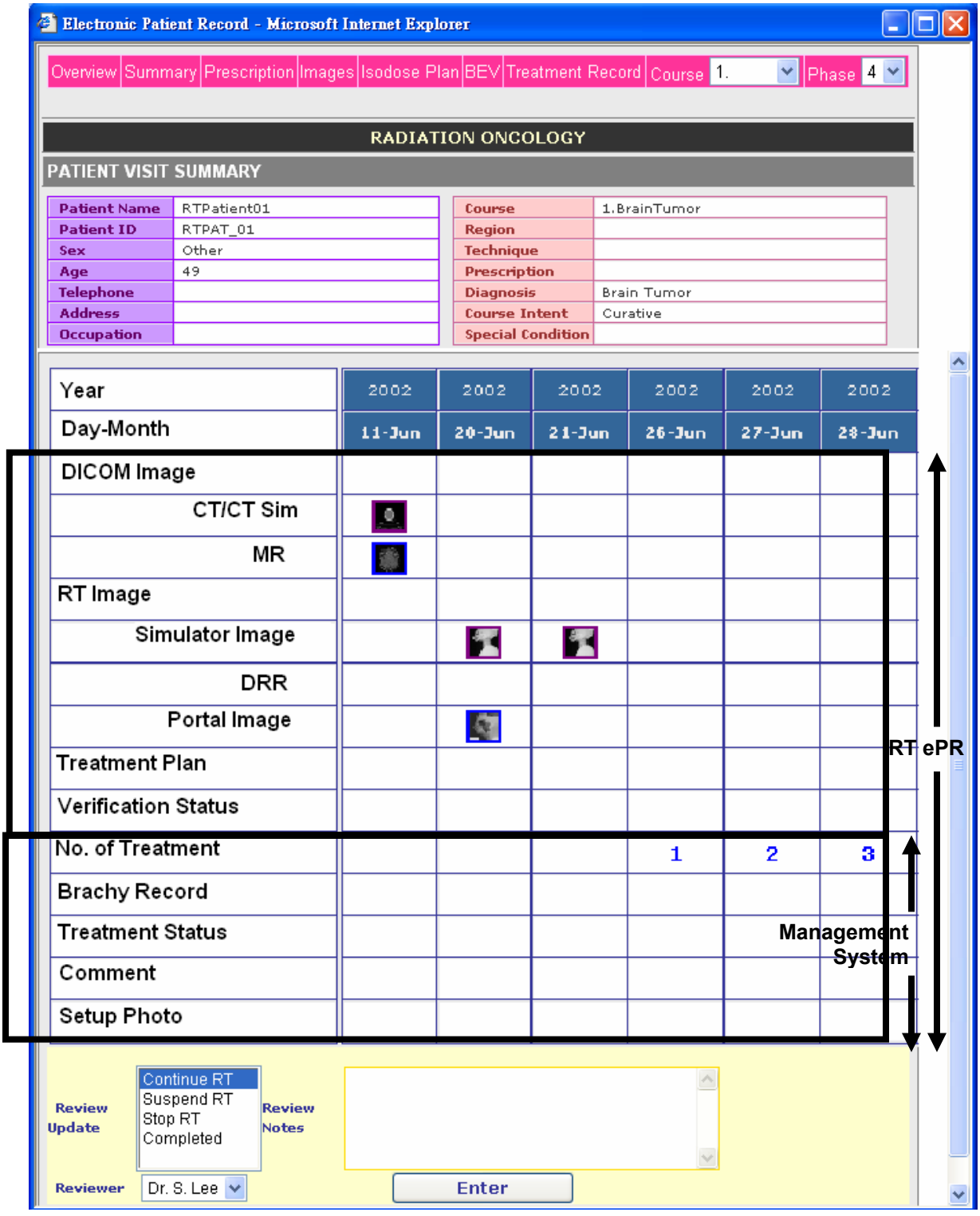

Figure 8: Timeline overview display of a patient in the DICOM-RT based ePR system. The RT ePR system has a richer database than the conventional RT information/management system. A given RT information management system has only the DICOM RT records (Bottom of figure), while the RT ePR is able to display the information extracted from all the DICOM objects including the DICOM RT plan, RT images, and DICOM images.

As a first step towards the medical imaging and informatics approach towards the development of decision-support tools, a clinical scenario where an oncologist needs to assess the isodose plan of critical structures from a treatment plan for a brain tumor patient has been identified and applied to this methodological approach to test and evaluate both the approach as well as the ePR system. During treatment planning for brain tumor patients, the treatment plan developed, usually by the

physicist, must be approved by the oncologist as shown earlier in the workflow in Figure 1. Part of the clinical decision-making process for the physician is to analyze the DVH curves of critical structure areas. These curves only show dose values in relation to the critical structure volume. The physician must then evaluate the various isodose plans to determine whether they are acceptable or whether the plan must be modified and recalculated. In order to make this clinical assessment, the oncologist must navigate through multiple image slices showing multiple isodose curve lines as well as overlapping critical structures to make the assessment. Navigation of all this knowledge, while crucial, is also extremely tedious and complex since there is no tool to quantify and visualize the direct relationship between the DVH curves to the diagnostic images and the corresponding dose and critical structure curves. In this case, the knowledge defined is what is needed to assess a treatment plan for brain tumor patients. The rudimentary knowledge base can be defined into class objects first. For example: 1) DVH; 2) Isodose curve; 3) Critical Structure; and 4) CT image. Then, for each of these classes, attributes can be defined as shown. For example, for the CT Image class, there can be attributes such as 1) Critical Structure Curve; 2) Isodose Curve; 3) Spatial Coordinates; 4) Pointer to Image data; and 5) DICOM data. The relationships between each of the class objects can also be determined and defined. For example, a CT image would contain multiple isodose curves and multiple critical structures. Another example is that a DVH curve represents a critical structure volume. Based on the knowledge defined and the clinical scenario, a tool has been designed to automatically display the DVH curve of a critical structure linked with the diagnostic image slice(s) that contain corresponding isodose curves and critical structure regions. In the case of Figure 10, the Optic Chiasm is a critical structure that is being assessed in a treatment plan.

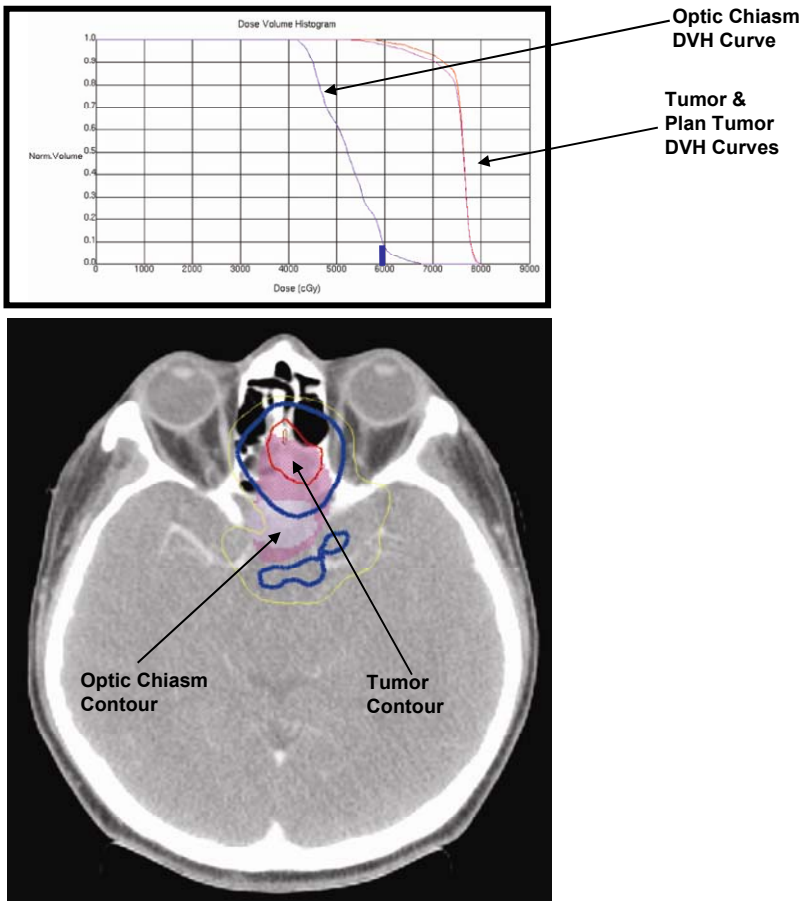

Figure 10: Mockup of the Decision-Support Tool for Clinicians. In this example, the DVH curve for a critical structure volume, the Optic Chiasm, has been automatically displayed. In addition, a CT image slices is automatically extracted and displayed with corresponding critical structure & isodose curves in order of significance. In addition, the user can move up and down the DVH curve above and linked pertinent diagnostic images with both critical structure and isodose curves will be displayed automatically.

The tool eliminates the tedious manual procedure of first analyzing the DVH curves and then having to toggle through a volume of CT image slices with multiple isodose curves to review and assess the plan. Since data is already mined, the exact diagnostic CT image slice together with the exact structure and isodose curves can be automatically displayed the moment the oncologist opens the case within the ePR system. The oncologist would then have the ability to continue to navigate the presented data or view a different DVH curve if desired to make a quicker assessment of the treatment plan for approval. If the oncologist decides that changes are needed in the treatment plan, the decision-support tools can be used to perform a real-time consult with the physicist either at different locations or at the same location or even directly on the treatment planning system, since the ePR is web-based and portable.

4. CONCLUSION

A DICOM-RT based ePR system for managing patients with brain tumor cases was designed and developed within the Radiation Oncology Department at USC Health Sciences Campus. Data obtained from sample brain tumor cases where the treatment was planned on both the Cyberknife TPS and the IMRT TPS was collected and integrated within the ePR system as an initial first step. A methodology was introduced for the development of decision-support tools based on the standardized DICOM-RT data within the ePR system. As a first step proof of concept of how crucial standardized RT data can be, a clinical scenario was developed where knowledge base was defined and quantification and visualization tools were designed to extract the knowledge and display it for a decision-making process. By implementing this DICOM-RT based ePR system, both clinical image and related informatics data are integrated into a one-stop source of pertinent clinical information necessary for making treatment decisions within the RT department and throughout the healthcare enterprise. The richness of the clinical data available was shown in comparison to standard RT information management systems. The initial results show the confirmation that the conversion of DICOM-RT objects are correct and can be displayed similar to what is displayed within the proprietary system. More importantly, with the availability of standardized DICOM-RT data, further knowledge base and decision-support tools development can be realized to aid the clinicians in critical decision-making processes. With the medical imaging informatics methodology introduced in this paper, the decision-support and knowledge base development can be easily extended to various lesion types as well as other inverse treatment planning methods. Future work includes the complete development and collection of the knowledge base and tools as well as a clinical evaluation of the decision-support tool design.

REFERENCES

1. Cyberknife, http://www.accuray.com/ck/local16.htm
2. Huang HK. 1999. PACS: Basic Principles and Applications. Wiley & Sons, NY, p. 521.
3. Palta J.R., Frouhar V.A., Dempsey J.F. Web-based Submission, Archive, and Review of Radiotherapy Data for Clinical Quality Assurance: A New Paradigm. In J Radiat Oncol Biol Phys, 2003; 57(5): 1427-1436.
4. Digital Imaging and Communications in Medicine (DICOM), Supplement 11: Radiotherapy Objects, 1997.
5. Digital Imaging and Communications in Medicine (DICOM), Supplement 29: Radiotherapy Treatment Records and Radiotherapy Media Extensions, 1999.
6. DICOM Standard 2003, http://medical.nema.org/dicom/2003.html.
7. USC/Norris:Cyberknife, http://ccnt.hsc.usc.edu/services/cyberknife/information.htm.
8. Law M.Y.Y., Huang H.K., Zhang X., Zhang J. The Data Model of a PACS-Based DICOM Radiation Therapy Server. Proceedings of the SPIE on CD-ROM, Medical Imaging 2003, 128-129, San Diego, CA, U.S.A.
9. Liu B.J., Huang H.K., Cao F., Zhou M.Z., Zhang J.Z., Mogel G., A Complete Continuous-Availability PACS Archive Server, Radiographics 2004; 24:1203-1209.
10. Liu B.J., Cao F., Zhou M.Z., Mogel G., Documet L. Trends in PACS Image Storage and Archive, Comput Med Imaging Graph 2003, 27:165-174.

A Tracking & Verification System Implemented in a Clinical Environment for Partial HIPAA Compliance

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ABSTRACT

The paper describes the methodology for the clinical design and implementation of a Location Tracking and Verification System (LTVS) that has distinct benefits for the Imaging Department at the Healthcare Consultation Center II (HCCII), an outpatient imaging facility located on the USC Health Science Campus. A novel system for tracking and verification of patients and staff in a clinical environment using wireless and facial biometric technology to monitor and automatically identify patients and staff was developed in order to streamline patient workflow, protect against erroneous examinations and create a security zone to prevent and audit unauthorized access to patient healthcare data under the HIPAA mandate. This paper describes the system design and integration methodology based on initial clinical workflow studies within a clinical environment. An outpatient center was chosen as an initial first step for the development and implementation of this system.

Keywords: LTVS, Location Workflow and Verification System

1. INTRODUCTION

This paper describes a novel Location Tracking and Verification System (LTVS) using wireless technology and facial biometrics to monitor and automatically identify staff and patients. This system provides a simple yet systematic solution to monitor and automatically identify staff and patients in order to streamline the patient workflow, protect against erroneous examinations and create a security zone to prevent and audit unauthorized access to patient healthcare data for partial compliance of the HIPAA mandate. The application is robust and flexible and can be used on a standard PC workstation with a web browser application with add-on features where the application can be accessed from a Personal Digital Assistant (PDA). The methodology for design and implementation of the LTVS within a clinical environment will be discussed and results from the LTVS for the Imaging Department at the Healthcare Consultation Center II (HCCII) will be presented. As the first step, a clinical workflow study of the day-to-day operations was performed to observe the physical locations of patients and clinical staff in procedure rooms, reading room area, and waiting room area of HCCII. Based on this workflow study as well as user needs, a system was designed with an application integrating both real-time locating system and facial biometrics identification which allows users to extract precise real-time location and identity verification information. The system was implemented in key areas of HCCII where identity verification was necessary according to the workflow study. Finally, the LTVS was implemented within the clinical environment of HCCII and initial results and experiences are discussed including overall clinical workflow efficiency improvements within the HCCII Imaging Department.

2. METHODS AND MATERIALS

2.1 Clinical Workflow Study

In order to design the system to optimize the workflow processes and best provide data security under the partial HIPAA requirements, a clinical workflow study of the day-to-day operations of the Imaging Department at HCCII was performed for three weeks. HCCII is an outpatient imaging facility located on the USC Health Science Campus. The Imaging Department is located on the ground level of a large outpatient medical office building (over 250,000 ft.^{2}) which houses many clinics requiring imaging services. Even though this imaging facility is small (13,000 ft.^{2}), it makes a good first step for proof of concept and design of the LTVS system. During the observation period, we found out the following problems could be representative of other healthcare institutions as well:

1) A healthcare environment is an ever-increasingly complex and dynamic environment, it is very common that a patient would become lost, especially for a new patient.
2) It is a major issue about how to locate an available staff immediately especially if there is an emergency case.
3) More information systems have become indispensable in their roles of running daily healthcare operation, these clinical information systems can include, PACS (Picture Archiving and Communications System), HIS (Hospital Information System), and RIS (Radiology Information System). Great care should be taken to protect patient

confidentiality within the healthcare setting.
4) Patient Misidentification has been highlighted as a serious issue in healthcare, even within a smaller-sized healthcare center.

Based on this study and the issues described above, the LTVS was designed and developed using wireless technology for tracking the location of patient and facial biometric technology to automatically identify staff and patients. Several key technical features of the LTVS were developed to address these clinical needs including:

1) Patients can be clearly identified and tracked through their course of examinations in the department to ensure the patients are not lost within the department through a simple image that is obtained from the patient at the time of registration along with providing the patient with a tag which can be worn.
2) For the staff, both physicians and technologists could be easily located in an environment where cell phones are not reliable. Several strategically placed monitors throughout the department could locate coworkers and reach them by landline telephone rather than using the intrusive overhead intercom.
3) Staff at the front desk as well as technologists performing the study and radiologists interpreting it can know the location and more importantly the amount of time spent by a patient during the overall examination. Prompts are put in place when the patient has remained in the waiting room for more than a specific amount of time to decrease wait time as well as track workflow inefficiencies throughout the time the patient is within the department.
4) From a security standpoint, facial recognition would provide instantaneous and highly reliable biometric identity information, to be certain that the examination is being performed on the right patient.
5) The HIPAA mandate and safety application to the facial recognition and tracking system allows a facility to create a security zone. In addition, automatic verification is performed to provide the access rights to vital clinical information by a health provider to ensure that he or she is authorized to do so.

Along with the above features, there are numerous advantages of the system, such as the immediate ability to monitor workflow on an almost real-time basis and maximize efficiency both from the standpoint of time as well as location. Technical features of the LTVS which could sufficiently meet certain clinical needs are shown in Table 1.

Clinical issues	System Technical features
Lost patients in the department	Real-time Identification of the movement of patients
Patient waiting too long	Provide a warning to the department personnel if a particular patient has been in one location (e.g., waiting room) beyond the time limit
Patient Misidentification	Patient identity can be verified biometrically through facial recognition
Security for Protection and Privacy of Patient information	System creates an information security zone in a given subunit. Verifies biometrically access rights to vital clinical information by a healthcare provider for authorization.

Table 1. Technical features of LTVS which address certain clinical issues.

2.2 Patient Location Workflow Study

The clinical workflow study focused on observing physical locations of patients and clinical staff as well as procedure rooms and reading area within the Imaging Department at HCCII, which implemented a fully digital environment with integrated HIS/RIS/PACS/VR (Voice Recognition). There are a total of 31 clinical personnel including 16 Radiologists, 8 Technologists, and 7 Support Staff in the imaging center, which also includes 1 CT Scanner, 1 MRI Scanner, 1 Ultrasound Scanner, 2 Computed Radiography (CR) units, and 1 Special Procedure Room (Fluoroscopy/Angiography). The patient location workflow study was first collected via an observation period of 4 weeks overall. In addition, workflow at the modalities was also observed (e.g., CT, MR, CR, US) including any interaction with the integrated HIS/RIS/PACS/VR

systems. Figure 1 shows the General Patient Tracking Location Workflow which includes 7 steps:

1) The patient is scheduled in the RIS (Radiology Information System).
2) Patient waits in the waiting room before the technologists call their name.
3) When the technologist calls the patient in, he or she will be taken to the working area based on the modality type of examination.
4) Patient is asked to change clothes in the dressing room.
5) When the patient is ready, technologist will escort patient into the procedure room and take the exam.
6) After the exam is completed, the patient returns to the dressing room and changes back into his or her own clothes.
7) The patient is released by the technologist and leaves the radiology department.

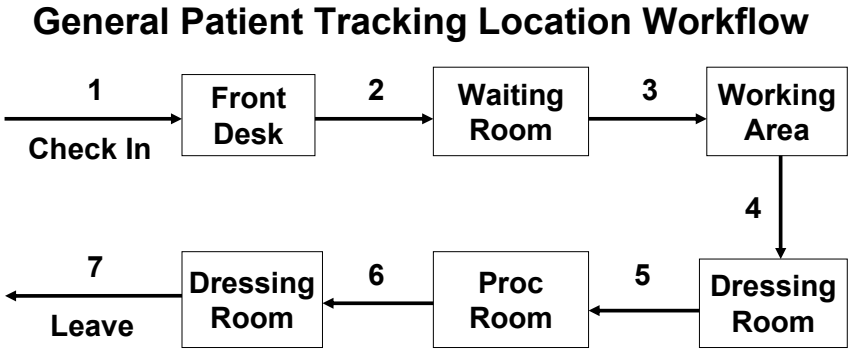

Figure 1. General Out Patient Tracking Location Workflow at HCC II is presented in seven steps.

Based on the workflow study, the areas where misidentification (the working area of each modality before patient enters the procedure room) and extensive waiting times (in the waiting room) occur for the patient undergoing a radiological examination is identified. The suitable staff including radiologists and technologists could not be easily located when they are away from the reading room and the working areas sometimes.

2.3 LTVS Application Design

Based on the workflow and user needs, an application was developed which allows users to extract real-time location information and verify the identity of the patient. First, the user can register a patient photo at the front desk by capturing patient facial images using a high resolution webcam and correlate it with patient information which is queried from the RIS and stored within the database of the LTVS. Then, the patient will be assigned a tag which links the patient information, such as the patient name and patient birth date. Once the tag is assigned to the patient or staff, the system allows the user to access patient location records including when, where and who, and provide the ability to locate available staff or patients on a real-time location tracking page. In addition, the application provides a warning message to the department personnel if a particular patient has been in one location (e.g., waiting room) beyond the time limit. In order to prevent patient misidentification, before the patient enters the procedure room for an exam, the technologist can verify the identity of the patient by capturing the patient's facial image, and the application will verify and confirm with the patient information including patient ID, name, and original photos. For security reasons, the system will trigger an alert if an unauthorized person enters a pre-defined and configurable restricted area, (e.g. reading room). These pre-defined rules are set for not only areas within the system coverage but also based on authorized and unauthorized subjects. For example, a technologist would be allowed within the Reading Room, but a patient would not. Pre-defined rules can be configured within the LTVS to reflect these restrictions. Because the system is a web-based application, it can also be used from any computer that can run a web-browser application as long as the devices have access to the central LTVS server. In addition, a web-based browser capable PDA could be used as a mobile application for users to monitor patient and staff and verify patient and staff identity. The registration page is shown in Figure 2, which serves as an example of the Graphical User Interface (GUI) developed for the LTVS application. The LTVS registration page has several features allows user to input a new patient's information, e.g. patient name, birth date, gender which are queried from RIS. After that, the original facial photos of the patient are taken through a high resolution webcam and correlated with the patient information. The maximum number of patient photos could be stored in the LTVS database is 10. With the patient information and facial images stored in the database, an active tag using wireless technology is assigned to the patient, which allows the user to monitor the location change of the patient. When the patient finished the exam, the tag would be recycled by front desk staff, and the tag's accession number which is

linked with the patient information is erased through the "release a tag" page, so the tag could be assigned to the next patient. The "verify patient" page allow a user to verify the identity of a patient. First, the patient facial image is captured, and the image will be sent to LTVS server and compared with the original image of the patient, the results of the comparison will be sent back to inform the user whether the new image is match with the original image stored in the database or not.

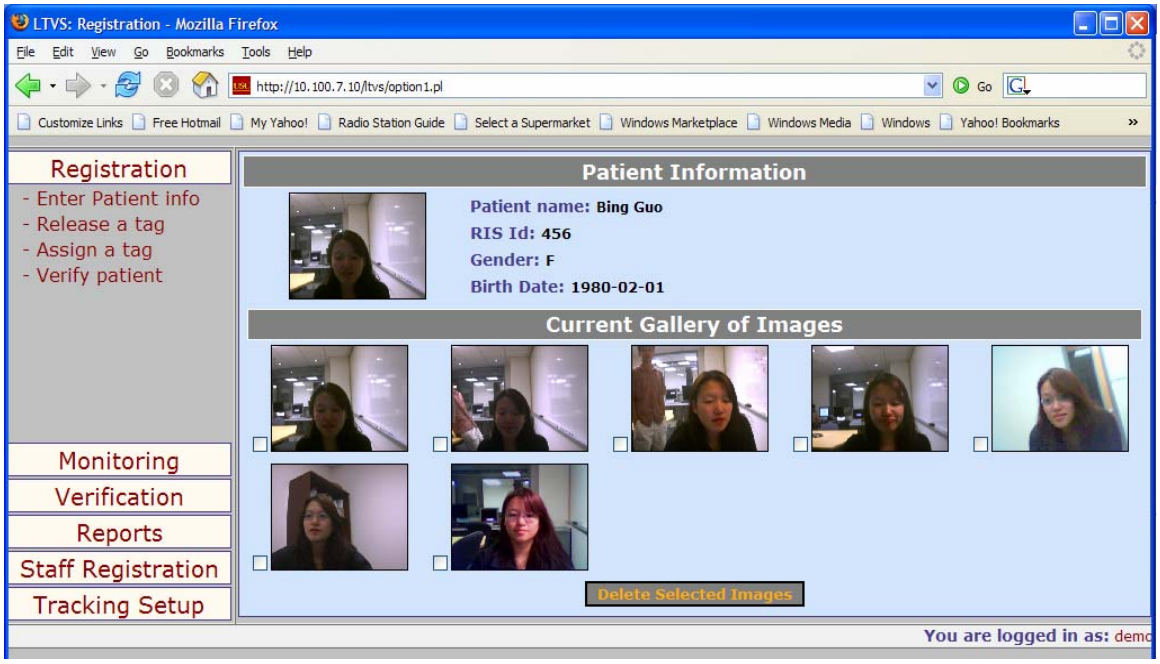

Figure 2. Registration page of LTVS developed for the LTVS application.

3. RESULTS & DISCUSSION

After GUI development of the application and the system design of the LTVS, the system was implemented at HCCII as a test bed. Data was collected from the report page of the LTVS such as the overall length of time for service. This was calculated from the time when the patient was registered in the LTVS to the time that the patient leaves the department and was measured from a given typical workweek. Figure 3 shows an example of patient named John Doe's location workflow with time recorded in the radiology department. An alert message appears describing "patient waiting longer than 25 minutes", since patient John Doe was in the waiting room longer than the time limit set by the administrator. The "Report Page" provides multiple choices for querying the report from the database, for example, RIS ID of the patient, location, tag number, etc.. Figure 4 shows an example when an unauthorized person enters a security area which is also configurable by the administrator. A warning message appears on the screen, which informs the administrator regarding an unauthorized entrance into a specific area, in this case, in order to test the system we defined a room 608 as a security area, a volunteer was asked to enter an unauthorized area, and the results were reflected with time, location and the warning message on the page says "Patient Entered Restricted Area".

The initial data from the LTVS was collected and analyzed during a test period of one week. With the LTVS, the alert time limit for patient waiting time was configured to 30 minutes. Based on this configuration, there were no recorded incidents of patients who had an X-ray exam waiting time of more than 30 minutes since the procedure time for X-ray is much faster than other modalities. There was no patient misidentification cases recorded since we integrated the system at HCCII during the test period. Finally, there were no unauthorized warning messages received during the test period, which seems reasonable since HCCII is a relatively controlled and secure facility. The next step is to continue test and collect more data in a longer period at HCCII to evaluate the LTVS system. Based on the initial data collected, which indicates numerous benefits could be achieved from the implementation of the LTVS:

1) It allows users to understand the operational bottlenecks at HCCII and recommend an improved workflow to reduce overall patient procedure time.
2) It improved the overall clinical management of policies and procedures in a clinical environment in order to partially fulfill HIPAA requirements for data security.
3) It prevented misidentification of patients undergoing a radiological procedure.

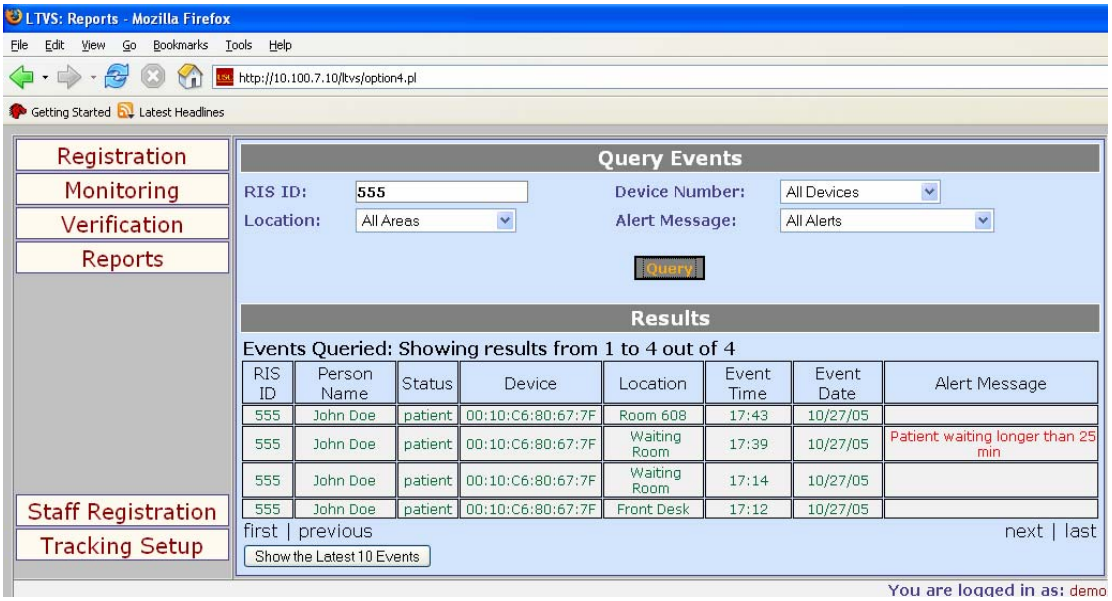

Figure 3. An example of patient John Doe's location workflow with time stamp.

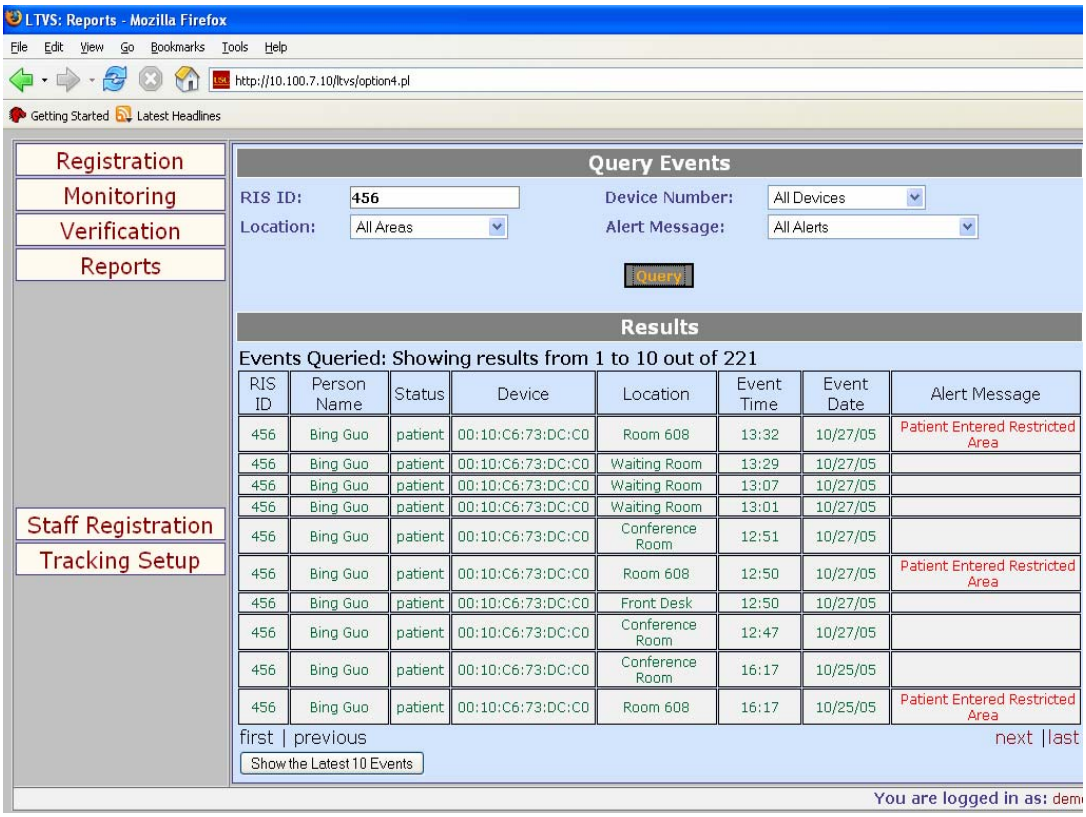

Figure 4. An example of unauthorized person enter a security area which is set by the administrator.

4. CONCLUSIONS

In conclusion, the Location Tracking and Verification System (LTVS) was developed and implemented in the Healthcare Consultation Center II Outpatient Imaging Center. A clinical workflow study was conducted to identify potential bottlenecks and issues within the day-to-day operations which the LTVS could address. From the clinical workflow study, specific emphasis was placed on areas where misidentification and extensive waiting times occur for the patient undergoing a

radiological examination. Based on the initial data collected once the LTVS was implemented, which indicates numerous benefits could be achieved including:

1) Workflow processes of patients at HCCII were streamlined and optimized reducing overall patient procedure time.
2) Improving overall clinical management of policies and procedures in a clinical environment in order to partially fulfill HIPAA requirements for data security.
3) Misidentification of patients undergoing a radiological procedure was virtually eliminated.

The system has the potential for making an even greater impact on a more large-scale clinical environment such as emergency rooms within large hospitals.

REFERENCES

1. HIPAA, http://www.cms.hhs.gov/hipaa/hipaa2/general/background/p1104191.asp
2. B.J. Liu, J. Lee, K. Ma, Technical Experiences of Implementing a Wireless Tracking and Facial Biometric Verification System for a Clinical Environment, SPIE Medical Imaging, In Process, 2006
3. Garcia, M.L., M.A. Centeno, C. Rivera and N. DeCario (1995). Reducing time in an emergency room via a fast-track. Proceedings of the 1995 Winter Simulation Conference, pp. 1048-1053.
4. Vissers, J.M.H. (1998). Patient flow-based allocation of inpatient resources: a case study. European Journal of Operational Research, V. 105, pp. 356-370.

Technical Experiences of Implementing a Wireless Tracking and Facial Biometric Verification System for a Clinical Environment

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ABSTRACT

By implementing a tracking and verification system, clinical facilities can effectively monitor workflow and heighten information security in today's growing demand towards digital imaging informatics. This paper presents the technical design and implementation experiences encountered during the development of a Location Tracking and Verification System (LTVS) for a clinical environment. LTVS integrates facial biometrics with wireless tracking so that administrators can manage and monitor patient and staff through a web-based application. Integration and implementation challenges fall into three main parts: 1) Integrating and refining a wireless tracking system tailored to the needs of clinical management, 2) Acquiring and verifying real-time face images in the clinical environment, and 3) System integration of both systems including database design, web-based application development, and integration with existing clinical information systems (e.g. RIS, PACS). An initial prototype LTVS has been implemented and evaluated within USC's Healthcare Consultation Center II Outpatient Facility, which currently has a fully digital imaging department environment with integrated HIS/RIS/PACS/VR (Voice Recognition).

Keywords: LTVS, Location Workflow and Verification System, HIS, RIS, PACS, HIPAA Security

1. INTRODUCTION

The Location Tracking and Verification System (LTVS) was developed and implemented to increase digital security in a healthcare environment where digital access to medical images and information is insufficient with possibility for human errors[1]. Multiple points of access in hospitals and medical imaging centers make certain clinical areas such as radiology reading rooms and PACS control workstations open to both the facility and patient privacy in terms of unauthorized access. The LTVS prototype developed is the initial steps in providing a more secure solution using patient tracking and facial biometrics. Thus, enabling healthcare institutions to better manage their clinical environments and provide more secure and efficient healthcare services. Clinical workflow can be improved and exam procedures can be administered with higher accuracy with less patient misidentification[4].

LTVS is a clinical application designed to integrate with HIS and RIS to provide accurate patient demographics[3,2]. The current user-interface allows users to assign wireless devices and perform facial biometrics of both patients and staff, associating both with existing departmental record numbers. Assigned persons can then be monitored on a virtual map in LTVS and biometrically verified at specific satellite locations such as exam rooms or offices. The core of LTVS' development is represented in three software pieces:

1) A Perl application for the GUI design
2) A Java application to manage information obtained from a third-party tracking system
3) A C++ application to perform facial verification with a third-party facial biometrics program.

This research paper will discuss the development of the LTVS in hopes of resolving possible difficulties in future development of such clinical-related applications.

1.1 Wireless Tracking

LTVS uses a wireless tracking system utilizing wifi-based positioning technology. This sophisticated real-time tracking system of wireless and portable devices utilizes the concept of radio-frequency signal fingerprinting where three or more access-point signals are detected by a portable wi-fi device and used to calculate location and movement on an x-y plane. The system has already served many purposes ranging from healthcare, to manufacturing, and to industry. The decision to integrate wi-fi technology over Infrared, passive RFID, and other technologies are because of its tracking capabilities, user-definable tags, relatively low costs, and scaleable setup since it utilizes existing wireless network infrastructure. These were key benefits in selecting our clinical tracking system because some of the requirements for LTVS include a design that is both extensive and modular. Although much initial effort was invested in achieving optimum tracking

calibration with the system, its basic wireless access point dependency enabled us to be more mobile during prototype development within the lab, various testing locations, conferences, and finally, the clinical environment in comparison with other more permanent and costly systems.

1.2 Facial Biometrics

The use of facial biometrics has been a popular solution in today's identity verification technology. With new HIPAA Security Standards mandating higher healthcare protection of digital information, facial biometric verification seems optimally suited in protecting against unauthorized use or disclosure. LTVS uses a software development toolkit (SDK) (Nevenvision, Inc.) integrated into the application that can register multiple-photo galleries of people and perform facial biometric verification simultaneously at multiple clinical workstations using simple PC webcams. To keep the image galleries and processing on a single protected LTVS server, each client workstation utilized image-capturing software that would send real-time images from satellite workstations back to the LTVS server for display or processing. Using a PC-based webcam and small image transfer software, clinical workstations already within the clinical environment can be utilized as LTVS client workstations which can perform robust matching of facial images with medical record numbers prior to authorizing access or treatment.

2. METHODS & MATERIALS

2.1 System Infrastructure

The LTVS project development centers around a modular design architecture that can easily be modified to accommodate other tracking and identity verification technologies such as radio frequency identification and digital fingerprinting. Although the entire LTVS architecture subsides on a single server, its multi-level branching design allows only the necessary individual modules to be changed rather than having to modify an entire system. Furthermore, although other potential technologies vary in methodology and may arise as better options in the future, LTVS modules implements universal parameters that further broaden the scope of capable technological systems that can be integrated.
The central LTVS server utilizes Apache2 web server to interact with the users as well as the tracking system and the facial recognition system. The application modules for these two systems perform the background processes for LTVS. The facial recognition module uses an application programming interface (API) that is able to maintain its own image database, whereas the tracking systems API requires the creation of a database to manage and communicate device tracking information to the LTVS user. As seen in the infrastructure diagram below, the tracking module's API can only provide real-time data of device information and locations, so the LTVS tracking application and a PostGreSQL database are left to manage both static and dynamic information regarding the entire LTVS tracking system.

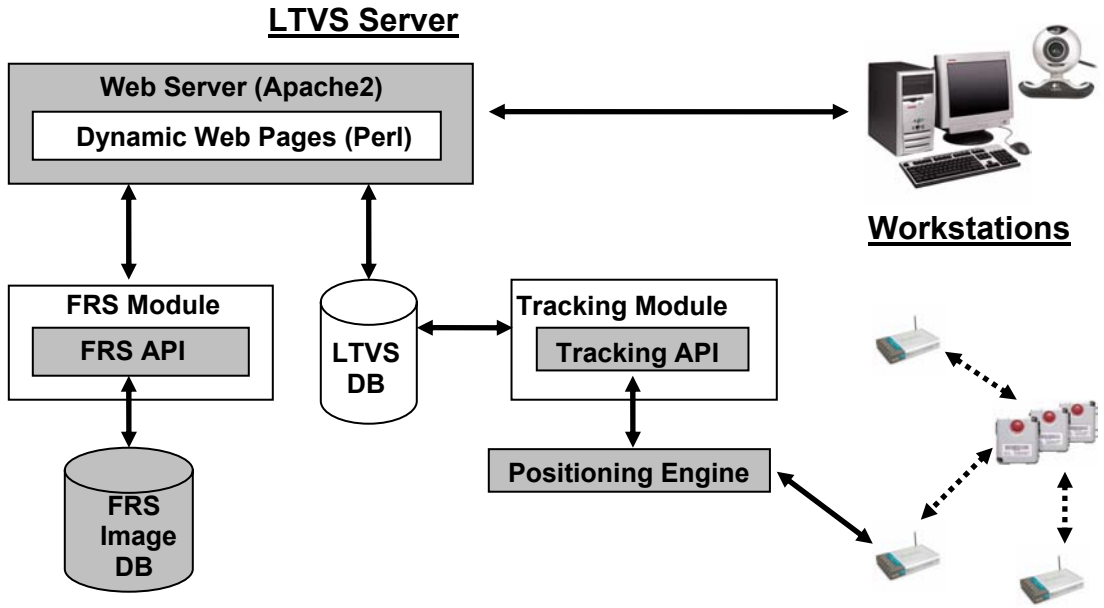

Figure 1. LTVS System Architecture

It can be seen that the LTVS server is the location of most of LTVS' processing components – the web-based application, the facial recognition module and facial image database, and the tracking module with LTVS database. The web-based application is written in Perl with dynamic web pages that interact with the external users at the clinical workstations as well as internally with the facial recognition module and tracking module through the LTVS database. It allows clinicians to register, track and verify patients and staff into the LTVS system by assigning them tracking devices and taking a facial photograph.

In addition to the server, some external hardware pieces are required for the actual tracking and facial recognition functions to work. The wi-fi tracking technology uses numerous wireless access points to track devices, which periodically send signal strengths back to the positioning engine so exact locations and movement can be calculated. Also, the clinical workstations need to be equipped with webcams and an image capturing/transfer application in order to view real time images through the LTVS application as well as provide images for the facial recognition functionality. Table 1 below lists the hardware and software components of the LTVS system.

Table 1. Hardware and Software Components of LTVS

HARDWARE	SOFTWARE
• Dedicated LTVS Server (on network) • Clinical Workstations equipped w/ Webcams (640x480 or higher) • WiFi Positioning Technology: Wireless Access Points Wireless tracking devices	• LTVS GUI web application Apache2 web server • LTVS Tracking API PostGreSQL Database with pgAdmin III Wi-Fi Positioning Engine • LTVS Facial Verification API Image-Capturing software (workstations)

3.2 Facial Recognition System Module: Registering, Adding, Deleting, and Verifying Facial Images

The facial recognition module is a program written in C++ that utilizes a facial recognition API to perform facial image biometrics. The facial recognition API has an internal database called the "Gallery" in which it stores the facial images and compares corresponding facial features values to perform facial biometric identification. Under proper conditions, this biometric system has proven to be a robust solution in recognizing new or existing facial images. In the figure below, the graphical user interface of LTVS is seen displaying a sample patient's information and picture.

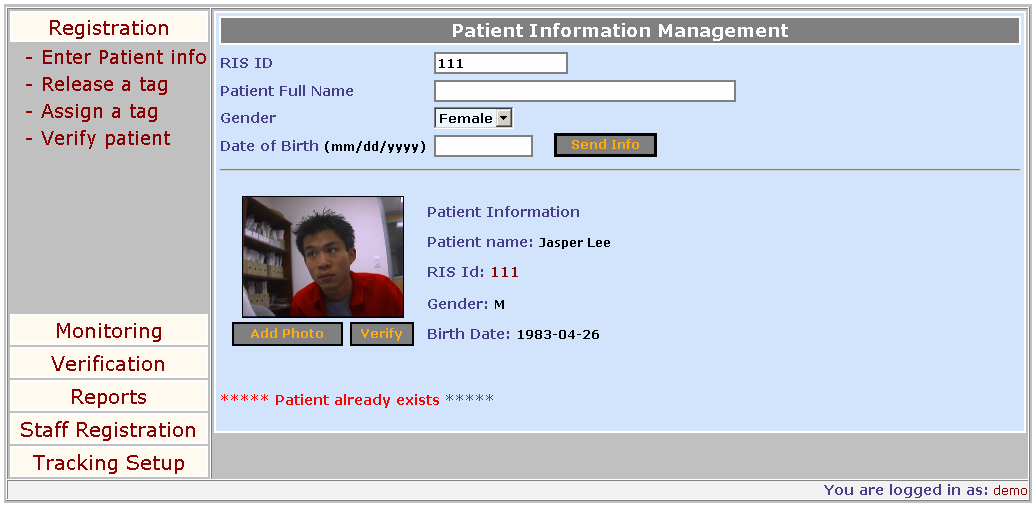

Figure 2. Patient information, Management Window

The facial recognition module is the main mechanism that enables LTVS to add and verify facial images. When the user clicks on either of these two options, a process is called in the module that compares the new images with the existing Gallery. While images are constantly being sent to the LTVS server from all the clinical workstations equipped with web cams, the server doesn't actually call upon the facial recognition module unless the user adds or verifies a photo. When one of the two options are selected, the file name of the temporary image is sent as a parameter to the facial recognition module where a facial biometric measurement is done and then compared in the image gallery. There are three possible results of this measurement and comparison: new face, existing face, or no face found. The facial recognition module's API does most of this processing, but the module portion determines what the response is for LTVS. If, for example, the user asks to add a new patient into the image gallery, then the API would most likely return the response of finding a new face that does not yet exist in the image gallery. The module would proceed to tell the API to create a new file for this patient in its gallery. For LTVS, the images for each patient are all kept in one permanent image folder with up to ten images per person in the gallery. Each image file is chronologically numbered and contains the patient or staff's unique identification number within the file name. For another example, if the user wants to add a new image into the gallery, the new image is still compared in the image database and is only added if it returns an identification number that matches and if there isn't already ten images that already contain that person's id number. In the LTVS prototype, this identification number would be known as a three-digit RIS id as seen in the screen shot above. In the figure 3 is a diagram summarizing the basic workflow of the LTVS facial biometric processing.

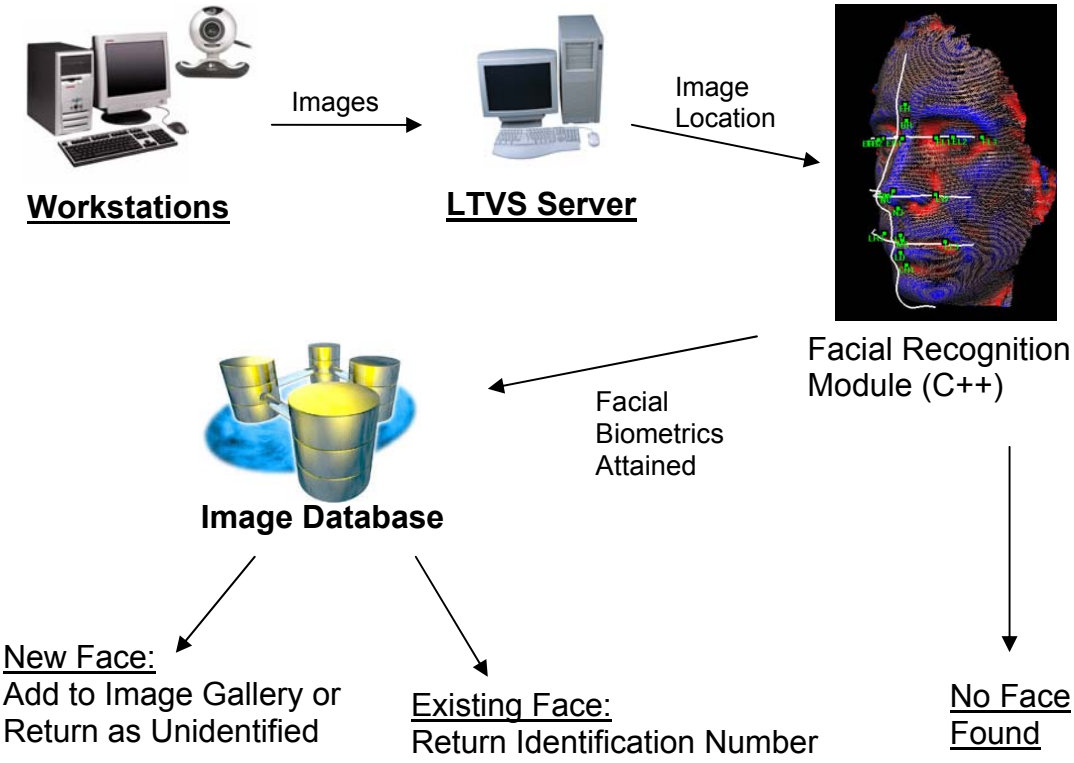

Figure 3 Diagram summarizing the basic workflow of the LTVS facial biometric processing.

Images in a gallery may also be removed as seen in the screen shot below. The facial recognition module also performs this task by working with the LTVS application in determining which images are to be removed from the API's image gallery. This delete function is necessary to LTVS because more images does not mean higher biometric fidelity (Fig 4).

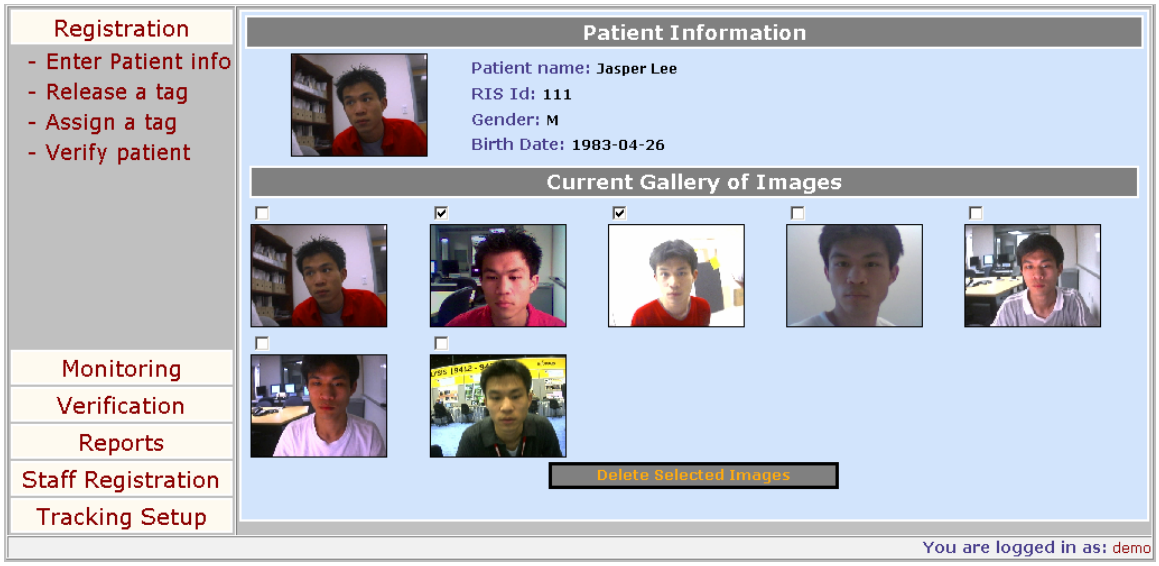

Figure 4 Patient information window.

3.2 Location Tracking Module: Design and Methodology

The LTVS tracking application was developed in Java to receive data from the location tracking system API and tailor it to the needs of LTVS. It acts as a listening module that receives device updates on location and movement from the positioning engine through the API. This allows real-time tracking information from the wifi tracking system to be sent through the API to the listening LTVS tracking module where each device's information can then be processed. Each device carries a unique MAC address that the LTVS tracking module and database use to identify it by. The processing of all the devices include maintaining a list of available and assignable tags, removing lost devices from both the patient and device lists, processing logical area restrictions according to each tag's assigned status, and, last but not least, maintaining a record log of all tracking events. Updating the database with the status of each device on whether it is assigned or available is crucial to tracking efficiency and involves the coordination of the tracking system and LTVS because there are different scenarios that formulate the final device availability. The table below describes the possible combinations of device status.

Table 2. Possible combinations of device status.

Device Status	Tracking System Found	LTVS Task	Status for User
off	False	Nothing	Not Available
activated	True	Add to list of devices	Not Assigned
assigned	True	Update LTVS database	Patient or Staff
released	True	Update LTVS database	Not Available
Off or lost	False	Remove from list of devices.	Not Available

Notice that only activated devices are available for assignment and only assigned devices that have a status of patient or staff qualifies for location and message updating. Whenever a device is assigned or release from a patient or staff, the table of devices (*ltvs_device*) must be updated to reflect its availability, the patient or staff who is assigned the device must have the MAC address added to its information in *ltvs_patient* or *ltvs_staff*, and lastly the device must be added or removed from the *ltvs_current* table which the GUI queries from to display all its devices being tracked.

Once a device in the *ltvs_device* changes status to being assigned, it is automatically tracked; meaning, data sent in from the positioning engine regarding this device's logical area and x-y coordinate is processed by the tracking module. The LTVS tracking application's main job is to keep the *ltvs_current* table in the database updated with the newest real-time device locations on all the assigned devices, but it also performs automated services such as updating the tracking history log every time a location changes and generating alert messages if restricted areas are breached by the assigned device owner.

As seen from the LTVS infrastructure, the LTVS application communicates with the tracking system through the LTVS database. The database is built in PostGreSQL and holds multiple tables of information. Some tables are dynamic interfaces for LTVS GUI to communicate and transmit data. Others are static definition tables where tracking variables and GUI menus can be queried from. Note that static tables are controlled via the LTVS Tracking Setup page, which can be seen farther down in the GUI discussion in figure 7. Below is the list of tables and functions that have been created for the LTVS database:

Table 3. Static Tables in LTVS Database

Dynamic Tables	FUNCTION
ltvs _current	Location information of all actively assigned devices
ltvs _device	All devices that are detected by EPE, identified by MAC
ltvs _log	Periodic log of the number of devices found
ltvs_patient	Relevant Patient Information from RIS or HIS ie. Name, Age, Sex, Exam Appointment, Medical Record Number, and Assigned Device MAC.
ltvs _staff	Relevant Staff Information from RIS or HIS
ltvs _tracking_history	Tracking history log with timestamps of all LTVS device activity including device assignments, change in patient or staff locations, breached restricted areas, unassignment or lost of devices, and when the tracking module is stopped or restarted.
Static Tables	FUNCTION
ltvs_area	List of areas defined in the Positioning Engine
ltvs _allowed_area	Allowed patient areas based on exam type
ltvs _exam	Clinical exams to determine allowed patient areas
ltvs _menu	Static table for GUI application display

ltvs _message	List of alert messages available to the tracking module ie. “Patient entered Restricted Area”, “Patient waiting for longer than 30 minutes”, “Device lost while assigned”, etc.
ltvs _variable	LTVS tracking parameters ie. frequency in which ltvs_current is updated, frequency of a periodic forced update of all devices, etc.

The design of the LTVS tracking module is complex in design, but simple in operation as it is a self-sufficient background program that works seamlessly to bring tracking capabilities to the clinical environment. The thoroughness of the device management rules are focused on increasing clinical security and awareness of human access within its compounds, but the monitoring of staff and patients also serve to improve clinical efficacy in finding its resources and clients in a bustling environment.

3.2 LTVS Application Design and Functionality

The design of the LTVS application was based on the clinical workflow study that was performed at HCCII[5]. The GUI developed for the application has a menu column on the left of the screen that lists the LTVS functions available – Registration, Monitoring, Verification, Reports, Staff Registration, and Tracking Setup. Each of these sections have various subsections to perform more specific tasks, but the general procedure of entering patients in the clinical environment starts by entering their RIS ID or any other form of medical identification number implemented by the clinic or hospital. Once a patient ID number is entered into the system, access to device-assignment and facial biometric registration and verification are available in the subsections of the GUI. Shown in Figure 5 below is the first page of the LTVS GUI application that clinical staffs can also use to find existing patients by entering their RIS ID, full name, gender, and or date of birth. If patients are not registered into the LTVS system, they may enter in their patient information and will be added to the ltvs_patient database automatically.

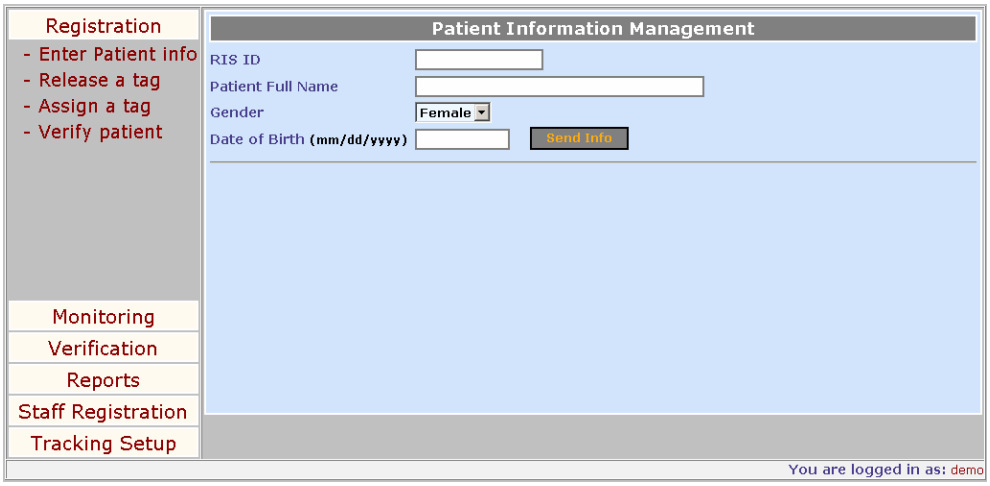

Figure 5. Patient Registration Page for LTVS

To perform facial verification later on inside the hospital or clinic, a photograph must be taken of the patient at the registration desk where the tracking devices are also assigned. Persons must stand or sit in front of a web cam for 1-2 seconds while their image is being taken and stored into the facial recognition image database. Once a photograph is attached to the person’s RIS ID, up to ten more photos may be taken at later days to improve facial biometric fidelity.

In order to assign devices to registered patients in LTVS, the clinician must enter the patient or staff's ID number and chose from a menu of available devices. Once this is performed, the device will begin to be tracked throughout the hospital until that device is either unassigned or lost due to a battery failure, whereupon the patient or staff may be assigned another device. Once assigned, LTVS allows users to monitor patients and staff on a map with the devices shown as dots moving in real-time. In the figure below, an image map of the clinical site at HCCII has been uploaded into LTVS. The labeled rooms and zones have predefined boundaries on the tracking system, but are not visible on the image map. Patient and staff who have been assigned a tag are labeled as "active" in LTVS and are thus tracked on the map in real-time with their names appearing next to their appropriate locations as shown in figure 6 below.

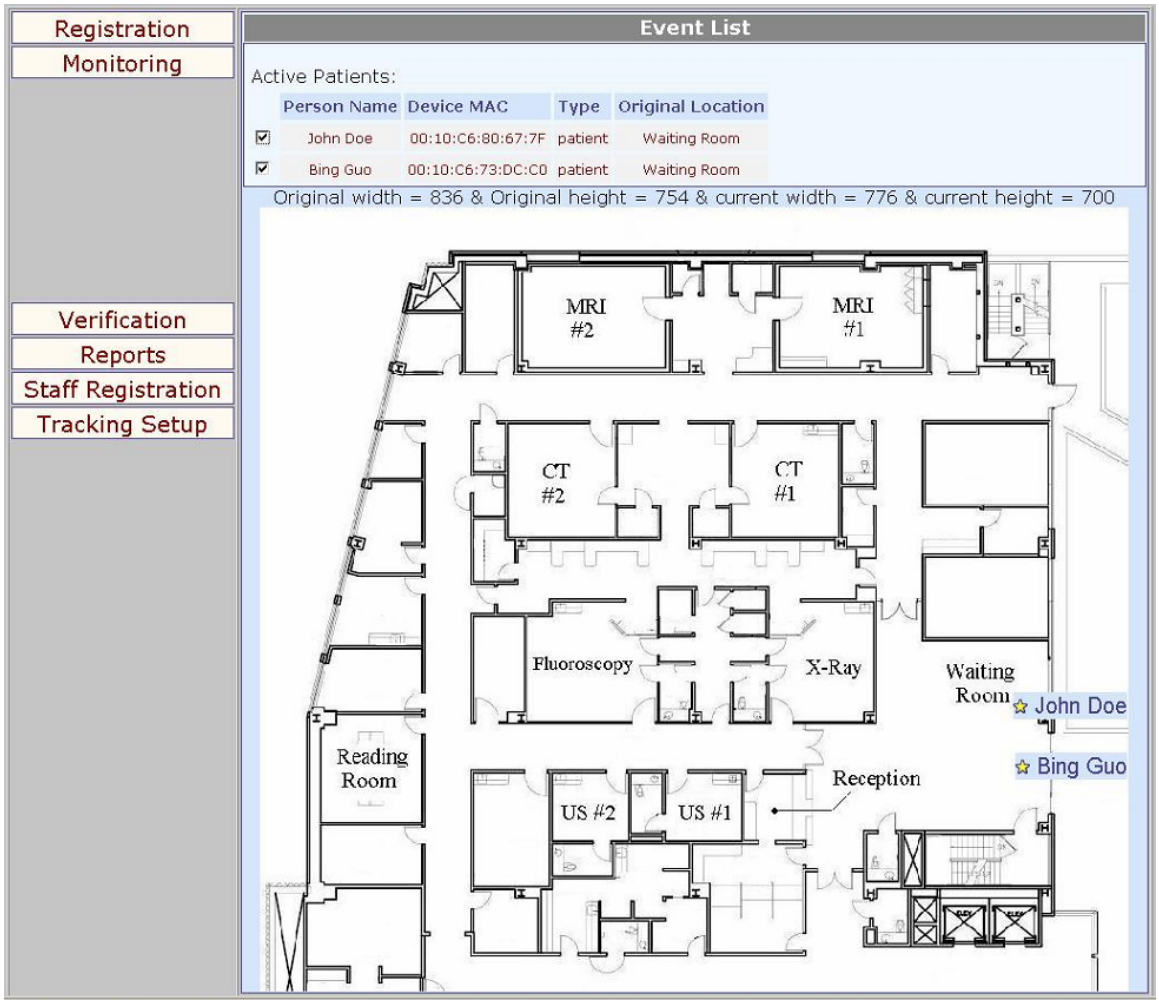

Figure 6. Monitoring Page for LTVS

When restrictioned areas are violated, such as by a patient entering a radiology reading room, an alert will be generated on the LTVS tracking history table and appear on the Reports page, as seen in figure 4 below. Patients and staff can be assigned particular logical areas that are restricted via the Tracking Setup page, making LTVS very user-focused. Below is a screen shot of the Reports page in which a sample patient in our lab entered Room 608, which is a restricted area. Note that the data displayed on the Reports page are compiled from various queries from the LTVS database tables (Fig.7).

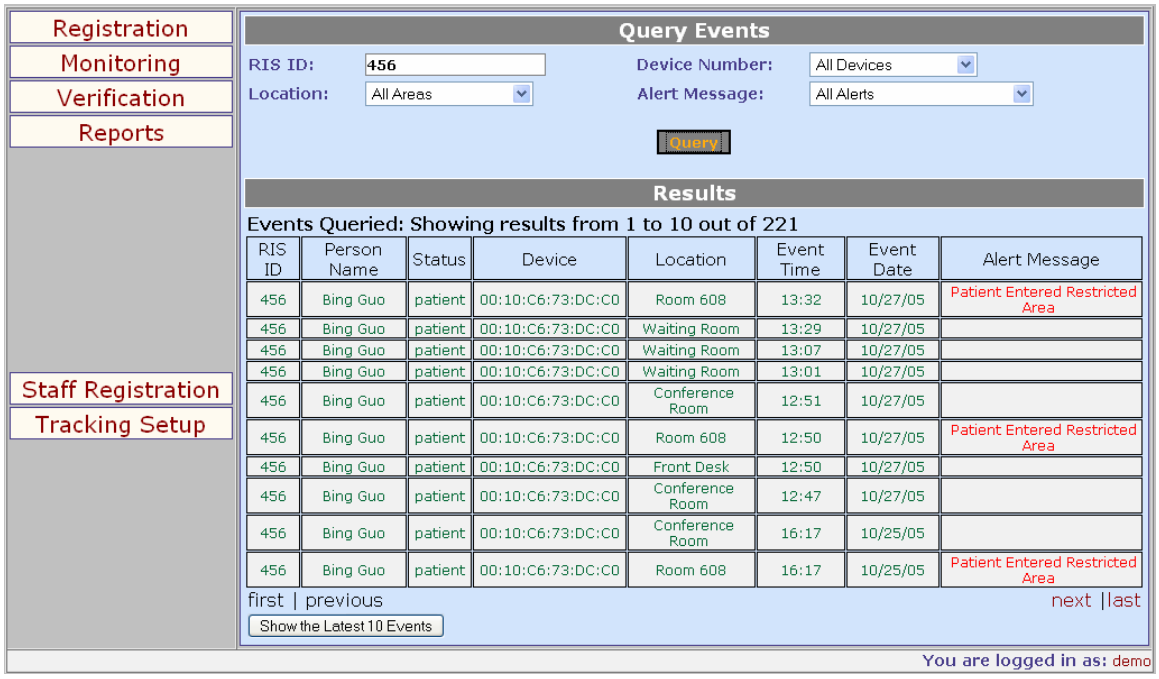

Figure 7. Reports Page for LTVS

The Tracking Setup page (Fig.8) enables the LTVS users to modify the static database tables listed earlier that pertain to the LTVS tracking system. In events of a relocation of the LTVS system to a new location, new image maps of the site must be uploaded, the list of logical areas and allowed areas must be updated, and perhaps the available exam types must be modified to fit the healthcare services. This page is made up of simple Perl tables that enables users to easily modify the information.

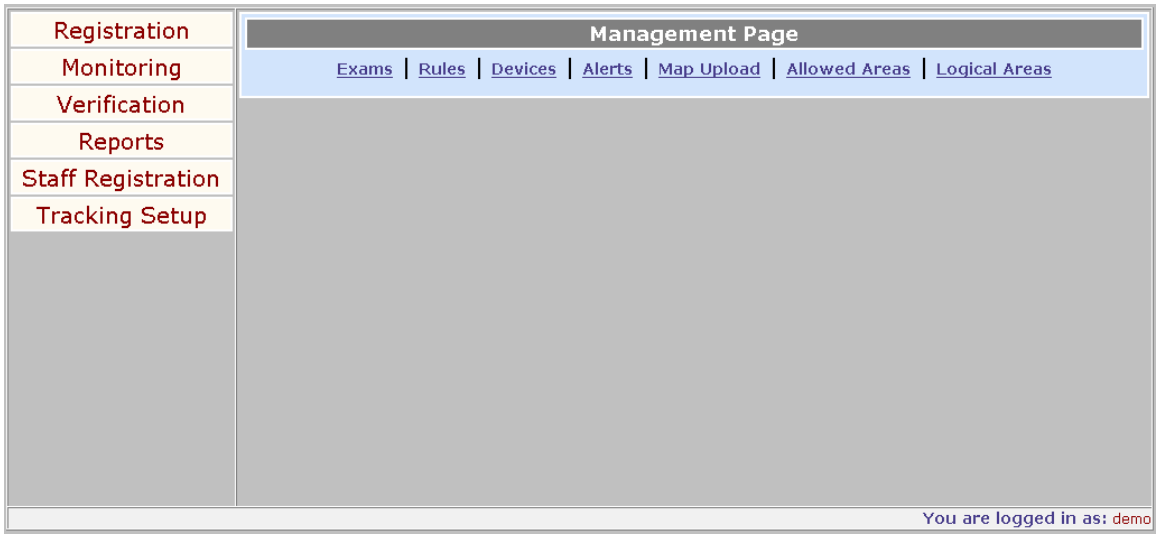

Figure 8. LTVS Tracking Setup Page

3. RESULTS & DISCUSSION

A capability of the LTVS tracking system is to integrate monitoring and authorization of patient and staff activity into existing healthcare system such as RIS or HIS. This allows registered patients and staff to be assigned a tag and facial photograph with all their relevant information already attached. By integrating patient information such as name, age, sex, exam, appointment, doctor, and medical record number, clinicians in bustling health facilities can better monitor patient workflow and confirm the correct patient and treatment procedures. This is LTVS' attempt to work along-side existing healthcare management programs.

During the development of this project, time and effort was devoted to understanding the facial biometric API and the tracking system API, then fine-tuning for performance purposes and integration of these modules into the LTVS system. The first challenge was overcome by reading their documentation and examples, and after playing a little bit with the toolkits successful utilization of these tools were available. The other challenge of integrating them into LTVS application involved more coordination among the developers because the final interface should be web-enabled and share a common GUI. Under this challenge the main issue was on how to display real-time images and real time tracking on the workstation.

The main implementation hurdle in regards to the facial recognition system was processing images at the LTVS server while the images were taken at various web cams located at the clinical workstations. Our solution came from using an external open source image-transferring program that allows web cams to send images to an externally selected location; in our scenario, all the web cams were configured to write to the LTVS server. Now, some security questions may arise such as allowing the web clients to only see the images that are captured from the same workstation. Doing some IP filtering on the server side and having the right configuration in the image-transferring program allowed us to solve this issue. So, if the client does not have a web cam or the web cam is installed without the transfer program running, then the user receives an error page with instructions on how to resolve this issue. If the web cam is installed and the transfer program is also running correctly, the proper images are displayed. After some testing we realized that due to the amount of data transferred from each client to the LTVS server, there were moments that images were not correctly written or read. We worked around this inconvenience by changing the frequency of writes and reads in the client. But the best solution would be to have the local client receiving the video stream directly from the web cam into the web page, and sending only key images to the LTVS server. At the time we developed this application we were not able to find a feasible solution for this.

The challenges in programming the LTVS tracking application involved creating the appropriate classes in which to allocate various tasks, and then maximizing device processing efficiency. With multiple tags constantly sending new x-y locations, up to 10 times per second, from the tracking system's positioning engine, LTVS tracking application was easily backed up initially and resulted in devastating delays at the LTVS GUI end. After an attempt was made to filter out unnecessary processing, we saw significant improvement in processing speeds because unassigned tags and stationary tags were no longer checked. However, the filtering did not solve all problems because the LTVS tracking application was still inconsistent. Periodic backups were happening because devices that passed through the filter were still sending up to 10 new locations per second; resulting in multiple-tag situations where nothing would get processed for up to half a minute, and then an inundation of data would come out simultaneously. To solve this, we forced each device to get in line by keeping track of the last device processed. This way no device location could get processed twice without first processing another device. Perhaps there are more efficient algorithms, but with motion-sensing devices that send can data both periodically or upon detecting movement, it is hard to predict when a device will send information. So creating more dependencies could be a potential hindrance instead. However, this is where being able to define the tag parameters were helpful because we were able to speed up the transmission frequency of every tag, and also lower the motion-sensitivity, creating a more predictable influx of device location information for LTVS to process.

Another obstacle confronted during development was the loss of tags on the tracking positioning engine due to a dead battery or went out of range. The LTVS tracking application queries device status each time an eligible device is processed, but sometimes an unassigned tag becomes unavailable for these same reasons. So to prevent the useless processing attempts of non-existent tags, a periodic flushing of the entire *ltvs_device* list is done – searching for all devices listed and removing those that have become lost due to a dead battery or traveled out of range. With the current prototype design, the LTVS tracking application automatically connects to the PostGreSQL database, erases all devices previously listed on *ltvs_device*, and then repopulates the device list with actual devices found on the tracking positioning engine.

Further Developmental Potential
-Track Patient workflow automatically by creating more specific patient tables that can check off the patient progress through the clinic.
-Stream video from webcam directly to the clinical workstation without having to go through the LTVS server.

4. CONCLUSION

In today's growing demand towards digital imaging and informatics, clinical access to patient data requires a more secure solution. The challenges of protecting clinical information has been made more difficult with fully digital environments that have multiple points of access. Passwords and ID badges are no longer sufficient because anyone with the correct combination can walk up to a clinical access point and obtain and/or manipulate sensitive patient data, which are mandated for privacy by HIPAA standards. Current external intrusion into a network can be prevented with firewall and encryption techniques, however there remain weak points within a healthcare facility that are open to corruption, either by administrative mistakes or physical intruders. In an attempt to address these issues, LTVS enables access, by patient or staff, to be authorized upon entrance and biometrically verified at each point of access. The potential uses of tracking and facial biometrics in LTVS include, but are not limited to:

1) Verifying patients before digital imaging exams and treatment appointments
2) Heightened digital security for staff by adding a second level of authorization to traditional network passwords
3) Performing physical location authorization to certain restricted rooms

Although the current LTVS capabilities allows monitoring, logging, and facial biometric verification, there are many other opportunities that can heighten security by integrating the functionality of wireless tracking with facial biometrics in a clinical environment.

The LTVS project development requires extensive system integration to support the user application. Therefore a system infrastructure was designed using an LTVS server that houses the web-server application, tracking and management programs, facial biometrics software, and a PostGreSQL database. The challenge was allocating tasks to the modules to provide real-time data efficiently for the web-based application.

RERERENCES

1 HIPAA, http://www.cms.hhs.gov/hipaa/hipaa2/general/background/p1104191.asp

2 Bing Guo, Jorge Documet, Brent Liu, Nelson King, Rasu Shrestha, Kevin Wang, H.K. Huang, Edward G. Grant, A Tracking & Verification System Implemented in a Clinical Environment for Partial HIPAA Compliance, SPIE Medical Imaging, In Process, 2006

3 Garcia, M.L., M.A. Centeno, C. Rivera and N. DeCario (1995). Reducing time in an emergency room via a fast-track. Proceedings of the 1995 Winter Simulation Conference, pp. 1048-1053.

4 Vissers, J.M.H. (1998). Patient flow-based allocation of inpatient resources: a case study. European Journal of Operational Research, V. 105, pp. 356-370.

5 B.Guo, J. Documet, N.King, B.J Liu, H.k Huang, E.G Grant, Patient tracking and Facial biometrics Integrated in a clinical Environment for HIPAA security Compliance, Radiological Society of North America, International Conference, RSNA Chicago, November 27-December 2, 2005, p 873

Carpal Bone Analysis in Bone Age Assessment

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ABSTRACT

A computer-aided-diagnosis (CAD) method has been previously developed in our Laboratory based on features extracted from regions of interest (ROI) in phalanges in a digital hand atlas. Due to various factors, including, the diversity of size, shape and orientation of carpal bones, non-uniformity of soft tissue, low contrast between the bony structure and soft tissue, the automatic identification and segmentation of bone boundaries is an extremely challenging task. Past research work on carpal bone segmentation has been done utilizing dynamic thresholding. However, due to the discrepancy of carpal bones developments and the limitations of segmentation algorithms, carpal bone ROI has not been taken into consideration in the bone age assessment procedure. In this paper, we present a method for fully automatic carpal bone segmentation and feature analysis in hand X-ray radiograph. The purpose of this paper is to automatically segment the carpal bones by anisotropic diffusion and Canny edge detection techniques. By adding their respective features extracted from carpal bones ROI to the phalangeal ROI feature space, the accuracy of bone age assessment can be improved especially when the image processing in the phalangeal ROI fails in younger children.

Keywords: Bone Age Assessment, Carpal Bone Segmentation, Anisotropic Diffusion, Canny Edge Detection

1. INTRODUCTION

Bone age assessment (BAA) is a clinical procedure performed in pediatric radiology to quickly and non-invasively evaluate the stage of skeletal maturation. Based on a radiological examination of skeletal development of a left hand wrist, the bone age is assessed and then compared with the chronological age. A discrepancy between these two values indicates abnormalities in skeletal development. The most commonly used method in clinical practice is the book atlas matching assessment developed by Greulich and Pyle[1]. This method is based on visual comparison of the patient's hand image with images collected in the atlas. The closest match is subjectively selected by the radiologist and yields the bone age of the patient (Figure 1).

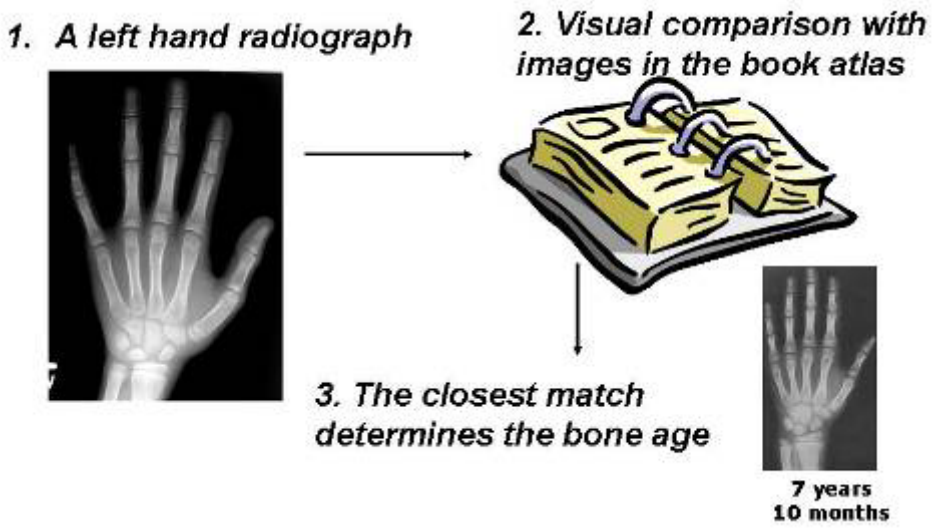

Figure 1 Bone age assessment procedure in clinical practice

However the book atlas remains unchanged from its initial publication in the early 1950s with data collected entirely from upper middle class Caucasian populations in the midwest of the United States. Due to changes both in population diversity and nutrition, an updated data collection becomes crucial to improve the bone age assessment process. In addition, our study found that two radiologists' readings on the 137 African American girls from newborn to 13 years old have the mean difference at 0.53 years and it could be up to 2.50, which confirm results achieved by other researches[2]. Double reading of hand images (consecutive reading by two radiologists) may increase the accuracy, but at high costs. So, an automatic bone age assessment tool is highly desirable in assisting the radiologists to achieve high efficiency and effectiveness.

2. MOTIVATION OF CARPAL BONE ANALYSIS

The classical bone age assessment of children is based on bone growth of three areas: phalanges, carpal bones, and the wrist joints (Figure 2). A computer-aided-diagnosis (CAD) method has been previously developed based on features extracted from phalangeal regions of interest (ROI) in a digital hand atlas[4, 5, 9]. The images in our collection have been subjected to fully automatic procedure of image processing yielding a vector of features for each successfully processed region of interest [6, 7]. To perform objective evaluation of the bone age based on extracted features, a fuzzy logic classifier has been applied [4].

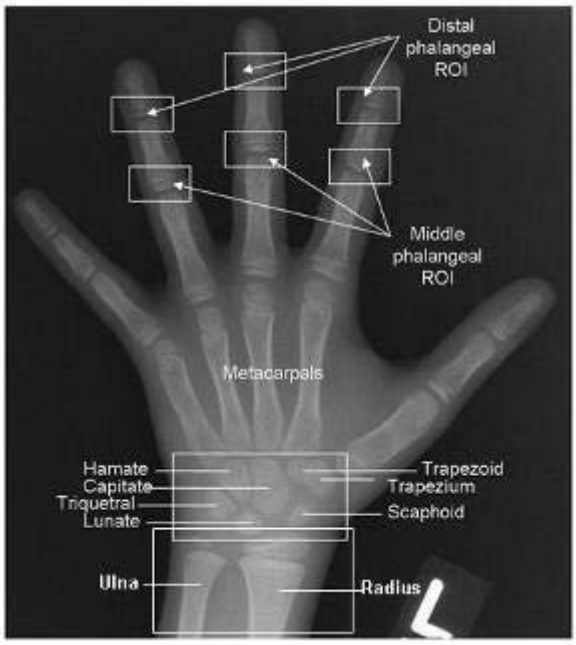

Figure 2 A hand and wrist radiograph with phalanges, carpal bones, and the wrist joints ROIs.

For cases of children 12 to18 years of age, phalangeal ROI features were successfully extracted by wavelet transformation; for cases of children 5 ~ 7 to18 of ages, phalangeal ROI features were successfully extracted by size and shape analysis. Very accurate bone age assessment was ensured for both age groups. However, for ages below 5 ~ 7, the ROI segmentation methods failed in some cases, particularly in very young children. Due to inaccuracies of hand position in the radiographs almost 10% of cases remain unprocessed. This value mainly includes X-rays performed in newborns and children below 3 years of age, where the up-right hand position is difficult to achieve. The number of unprocessed images is also increased by an additional 10% of cases where the image processing methodology was unsuccessful due to poor image quality. Hence, the bone age could not be calculated for a total of 20% of the cases. Figure 3 demonstrates the number of images for each age group in African American girls at the age ranging from newborn to 12 years old.

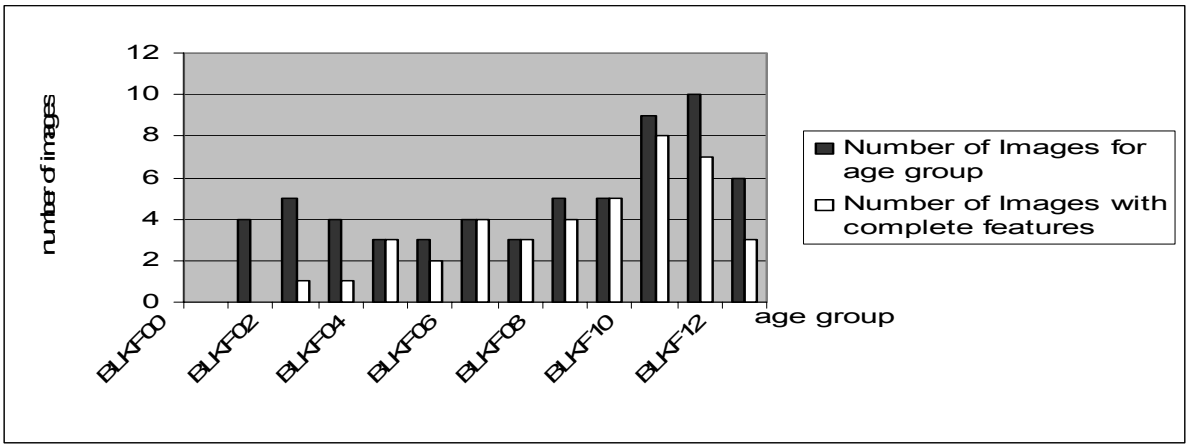

Figure 3: Images collected for African American girls by age group

Therefore in order to achieve similar degree of accuracy in bone age assessment for children of all ages, we hypothesize that the CAD method may benefit from the augmentation of features extracted from the carpal bone ROI. This paper proposes to augment the bone age assessment method by using a novel carpal bone ROI analysis with the existing phalanges ROI analysis to improve the accuracy of computerized bone age assessment and adding the features of carpal bones ROI to the phalangeal ROI feature space. Before the carpal bones start to overlap, the carpal bone segmentation and feature extraction could be very reliable. (Table 1)

Table 1 Reliability of ROI analysis for different age groups

Age Groups	Phalangeal ROI Analysis	Carpal Bone ROI Analysis
0 – 5 (female) 0 – 7 (male)	Size & Shape analysis of epi-metaphysis* - Features extraction is not reliable	Size & Shape analysis of each carpal bone - Features extraction may be reliable
5 – 12 (female) 7 – 12 (male)	Size & Shape analysis of epi-metaphysis* - Features extraction is reliable	Degree of overlapping of carpal bones - Features extraction may not be reliable
12 - 18 (female & male)	Degree of fusion of epi-metaphysis* - Features extraction is highly reliable	

Note: items with * represent work have been done

Due to various factors including the size, shape, and orientation of carpal bones, non-uniformity of soft tissue, low contrast between the bony structure and soft tissue, automatic identification and segmentation of bone boundaries is an extremely challenging task. Past research work on carpal bone segmentation has been performed utilizing dynamic thresholding. The discrepancy of carpal bones growth development and limitation of segmentation algorithms have limited its uses in bone age assessment procedure. This paper describes a method for fully automatic carpal bone segmentation and feature analysis in pediatric hand X-ray radiographs. By including their respective features extracted from carpal bones ROI and combining them with the phalangeal ROI feature space, the accuracy of bone age assessment can be improved significantly, especially when the image processing in the phalangeal ROI fails in younger children.

3. DATA COLECTION

We have acquired a total of 1,103 digitized hand images of normally developed children, 5 images for each group of pre-pubertal children and 10 images for children during puberty from the Childrens Hospital Los Angeles (CHLA) [19]. The cases were grouped accordingly to sex and age. Thus there are 19 clusters (newborn, 1 – 18) in eight categories (i.e. Caucasian, African-American, Hispanic, and Asian). In order to evaluate and compare other findings, two readings were performed by radiologists for all images collected in the database. All the films were digitized using laser scanner and stored in DICOM (Digital Imaging and Communications in Medicine) format.

A normal image collection is a key issue in the hand atlas. Two radiologist experts were asked for independent readings of our collected image data. The image was accepted only when both readings fall within the standard deviation of the corresponding image in the book atlas.

4. CARPAL BONE SEGMENTEION METHODOLOGY

The workflow of carpal bone segmentation procedure is shown in Figure 4. The carpal bone region of interest is first extracted from the entire hand image. Due to the non-uniform background and noise, the carpal bone ROI is subjected to an anisotropic diffusion filter which smoothes out the noise and preserves the edges at the same time. Then, the object contours are extracted by the Canny edge detector. A series of knowledge-based morphological operations are implemented in order to eliminate the non-carpal bones. The carpal bones contours will go through feature extraction phase which will be part of future work. The following sections discusses the procedure in detail step by step.

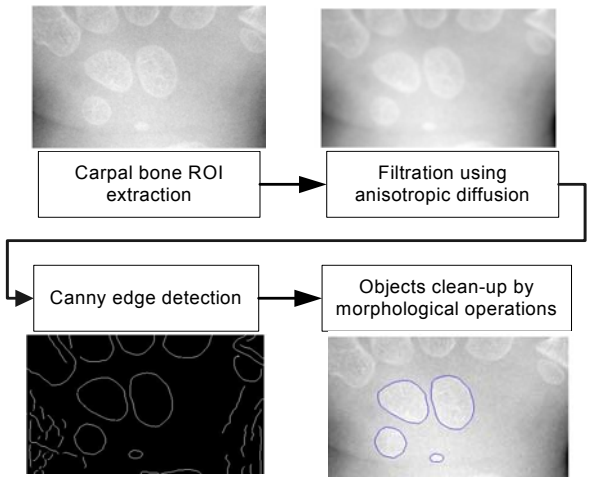

Figure 4 Carpal bone segmentation workflow

4.1 Carpal Bone ROI Extraction

The carpal bone ROI was located and extracted before the segmentation procedure. Robust image preprocessing needs to be developed to handle the difficulty in positioning the hand of the subject adhering to the image acquisition protocol. The entire hand image is divided into four quarters, and the background is estimated based on the histogram of each quarter[9]. The corrected image after background subtraction undergoes adaptive thresholding which yields the binary image. Various labels, markers or clips might be placed within the radiation field. Therefore, the objects in the binary image are labeled and the small objects are removed based on the size and shape of the objects. The outcome image is the hand silhouette. Analyzing the hand silhouette, the carpal bone region of interest (CROI) is located. The upper edge of the CROI is found by scanning a horizontal line and searching for the junction between the second and third metacarpal bone. Perpendicular to the upper edge of the image, starting from its middle, two lines are scanned one pixel at a time toward the left and right borders of the image. The first line on both sides that does not intersect the wrist, fixes the left and right border, respectively. The lower edge of the CROI is the line that intersects the forearm with the minimal width. It is determined by scanning the forearm, one line at a time, from the proximal end of the hand and moving toward the distal end. The CROI image is defined within these four edges.

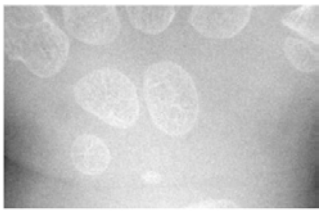

Figure 5 Carpal bone region of interest image

4.2 Anisotropic Diffusion

Carpal bone ROI (CROI) images are generally poor in contrast. Furthermore, the objects' edges are often degraded by artifacts. In order to obtain a better quality CROI image, image preprocessing was applied to remove artifacts and to improve image quality due to blurring and noise. An anisotropic diffusion filter proposed by Perona and Malik[16] was applied to the CROI.

The principle is to smooth out noise locally by diffusive flow while at the same time prevent flow across object boundaries. The diffusion coefficient is chosen to vary spatially in such as way as to encourage intra-region smoothing in preference to inter-region smoothing.

The filtered image is modeled as the solution to the equation

$$\frac{\partial I(x,y,t)}{\partial t} = div(c(x,y,t)\nabla I(x,y,t)) \quad (1)$$

Larger values of t, the scale-space parameter, correspond to images at coarser resolutions.

Where we indicate with $I(x,y,t)$ the image intensity at position (x,y) and time t, div the divergence operator, ∇I the spatial gradient, $\partial_t I$ the temporal derivative. The divergence operator is defined as

$$divI(x,y) = \frac{\partial I}{\partial x} + \frac{\partial I}{\partial y} \quad (2)$$

And c(x,y,t) is the diffusivity function. If c is a constant, independent of x, y, or t, it leads to a linear diffusion equation, with a homogeneous diffusivity. In this case, all locations in the image, including the edges are smoothed equally. If the function c is image dependent, then the linear diffusion equation becomes a non-linear diffusion equation. For example, by using a function c that was based on the derivative of the image at time t, we were able to control the diffusion near the edges in the image. Perona and Malik[16] proposed the use of diffusion coefficients based on a measure of edge strength. In this paper, we applied the diffusivity function as

$$c(x,y,t) = \exp\left[-\left(\frac{\|\nabla I\|}{k}\right)^2\right] \quad (3)$$

where smoothing if $\|\nabla I\| \le k$ and sharpening if $\|\nabla I\| > k$

The diffusion coefficient c(x,y,t) then adaptively controls the diffusion strength, smoothing the image within a moderately continuous region while not smoothing across sharp discontinuities. The diffusion process achieves piecewise smoothing while reserving the relevant image edges.

Figure 6(a) and Figure 6(b) show the original carpal bone ROI image and the result after anisotropic diffusion filtration, respectively. The comparison of profiles along one horizontal line (same position in both images) which come across capitate and hamate is given in Figure 6(c) and 6(d). It demonstrates that noise is greatly suppressed by the diffusion process while the sharp edges are well recovered.

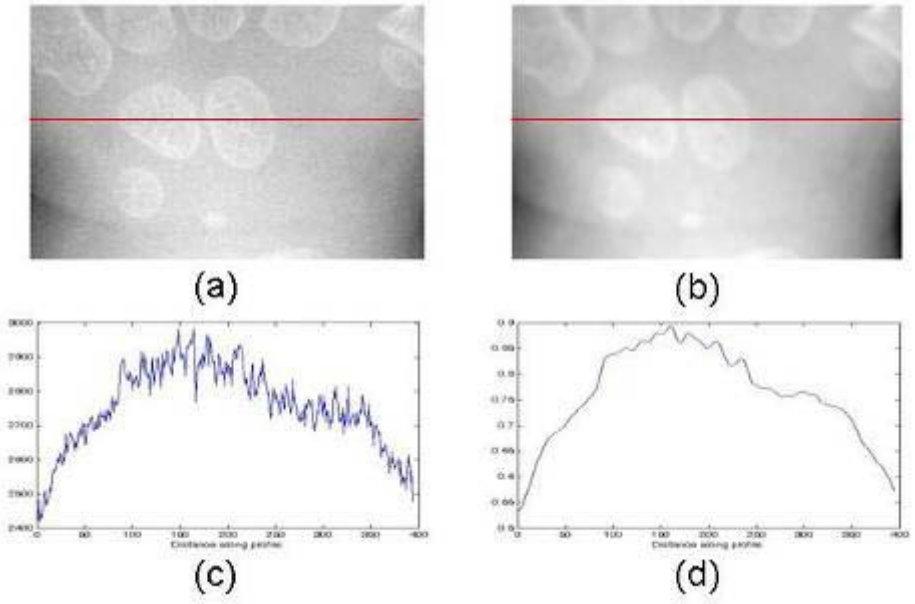

Figure 6 (a) original carpal bone ROI image (b) the result after anisotropic diffusion filtration (c) profile of the original image along the horizontal line (d) profile of the filtered image along the horizontal line

4.3 Canny Edge Detection

There are three important performance criteria in the edge detection methodology. The first and most obvious is low error rate. It is important that edges in images should not be missed and that there should be no responses to non-edges. The second criterion is that the distance between the edge pixels as found by the detector and the actual edge is to be at a minimum. The third criterion is to have only one response to a single edge.

Based on these above criteria, the Canny edge detection algorithm is applied to carpal bone segmentation. Figure 7 shows the Canny edge detection workflow.

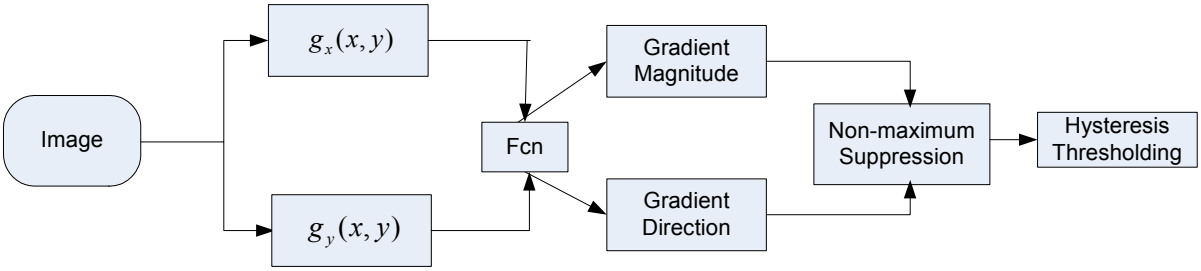

Figure 7 Canny edge detection workflow

Canny edge detector finds a linear, continuous filter that maximized the three given criteria and is known as the optimal edge detector. The Canny method differs from the other edge-detection methods in non-maximum suppression and hystersis[17,18]. It finds the image gradient to highlight regions with high spatial derivatives. The algorithm then tracks along these regions and suppresses any pixel that is not at the maximum (non-maximum suppression). Hysteresis uses two different thresholds (to detect strong and weak edges), and includes the weak edges in the output only if they are connected to strong edges. If the magnitude is below the low threshold, it is set to zero (made a non-edge). If the magnitude is above the high threshold, it is made an edge. And if the magnitude is between these two thresholds, then it is set to zero unless there is a path from this pixel to a pixel with a gradient above high threshold. Hysteresis is used as a means of eliminating streaking. Streaking is the breaking up of an edge contour caused by the operator output fluctuating above and below the threshold. This method is therefore less likely than the others to be fooled by noise, and more likely to detect true weak edges.

Figure 8 shows an example of a filtered image by using the anisotropic diffusion (shown in Figure 8(b)) and the edges detected by Canny method.

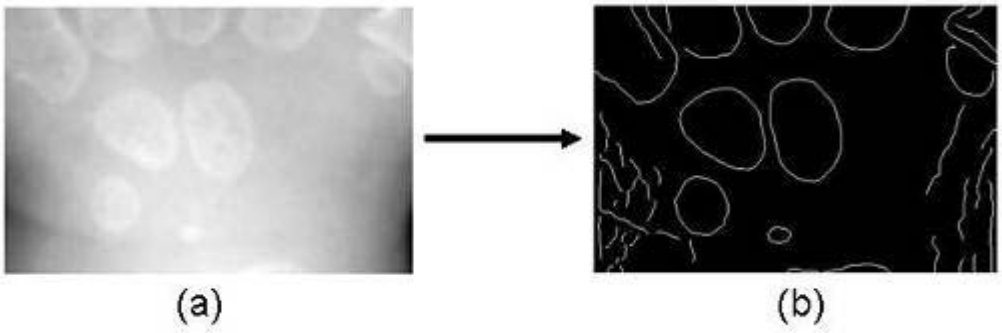

Figure 8 (a) Original smoothed image and (b) Result image after Canny edge detection

4.4 Objects Clean-up by Morphological Operations

The CROI includes carpal bones and parts of the radius, ulna, and metacarpals. Before the features that describe the carpal bones are extracted, the carpal bones themselves need to be identified from the result of Canny edge detection. In order to extract the contours of carpal bones, the contours of metacarpal bones and wrist and short lines and spots need to be removed. Knowledge-based morphological operations were used to clean-up the objects.
An original image and the final result after clean-up are shown in Figure 9 (a) and (b) respectively.

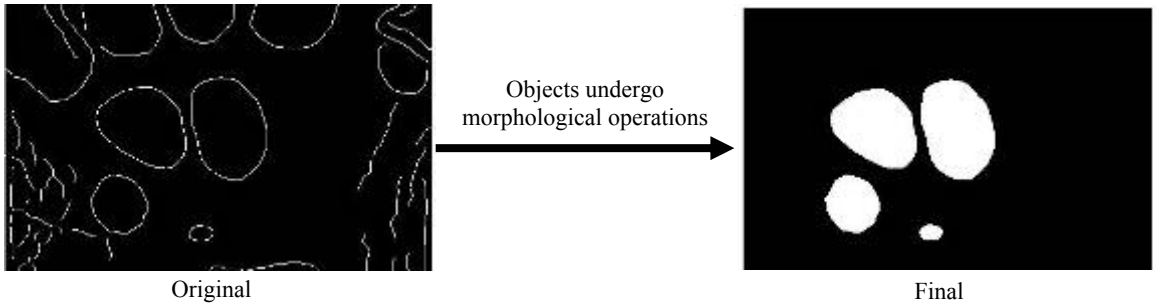

Figure 9 The goal of clean-up procedure shows four carpal bones

5. RESULTS

Carpal bone segmentation procedure was tested on 130 bones from 30 African American cases of age groups 1-5 years old. Figure 10 shows examples of Successful Cases.

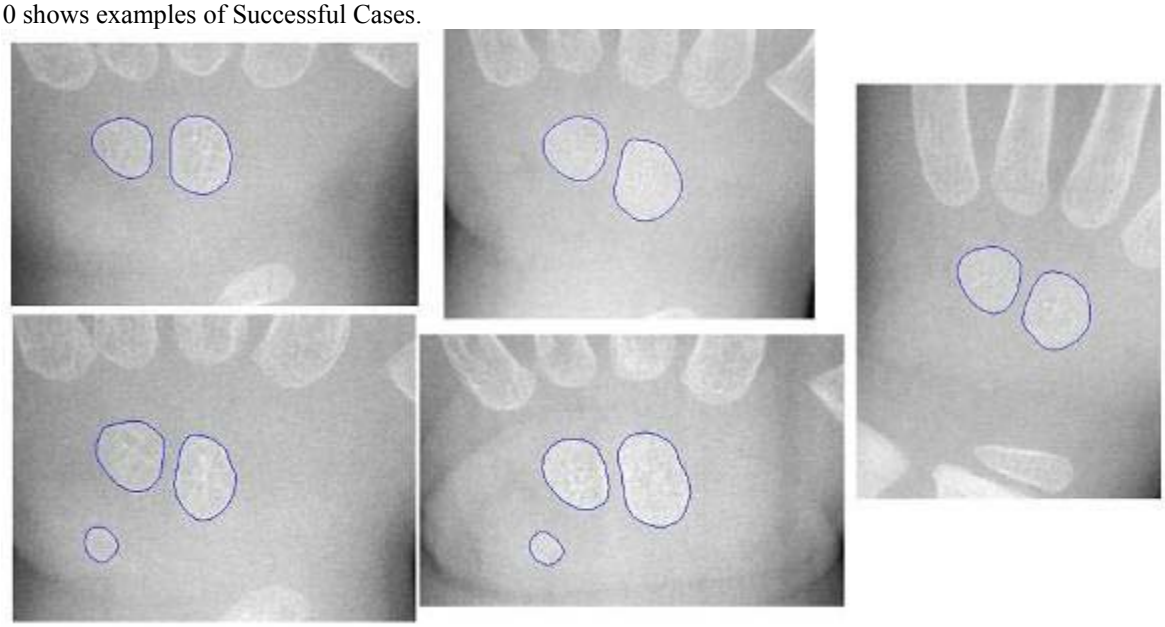

Figure 10 Examples of Successful Cases

The preliminary result shows that 83% and 76% success rate were achieved in males and females respectively, up to 5 years of age. It also demonstrates that the segmentation success rate is higher in male cases than female cases. This is due to the discrepancy of bony development between boys and girls especially in younger ages.

6. FUTURE WORK

This paper presents a new carpal bone segmentation procedure based on anisotropic diffusion and canny edge detection.
The segmentation algorithm will be applied to the cases in our database. And knowledge-based model will be built to improve the segmentation algorithm to refine current Carpal Bone segmentation results. After each carpal bone is identified correctly, features will be extracted by Fourier Series Descriptors from each carpal bone. A fuzzy classifier which takes into account both phalangeal features which already have been extracted and carpal bone features will be developed for the automatic bone age assessment. Lastly, the performance of the bone age assessment CAD system will be evaluated by comparing with radiologists' readings.

ACKNOWLEDGEMENT

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REFERENCES

1. W. Grelich, S. Pyle, *Radiographic Atlas of Skeletal Development of Hand Wrist*, Stanford, CA: Stanford University Press, 1959.
2. D. Kirks, *Practical Pediatric Imaging*, Diagnostic Radiology of Infants and Children, (Little, Brown & Company, Boston/Toronto), 1st ed., 1984, chap. 6, pp. 198-201.
3. J.M. Tanner, R.H Whitehouse, *Assessment of Skeletal Maturity and Prediction of Adult Height (TW2 Method)*, Academic Press, London, 1975.
4. E. Pietka, S. Pospiech, A. Gertych, F. Cao, *Integration of Computer Assisted Bone Age Assessment with Clinical PACS*, Computerized Medical Imaging and Graphics, 1-12, 2002.
5. F. Cao, HK. Huang, E. Pietka, V. Gilsanz, *Digital Hand Atlas and Web-based Bone Age Assessment: System* Design and Implementation, Computerized Medical Imaging and Graphics, 297-307, 2000.
6. H.K. Huang, *Picture Archiving and Communication Systems: Principle and Applications*, Wiley & Sons, NY, p. 521, 1999.
7. A. Zhang, et al. *Data Mining for Average Images in a Digital Hand Atlas*. Proceedings of SPIE Medical Imaging, Vol. 5371, pp. 251-258, February 2004.

8. E. Pietka, A. Gertych, S. Pospiech, F. Cao, HK. Huang, V. Gilsanz, *Computer Assisted Bone Age Assessment: Image Processing and Epiphyseal/Metaphyseal ROI Extraction*, IEEE Trans. Medical Imaging, 20, 715-729, 2001.
9. E. Pietka, S. Pospiech, A.Gertych, F. Cao, H.K. Huang, V. Gilsanz, *Computer Automated Approach to the extraction of epiphyseal regions in hand radiographs*, Journal of Digital Imaging, 14, 165-172, 2002.
10. F. Cao, HK. Huang, E. Pietka, V. Gilsanz, P. Dey, A. Gertych, S. Pospiech, *An Image Database for Digital Hand Atlas*, SPIE Medical Imaging, vol 5033, 461-470, 2003.
11. S. Pospiech-Kurkowska, E. Pietka, F. Cao, H.K. Huang, *Fuzzy System for the Estimation of the Bone Age from Wavelet Features*, Proc. BIOSIGNAL 2002, Brno, 441-443, 2002.
12. E. Pietka, A. Gertych, Witko K, *Remotely Accessible Computer Assisted Skeletal Maturity Assessment*, Proc. RSNA Chicago, p.807, 2004.
13. E. Pietka, A. Gertych, S. Pospiech-Kurkowska, F. Cao, HK. Huang, V Gilsanz, *Computer Assisted Bone Age Assessment: Graphical User Interface for Image Processing and Comparison*, Journal of Digital Imaging, 17(3), 175-188, 2004
14. A. Gertych, E.Piętka, *An automated segmentation and features extraction from hand radiographs*, Archive of Applied and Theoretical Informatics, vol. 15, Book 3, pp 315-326, 2003, ISSN 0867-2121.
15. K. Simmons, *Brush Foundation Study of Child Growth and Development II: Physical Growth and Development*, Periodicals Service Co, 1972.
16. P. Perona, J. Malik, "Scale-space and edge detection using anisotropic diffusion", PAMI 12(7), pp. 629-639, 1990.
17. J. F. Canny, Finding edges and lines in images, Master thesis, Massachusetts Institute of Technology, 1983.
18. J. F. Canny, A computational approach to edge detection, IEEE transaction PAMI, Vol. 8(6), p. 679, 1986.
19. A. Zhang, Arkadiusz Gertych, Brent J. Liu, H.K. Huang, Sylwia Kurkowska-Pospiech, Carpal Bone Segmentation and Features Analysis in Bone Age Assessment of Children. Proceedings of RSNA Conference, Chicago, pp. 688, 2005.

Content-Based Image Retrieval in Picture Archiving and Communication Systems

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ABSTRACT

Traditionally, Picture Archiving and Communication Systems (PACS) use textual-based retrieval, which have their limitations. General-purposed content-based image retrieval (CBIR) systems often do not perform well in medical images and are not integrated with PACS and Radiology Information System (RIS). In this presentation we design a CBIR system that is integrated with PACS and RIS, by using a user-supplied query image to retrieve similar images from PACS and get corresponding reports from RIS. We also employ ACR index for radiological diagnosis to reduce the search space and to provide meaningful results in our CBIR system. We use high resolution CT lung images as the test data. A key image is selected for each series, and after a radiologist delineates the pathology bearing region, local texture features as well as ACR indexes and series UID are stored in a CBIR server. Series UID can be used to retrieve images from PACS and to obtain corresponding reports from RIS. The system is a useful learning tool for radiology education and can provide valuable references for radiologists when a new case comes.

Keywords: CBIR, PACS, RIS, DICOM

1. INTRODUCTION

Medical images are important evidences for medical diagnosis, and picture archiving and communication systems (PACS) emerge to manage these images and provide digital platform for imaging diagnosis. With the growth of medical databases, more and more efforts are paid to analyze these data content statistically, such as breast cancer screening, cardiac analysis, and lung nodules detection. These databases use the image content, particular pathology or specific features in images, to manage the images, and not use the patient text information to manage them, such as patient name and study date.

All today's PACS systems index images using text-based information that is called meta-data generated at acquisition time according to DICOM Information Object Definition (IOD) model. This textual approach fails to account for quantitative analysis of medical structures within images that are visible to a trained radiologist but not codable in conventional database terms [1]. In many medical practical applications, the image content is very important and useful for image indexing and retrieval.

Since the limitation of traditional text-based approach, the concept of Content-Based Image Retrieval (CBIR) was emerged in the early 1990s, but mainly successful in indexing color photographs. These color images are represented as a feature vector of a feature space, and a similarity measure is defined from distance in the feature space. Color, shape and texture are used in the first approaches such as QBIC [4] and Photobook [5]. Manjunath proposes Gabor wavelets features and its discrimination ability was better than that of many other features [2]. Blobworld [7] includes a segmentation step to integrate higher level information. Iqbal et al. uses structure as well as gabor features to locate images containing manmade objects such as buildings [14]. However, two or three level of semantic layers are insufficient to model the complexity of images [8]. This loss of information from an image to its representation in a feature space is called the semantic gap [9].

Medical images are even more difficult to tackle. Most medical images are intensity images carrying less information than color images with low resolution and high noises. Moreover, medical images interpretation is often difficult even for trained radiologists.

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Though difficult, some medical CBIR systems have been proposed in recent years. Based on open source project GIFT, medGIFT shows how little changes in the features space significantly improve the retrieve results [17]. Glatard et al. present a CBIR system dedicated to cardiac imaging, which segments and indexes acquired images without user supervision [3]. Chia-Hung Wei et al. represents a general framework that retrieves mammograms using gray level co-occurance matrices [13]. Winnie Tsang et al propose a CBIR system for normal anatomical regions present in CT studies of the chest and abdomen, by means of both pixel and global based co-occurance texture features [1]. Lehmann et al. propose general interfaces that are required for integration of CBIR system to routine PACS in hospitals and Image Retrieval in Medical Applications (IRMA) as an example application [12]. IRMA proposes a multi-step approach which results in six layers of information modeling medical expert knowledge [10]. ASSERT dedicates to HRCT lung images retrieval, involving physicians to specify anatomical landmarks and pathology bearing regions [6].

In this paper, we describe an approach to design a CBIR system that is integrated with PACS and RIS, by using a user-supplied query image to retrieve similar images from PACS and get corresponding reports from RIS. We also use ACR index for radiological diagnosis to reduce the search space and to provide meaningful results in our CBIR system. This paper is organized as follows. Section 2 presents the design concept in our approach, section 3 describes the algorithms used to extract the image features combined with the radiologists' knowledge to index images, section 4 gives the implementation of our CBIR system in a clinial PACS environment, and section 5 presents the preliminary results.

2. DESIGN CONCEPT

In our approach, we use CT lung image as testing model to develop a new method of content-based image retrieval. We use both information of images and reports to index and retrieve images. Images and reports are managed in separate information systems and are indexed in different ways.

Images are stored in a PACS and indexed based on DICOM IOD information model, which is a four level hierarchy: patient, study, series, and image. A PACS implements a DICOM query/retrieve SOP (service-object pair) class to provide query/retrieve service to the client users. Reports are stored in a radiology information system (RIS). Radiology department uses RIS to manage the workflow as well as diagnostic reports. In our clinical practice, reports are indexed by ACR code. The ACR index consists of two portions, anatomical classification codes and pathology diagnostic codes.

We build CBIR system on top of RIS integrated PACS, and identify the content of images by using low level features extracted by using image processing algorithm, and that from radiologists' knowledge to do the content-based index for the images. As users of the CBIR system, radiologists are usually responsible for selecting the key images from a series and the regions of pathology interested in that images. The image features of the regions with pathology interested are extracted by using some image processing algorithms. This manual delineation carries some semantic information for later on content-based indexing and retrieval. Users are also required to classify the diagnosis by using ACR codes on the selected pathology images. This ACR indexing procedure also carries the high level understanding of the images. Thus, the selected images are classified by using ACR code, their low level image features are extracted, and both of the information are used to do the content-based indexing. The ACR codes and image features are stored in CBIR server, and can be used to retrieve images with similar features and indexes from the CBIR server.

Our CBIR system is compatible with radiological workflow. In the indexing procedure as shown in Figure 1, a series of images of a study were first viewed and related reports are created. Then, the reports are stored into RIS from the PACS display workstation. Meanwhile, a key image, which is to be indexed by our CBIR system, is chosen from a series and a region of interest (ROI) is delineated. The ACR codes of this study were also specified, the image features were extracted using proper algorithms. Finally, the features, ACR codes as well as the thumbnail image of the key image were stored in our CBIR server.

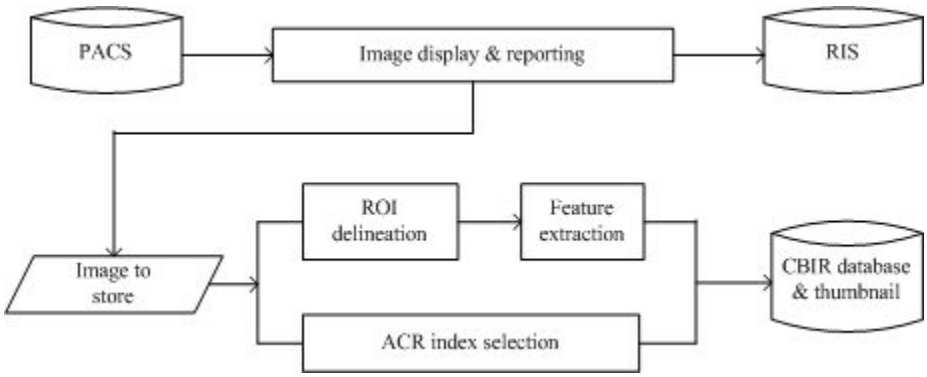

Figure 1: Indexing procedure

Figure 2 shows the retrieval procedure. When a new case came from a modality or a clinical PACS and was viewed on PACS workstation, a radiologist might want to find the case with similar image features or content from the PACS. The radiologist first created a content-based query with the extracted features from an input image and anatomical codes from ACR codes. Then features and indexes were sent to CBIR system to search the similar images. Then, result images were ranked by a dissimilarity metrics. Thumbnails of the best matched images were returned to the display workstation, relevant reports from clinical RIS and image series from clinical PACS were also retrieved.

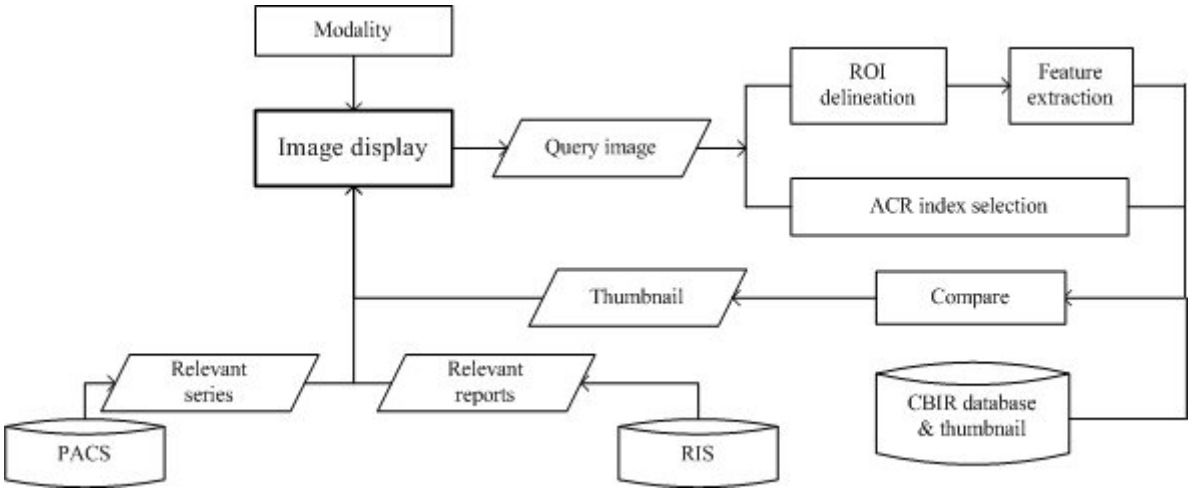

Figure 2: Retrieval procedure

3. FEATURES AND ACR CODES FOR INDEXING IMAGES

Though accurate retrieval of medical images needs semantic information of images, in our preliminary study, we rely highly on low level features. In following subsections, we discussed some major image processing algorithms used in our CBIR.

3.1 Histogram

Among all features, histogram may be the simplest, and this simple method may be as well effective. The idea is that two similar regions with similar pathology bearing usually show similar histograms, especially in the case of CT images where different pathological changes often result in different intensities. In our CT lung images (Siemens 16 multi-slices CT), the pixel values of the lung region mostly range from 0 to 1280. We group 64 pixels to a bin, so that the histogram contains 20 bins. The histogram is then normalized and gives 20 features.

3.2 Gabor filters

The use of gabor filters is one of the most popular approaches in texture analysis field. It is reported that gabor filters can be used to model the human visual system. Gabor filters can also provide optimal time and frequency resolution. A range of filters at different scales and orientations are applied to an image to decompose it into several texture feature images.

An image I(x, y) filtered with gabor flter g_{mn} at scale m and orientation n results in a feature image w_{mn} ,

$$w_{mn}(x,y)=\int I(x,y)g_{mn}^{*}(x-x1,y-y1)dx1dy1$$

We implemented our system based on the method of Manjunath et al [2]. Filters at 3 scales and 4 orientations were used to decompose the input image, the mean and standard deviation of the ROI in the texture images were computed and normalized respectively, which yields 12 features.

3.3. Wavelet Frame Decomposition

Wavelet Frame Transformation was proposed by Unser [11], which is an overcomplete wavelet decomposition. This transform yields a transition invariant description of image texture, which is desirable in image texture analysis.

Unlike fast wavelet transform proposed by Mallat, instead of down-sample the image, wavelet frame transform up-sample the low-pass and high-pass filters at each scale. Decomposition at each scale results in horizontal, vertical, diagonal detail and averaged images. The averaged image is decomposed at the next scale. We used 3 scale decompositions, which yields 9 detail images. The energy of the ROI in the 9 images were calculated and normalized, thus yields 9 features.

3.4. Multi-Husrt parameters

Roughness is an important feature to describe texture. Fractal analysis is a way to investigate the roughness of images. Some researchers propose to use fractal analysis to index medical images.

One of fractal analysis techniques, fractal Brownian motion (fBm) models images that show the same roughness at all scales, and the roughness is determined by Hurst parameter. Kaplan et al expand Hurst parameter to multi-scale Hurst parameters, a better representation of natural textures, which outperform standard Hurst features in segmentation applications. The idea is to model a digital image as a 2-D extended self-similar process [19]. When the digital image is subsampled by a factor of 2^s, the fractal dimension can be estimated as:

$$H_s = \frac{1}{2}\log_2\left(\frac{f(2^{s+1})}{f(2^{s+1})}\right)$$

Where: f is a structure function that is normalized so that $f(1)=1$.

We adopted the multi-scale Hurst features implementation proposed by Kaplan [15]. We computed Hurst parameters at 4 scales, and got the mean and standard deviations of the Hurst parameters at each scale. These features were normalized, thus yields 8 features.

3.5.Dissimilarity measure

Dissimilarity metrics are ways to determine how different two images are. Many metrics have been proposed, such as Euclidean distance, city block distance and Jeffrey-divergence. Y. Rubner et al [18] compare nine families of dissimilarity measures for color and texture. In our preliminary study, we determined the distance as a weighted sum of all families of features, inside each family of features, the distance was determined by city block metrics.

3.5. ACR indexes

Low level features have limitations in image retrieval due to the semantic gap. In our approach, radiologists, the users of our system, were responsible to provide some semantic information for retrieval. Besides the manual specifying pathology bearing regions, we made use of ACR code for radiological diagnosis, which carries the knowledge of radiologists, to index images, to narrow the search space and to provide more meaningful retrieval results.

4. SYSTEM IMPLEMENTATION

In our implementation, integrating CBIR system to PACS and RIS does not interfere the operating of the clinical PACS, because both CBIR and PACS are self-standing applications. Since medical applications were distributed in nature, we decoupled our system to a CBIR server side and a CBIR client side. The server is responsible for providing storage and retrieval functions. The CBIR clients running on different PACS workstations exchange information with the CBIR server.

CBIR client acts as a mini PACS workstation, implemented with a DICOM service class user and provider which communicates with PACS according to the DICOM standard. The CBIR client also can navigate to the diagnosis reports of retrieved studies from RIS which is implemented with Web based architecture. CBIR client communicate with CBIR server by means of web service. A radiologist delineated the pathology bearing regions on a CBIR client, the features were extracted, ACR codes were assigned and the thumbnail image was generated, then the selected features, ACR codes and thumbnails were packaged as an XML string parameter to call the web service to send to CBIR server. The CBIR server was

responsible to provide storage and retrieval service of CBIR. Figure 3 is the diagram of the system integration of PACS, RIS with CBIR.

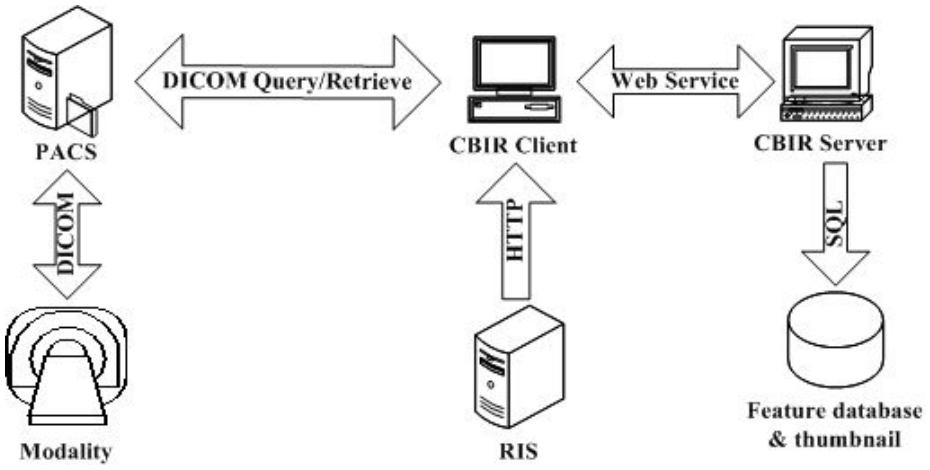

Figure 3: Integration of CBIR, PACS and RIS

5. PRELIMINARY RESULTS

It is hard to evaluate the system's performance due to the fuzzy nature of CT lung images. Different pathologies may have similar CT images, and the same pathology may shows obviously dissimilar images. Moreover, in many cases, it is hard to tell whether a retrieved image is relevant to the example image or not. So we don't provide a precision-recall graph here.

In our preliminary test, we have 50 series of images as training data and another 10 series as test data. One key image for each series is chosen and indexed for CBIR storage and retrieval.

Ideally, if we used an image, which was already stored in the CBIR database, as example image to retrieve the CBIR, the retrieved image would match the example image perfectly, and it would be the first and also the last one image to be retrieved. We used P_i to denote the probability that the retrieved image was identical with the example one after the *i*-th retrieval operating, and P_i can be estimated as:

$$\frac{\text{times when identical image is the i-th retrieved}}{\text{number of total retrieval times}}$$

Our testing shows that P_1=0.88, P_2 = 0.06, which means that our CBIR system is not sensitive to the delineation of pathology bearing regions.

We also compared the content-based retrieval results by using ACR codes in indexing procedures with those not by using ACR codes. It shows that the content-based indexing with ACR codes speeds up the search procedure and helpful for radiologists to retrieve the correct images. Figure 4 shows the first seven retrieved images that bear inflammation in the left upper lobe. Figure 5 shows the retrieved images not using ACR codes in indexing.

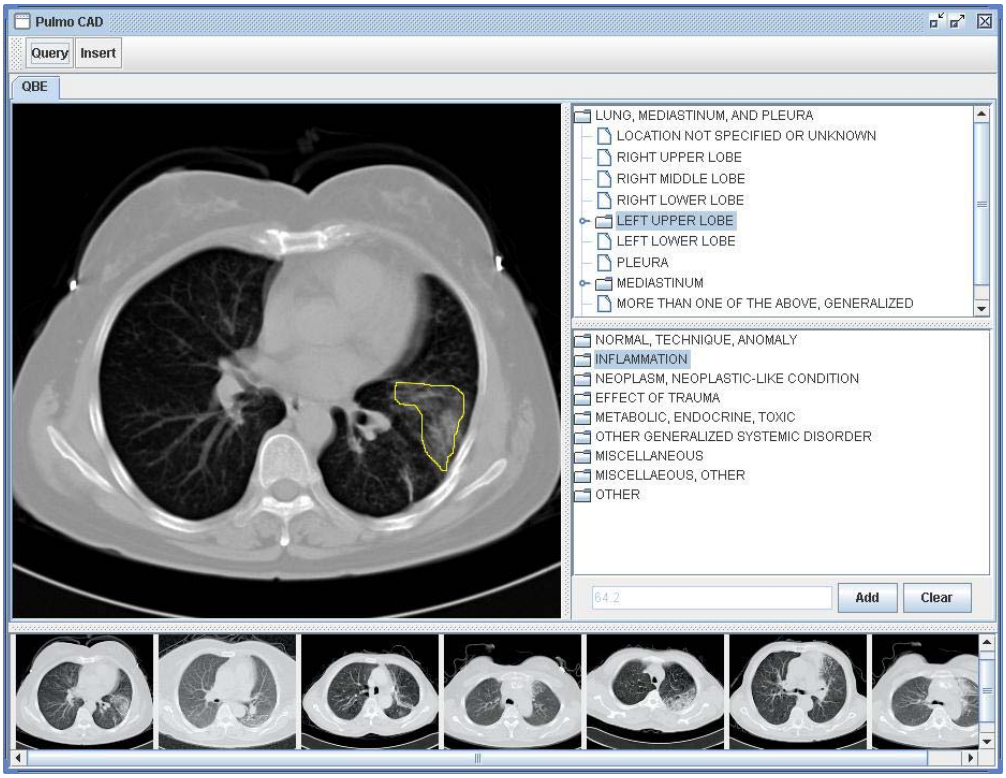

Figure 4. The seven retrieved images by using the image with bear inflammation as shown in the left upper lobe from CBIR system when ACR codes were used in the indexing procedure.

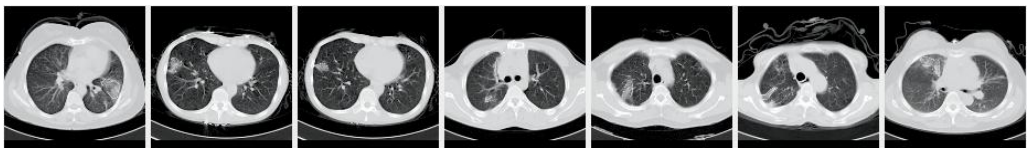

Figure 5 The seven retrieved images by using the image with bear inflammation from CBIR system, but ACR codes were not used in the indexing procedure.

The CBIR system was implemented with DICOM Storage SCU and SCP, so that it can be integrate into a clinical PACS environment seamlessly. Radiologists can retrieve and view the relevant series of images from PACS after selecting correct thumbnail image from CBIR server. Figure 6 shows one series of images retrieved from PACS according to the correct thumbnail image from CBIR server.

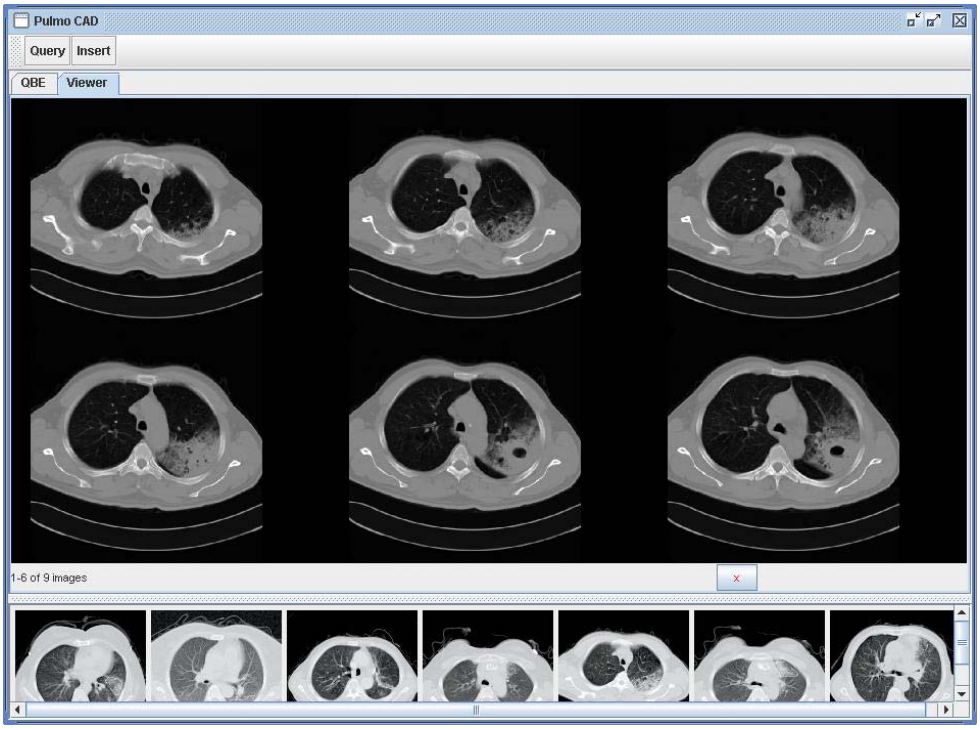

Figure 6: retrieved relevant a series of images from PACS

The corresponding reports of the retrieved a series of images were also retrieved from RIS. Figure 7 shows one corresponding report retrieved from RIS.

Figure 7: One corresponding report of the retrieved a series of images by using CBIR system.

6. CONCLUSION

We designed and implemented a content-based image retrieval system for lung CT images by using both of image feature recognition and ACR code classification in image content-based indexing, which was integrated with a clinical PACS and RIS. From the preliminary research results, we think that the low level features combined with the ACR codes for anatomy and pathology have certain discrimination power in lung CT image content-based retrieval. Future work will focus on improving and evaluating the CBIR performance of the system.

7. ACKNOWLEDGMENTS

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REFERENCES

1. W. Tsang, A. Corboy, K. Lee, D. Raicu, and J. Furst, Texture-based image retrieval for computerized tomography databases, Proceedings of 18th IEEE Symposium on Computer-Based Medical Systems (CBMS'05) June 23-24, 2005.
2. B. Manjunath and W. Ma, Texture features for browsing and retrieval of image data, IEEE Trans. Pattern Analysis and Machine Intelligence. 18 (8), 1996, 837-842.
3. T. Glatard, J. Montagnat, and I.E. Maginin. Texture based medical image indexing and retrieval: application to cardiac imaging. ACM SIGMM international workshop on Multimedia Information Retrieval (MIR'04) Proceedings ACM Multimedia 2004, New-York USA, October 15-16, 2004.
4. W. Niblack, R.Barber, W. Equitz et al. The QBIC project: querying images by content using color, texture, shape. Proceedings SPIE: Storage and Retrieval for Images and Video Databases, vol. 1908, pp. 173-187, 1993.
5. A. Pentland, R. W. Picard, S. Scarloff, "Photobook - Content-based manipulation of image databases, Proceedings SPIE 1994; 2185:34-47.
6. CR Shyu, Carla Brodley, A. Kak, and A. Kosaka, ASSERT - A physician-in-the-loop content-based retrieval system for HRCT image databases. Computer Vision and Image Understanding 1999; 75 (1/2):111-32.
7. C. Carson, S. Belongie, H. Greenspan, and J. Malik, Blobworld – Image segmentation using expectation-maximization and its application to image querying. IEEE Transactions on Pattern Analysis and Machine Intelligence 2002; 24 (8):1026-38.
8. T.M. Lehmann, M.O. Güld, C.Thies, B. Fischer, K. Spitzer, D. Keysers, H. Ney, M. Hohnen, H. Chubert, and B. B. Wein, Content-based image retrieval in medical applications, Methods Inf Med 2004; 43:354-61.
9. A.W.M. Smeulders, M. Worring, S. Santini, A. Gupta, and R. Jain, Content-based image retrieval at the end of the early years. IEEE Transactions on Pattern Analysis and Machine Intelligence 2000; 22 (12): 1349-80.
10. T.M. Lehmann, B. Wein, J. Dahmen, J. Bredno, F. Vogelsang, and M. Hohnen: Content-based image retrieval in medical applications: A novel multi-step approach. Proceedings SPIE 3792:312-320, 2000.
11. M. Unser, Texture classification and segmentation using wavelet frames, IEEE Transactions on Image Processing, vol 4, November, 1995; 1549-60.
12. T.M. Lehmann, B. Wein, and H. Greenspan, Integration of content-based image retrieval to picture archiving and communication systems. Proceedings Medical Informatics Europe (MIE 2003), IOS Press, Amsterdam.
13. C.H. Wei, C.T. Li, and R. Wilson, A general framework for content-based medical image retrieval with its application to mammograms. SPIE Medical Imaging, 2005, Volume 5748, pp. 134-143.
14. Q. Iqbal, and J.K. Aggarwal, Using structure in content-based image retrieval. Proceedings IASTED International Conference, Signal and Image Processing, Oct. 18-21, 1999, Nassau, Bahamas, pp. 129-133.
15. L.M. Kaplan and R. Murenzi, Texture segmentation using multiscale Hurst features. IEEE 1997 International Conference on Image Processing, Santa Barbara, CA, Oct. 26-29, 1997.
16. P. Howarth, A Yavlinsky, D. Heesch and S. Rüger, Visual features for content-based medical image retrieval. In Notebook of the Cross Language Evaluation Forum (CLEF, Bath, UK, Sept 2004), 2004.
17. Henning Müller, A. Rosset, J.P. Vallée, A. Geissbuhler, Comparing feature sets for content-based medical information retrieval, SPIE Medical Imaging, San Diego, CA, USA, February 2004.
18. Y Runbner, J. Puzicha, C. Tomasi, and J.M. Buhmann, Empirical evaluation of dissimilarity measures for color and texture. Computer Vision and Image Understanding, 84, 25-43 (2001)
19. L. M. Kaplan and C. Kuo, Extending self-similarity for fractional Brownian motion, IEEE Transactions on Signal Processing, vol. 42, pp. 3526-30, Dec. 1994.

HIPAA-Compliant Automatic Monitoring System for RIS-Integrated PACS Operation

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Abstract

As a governmental regulation, Health Insurance Portability and Accountability Act (HIPAA) was issued to protect the privacy of health information that identifies individuals who are living or deceased. HIPAA requires security services supporting implementation features: Access control; Audit controls; Authorization control; Data authentication; and Entity authentication. These controls, which proposed in HIPAA Security Standards, are Audit trails here. Audit trails can be used for surveillance purposes, to detect when interesting events might be happening that warrant further investigation. Or they can be used forensically, after the detection of a security breach, to determine what went wrong and who or what was at fault. In order to provide security control services and to achieve the high and continuous availability, we design the HIPAA-Compliant Automatic Monitoring System for RIS-Integrated PACS operation. The system consists of two parts: monitoring agents running in each PACS component computer and a Monitor Server running in a remote computer. Monitoring agents are deployed on all computer nodes in RIS-Integrated PACS system to collect the Audit trail messages defined by the Supplement 95 of the DICOM standard: Audit Trail Messages. Then the Monitor Server gathers all audit messages and processes them to provide security information in three levels: system resources, PACS/RIS applications, and users/patients data accessing. Now the RIS-Integrated PACS managers can monitor and control the entire RIS-Integrated PACS operation through web service provided by the Monitor Server. This paper presents the design of a HIPAA-compliant automatic monitoring system for RIS-Integrated PACS Operation, and gives the preliminary results performed by this monitoring system on a clinical RIS-integrated PACS.

Keywords: Monitoring, RIS-Integrated PACS, HIPAA.

1. INTRODUCTION

The shift of medical records from paper to electronic formats has increased the potential for individuals to access, use, and disclose sensitive personal health data. Although protecting individual privacy is a long-standing tradition among health-care providers and public health practitioners, previous legal protections at the federal, tribal, state, and local levels were inconsistent and inadequate. The HIPAA Privacy Rule [1] provides the first national standards for protecting the privacy of health information. The Privacy Rule regulates how certain entities, called covered entities, use and disclose certain individually identifiable health information, called protected health information (PHI).

RIS-integrated PACS (RIS-PACS) is a large system consisting of many components. Chances of any of these components fail at a given period of time are high. When it happens, immediate attention and service were required to resume PACS normal operation. Also, the HIPAA requires security services being implemented in healthcare information systems, and DIOCM Supplement 95 [2] defines a mechanism to collect the Auditing Trail Messages generated by applications to facilitate detection of improper creation, access, modification and deletion of Protected Health Information. For this reason, we designed an HIPAA compliant automatic monitoring system (HC-AMS) with a novel architecture to monitor and manage the RIS-PACS operation.

The HIPAA-compliant automatic monitoring system for RIS-Integrated PACS Operation is designed to facilitate detection of improper creation, access, modification and deletion of PHI and the running status of whole RIS-Integrated PACS including servers and workstations. To enable security features of privacy and security in automated systems, auditing trial messages need to be collected and processed to generate the security information, which may be reviewed by administrative staff to verify that healthcare data is being used in

accordance with the healthcare provider's data security requirements and to establish accountability for data use. In the typical healthcare IT environment, many systems from various vendors and developers have not implemented common or interoperable security administrative functions, although they may have activity logs. Our designed monitoring system consists of two parts: monitoring agents running in each PACS component computer and a Monitor Server running in a remote computer. Monitoring agents are deployed on all computer nodes in RIS-Integrated PACS system to collect the Audit trail messages defined by the Supplement 95 of the DICOM standard: Audit Trail Messages. The Monitor Server gathers all audit messages and processes them to provide security information in three levels: system resources, PACS/RIS applications, and users/patients data accessing. In following sections, we presented our architecture design and implementation of the HC-AMS built on top of our clinical RIS-integrated PACS running in Huadong Hospital (Shanghai, China), and gave the preliminary results.

2. DESIGN REQUIREMENTS

We had developed an automatic monitoring system to monitor and control the operation of PACS to decrease the total cost of ownership (TCO) for hospitals in last a few years [3]. In order to achieve the HIPAA compliant security management in PACS operation and applications, we re-design the system to enable the HIPAA compliant security services and operation management in RIS-integrated PACS. This new HIPAA compliant automatic monitoring system (HC-AMS) can monitor, control and manage the security in three levels: system or component resources, PACS/RIS application processes, and user data accessing behavior in using PACS/RIS. The required security features or functions of the HC-AMS on every component are:

1. Security records of all users accessing patient images and medical records in imaging diagnostic procedures from ordering to final reporting;
2. Both normal and abnormal events happened in RIS/PACS applications including image transmission, image file I/O operations, and database operations;
3. Resource status and performance of the PACS components, e.g., disks/partitions usages, the amount of image input and output per day/hour, the transferring speed of the image dataflow, as well as the working status of each node in the RIS-Integrated PACS system including network connection, CPU usages and application processes

.

The audit messages come from different subsystem, such as PACS acquisition workstations, PACS/RIS servers, image display workstations. According to different security purposes, the different security information acquisition and processing procedures are designed, and the acquired security messages are encoded based on the common XML schema defined by Supplement 95 of the DICOM standard: Audit Trail Messages [2]. In order to monitor RIS/PACS operating across platforms such as in Unix, Linux, Windows, we use J2EE technology to build the monitor system.

3. ARCHITECTURE AND METHOD

The HC-AMS consists of two parts: monitoring agents running in each PACS/RIS component and a Monitor Server running in a Web server. Monitoring agents connect to all services in each PACS/RIS component. The Monitor Server monitors each agent tracking the status and data flows of individual component, and verifies image data and reports being used in accordance with the healthcare provider's data security requirements. The agent services module has three kinds: PACS agent module, web PACS agent module and RIS agent module. They collect audit messages and send to monitor server via normalized XML. Figure 1 shows the architecture.

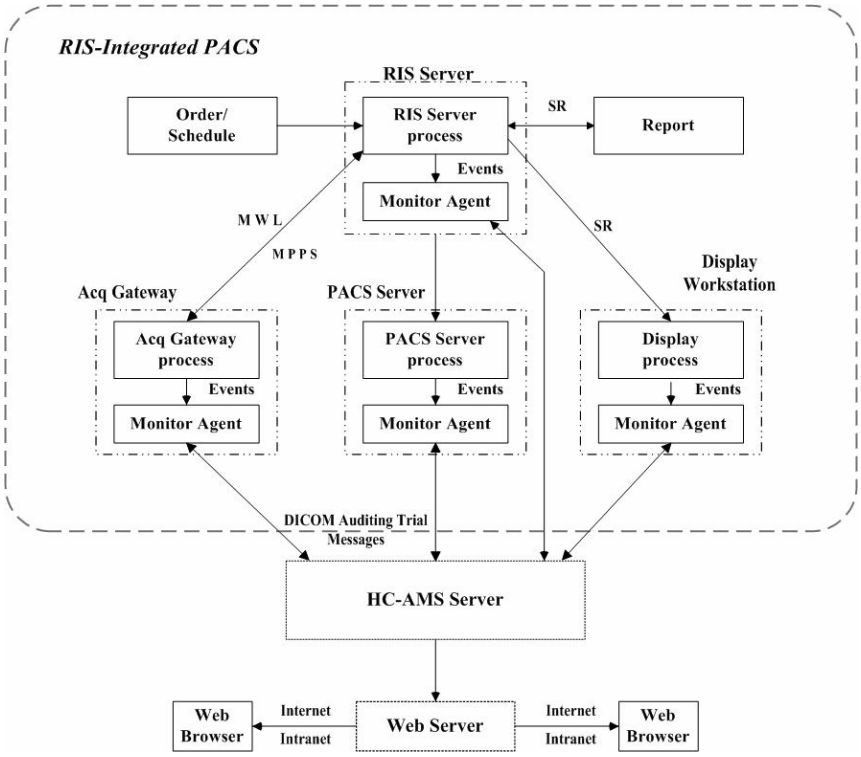

Figure 1. Architecture of HIPAA-Compliant Automatic Monitoring System for RIS-Integrated PACS Operation

There are two kinds of operation modes in the monitoring system: the Active mode and Passive mode. In Active mode, the most functions or tasks are performed periodically. But, in passive mode, the monitoring tasks are executed real-time.

The monitoring agents are deployed on each server and collect audit messages to create normalized XML to send to the Monitor server. The Monitor server processes the audit messages, then put them into the monitor database with Hibernate (database O/R mapping). We use Web services to perform the processes of sending and receiving XML. The XML receiving process is multi-thread and thread-safe to assure the reliability and efficiency of data collecting in automated systems. The Implementations of Audit Message claimed conformance to this profile use the XML schema, as defined by Supplement 95 of the DICOM standard: Audit Trail Messages shown in Figure 2, to format audit trail messages that includes Event Identification, Active Participant, Audit Source Identification and Participant Object Identification of complex types.

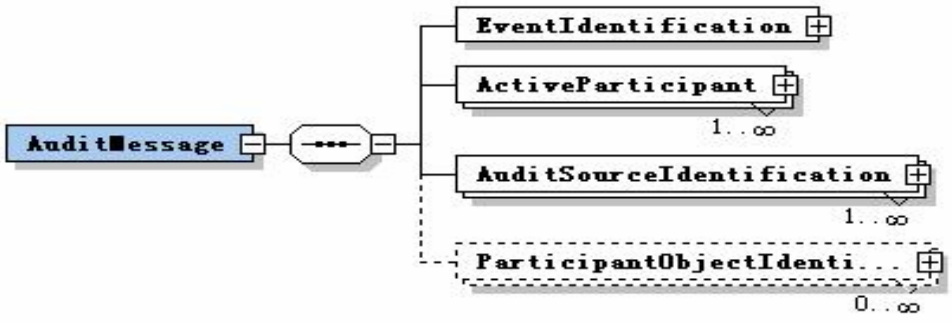

Figure 2. XML-based Audit Message defined by the Supplement 95 of the DICOM standard

The System monitor agents use JMS to communicate with all monitored nodes in the RIS-Integrated PACS. The nodes can be the PACS server, RIS server, web PACS server, gateway computers, and display workstations. The processed messages are put into the database of Monitor Server, and then reviewed by PACS/RIS administrators through the monitor Web client.

4. IMPLEMENTATION AND INSTALATION

Our HC-AMS is built based on J2EE and uses JBOSS as application server, Both the Monitoring Server and Agent clients can run on windows, Linux and Unix. We upgraded our old monitoring system to new HC-AMS in a clinical PACS running in Huadong hospital (Shanghai, China) [x] from September 2005, and the Monitor Server was installed on Windows Server 2003. The installation was painless, did not interrupt the normal PACS operation. The agent services were installed in acquisition gateway computers (Windows 2000), and display workstations (Windows XP), the PACS server (Sun Fire V480 with Solaris 9 and Oracle 9i database), the RIS server (Windows server 2003), and web-based PACS server (Linux Enterprised Advance Server 3 with Mysql database). The major functions and features the HIPAA-Compliant Automatic Monitoring System are:

1. Capture all warning, error and normal messages happened in PACS acquisition gateways, PACS server, RIS server, web PACS server, and display workstations, and send them to central monitor server;
2. Remote monitor and analyze RIS-Integrated PACS component computer resource status, e.g., storage spaces, networking;
3. Remote monitor and analyze user's operation on patient's healthcare data and guarantee that the data are used securely according to HIPAA requirements.
4. Analyze the performance of the RIS-Integrated PACS server, e.g., the usages of images, the transferring speed of the dataflow in every key component.

The PACS administrators can monitor the entire PACS operation and dataflow from the remote Monitor Server. The auditing trial messages with the information of detection of improper creation, access, modification and deletion of Protected Health Information, which are generated from the applications running in the servers, workstations of PACS and RIS, are sent to the Monitor Server for the administrators to analyze and manage the security of the RIS and PACS.

5. Preliminary Results

The major works of an administrator in monitoring and controlling RIS-Integrated PACS operation with the HC-AMS were to operate the Web client of the Monitor Server and read the information displayed on Web client. The routing works for an administrator using the HC-AMS to manage and maintain the RIS-Integrated PACS becomes:

1. Read the HC-AMS messages or information displayed on monitor client through web;
2. Identify problem reasons or sources if they found the errors among the messages sent from a remote RIS-Integrated PACS component and fix the problems if they can, otherwise call for technical support;
3. Analyze the network connect status, resource usages, running process of RIS-Integrated PACS component;
4. Track patient/image dataflow and patient healthcare dataflow (whole process of patient's imaging diagnosis);
5. Track users data accessing and monitor the remote users logon/off status, guarantee images secured used;
6. Do statistics on radiological examinations with monitor statistical functions, e.g., count performed image byte size of every day on CT, MR by each PACS server and PACS client, accessed image number of every day on CT, MR by each user.

The diagrams shown from Figure 3 to Figure 9 are the some examples of HC-AMS used by the RIS-Integrated PACS administrators. From the Figure 3 to Figure 6, they are about monitoring results of the system resources and application processes. Figure 7 (a) and (b) are about the users' accessing behavior on the patient images/reports. These tracking functions enable security officer of the hospital to audit user activities to assess compliance with security domain policies of the hospital, such as for users, which patients' PHI was accessed, and for patients PHI, which users accessed it. Figure 8 and Figure 9 shows the statistic results of user manipulation on PACS images or RIS reports, and as well as the image dataflow performance happened in a specific PACS component.

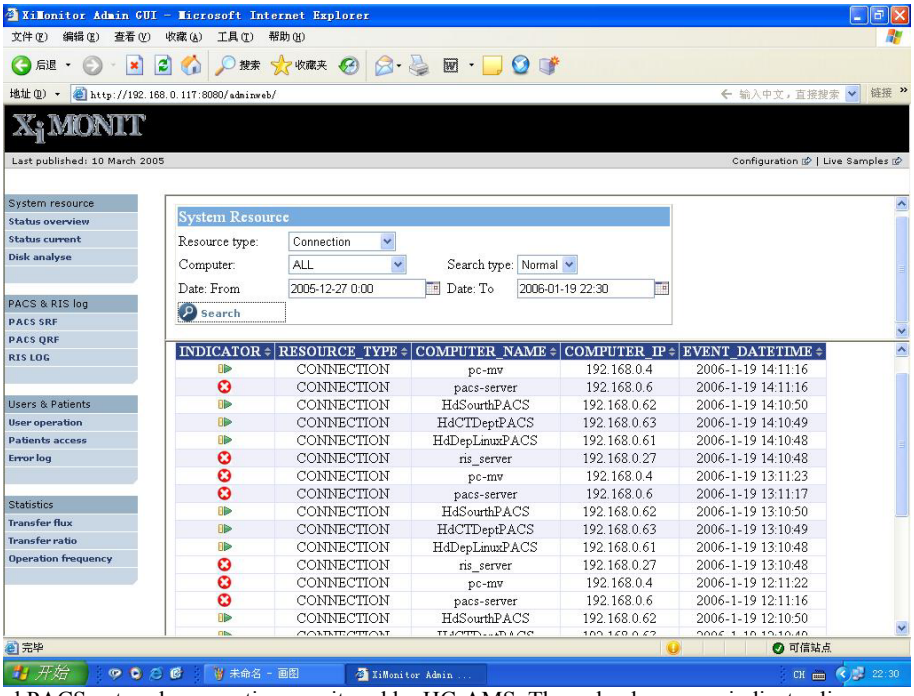

Figure 3. RIS-Integrated PACS network connection monitored by HC-AMS. The red colors cross indicator lines mean the network connection was not available for that computer at the indicated time, the green arrow indicator lines mean the network connection was available for that computer at the indicated time. The system monitor agent scanned the network status of all components once per hour.

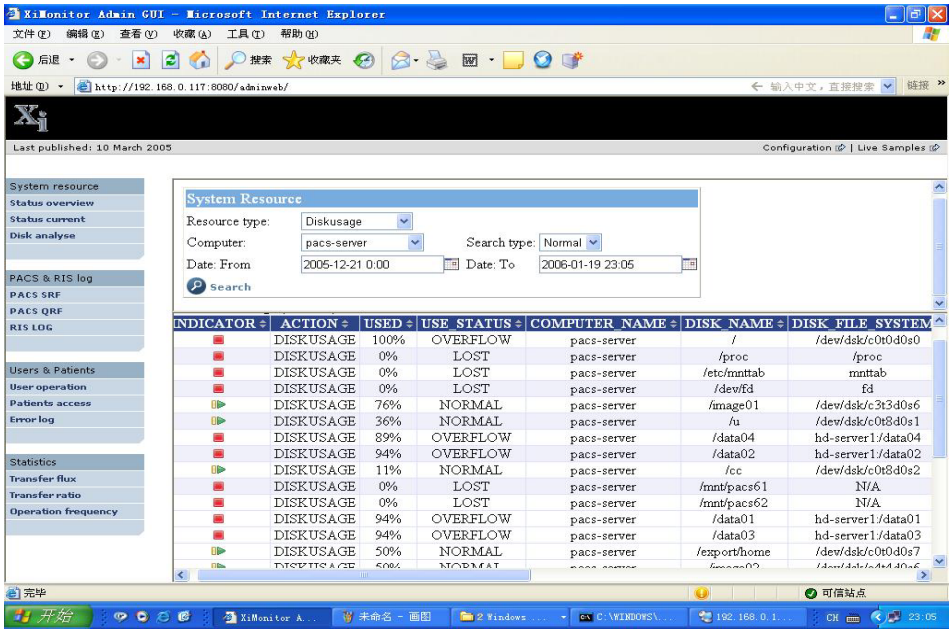

Figure 4. RIS-Integrated PACS disk usages monitored by HC-AMS. The red colors indicator lines mean that the disk/partition was in lost or almost in full status at the indicated time, the green arrow indicator lines mean that the disk/partition was in normal status. We prefer 85% as the threshold of a disk/partition being full. The system resource monitor agent scanned the components once per hour.

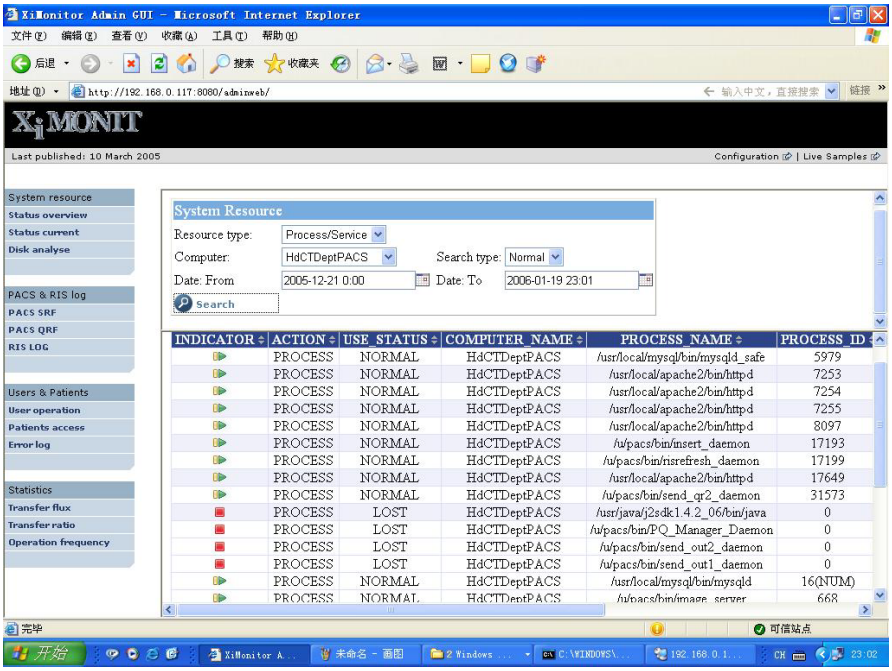

Figure 5. RIS-Integrated PACS application processes were monitored by HC-AMS. The red color indicator lines mean that the indicated processes were in inactivated status at that time, the green arrow indicator lines mean that the indicated processes were in normal status. The system resource monitor agent scanned the components once per hour.

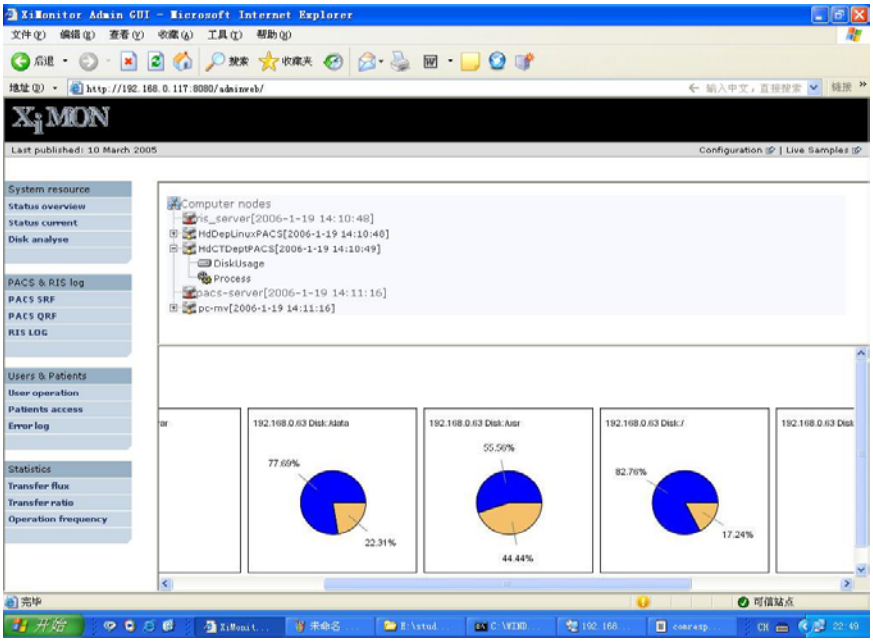

Figure 6. RIS-Integrated PACS system resources were monitored by HC-AMS at given time. The disk space usages of the Disk/Partition were showed by pie chart.

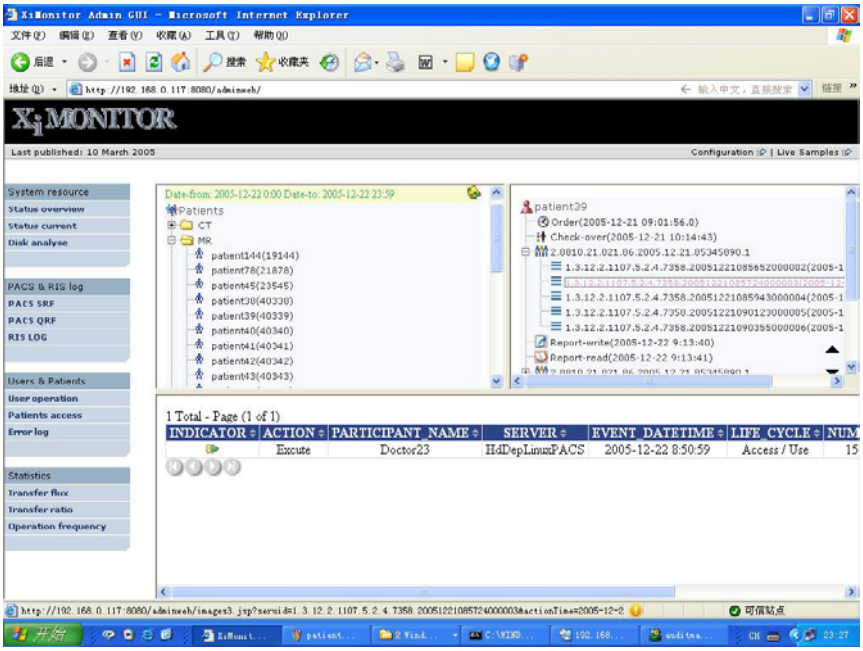

Figure 7 (a)

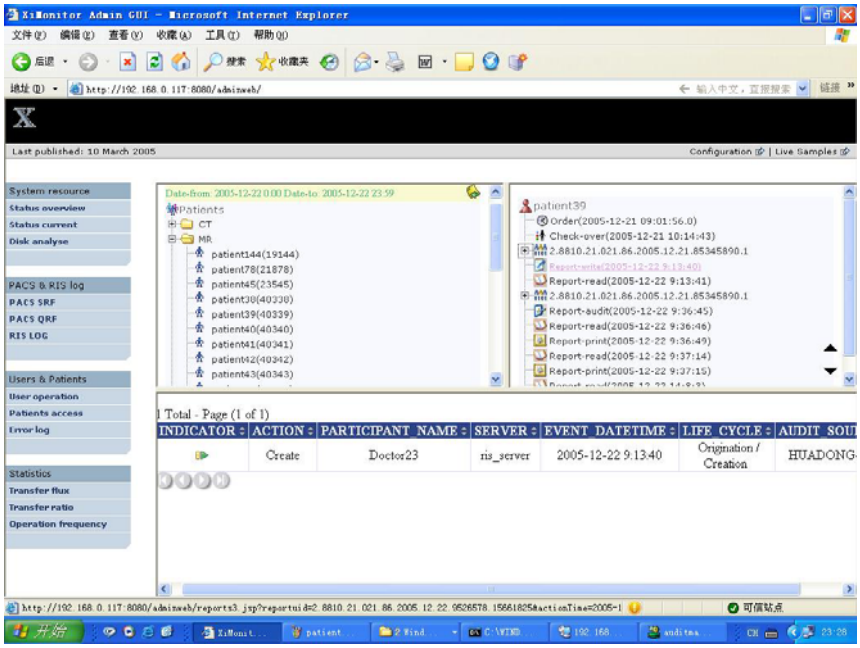

Figure 7 (b)

Figure 7. Accessing Patient image/report data were monitored by HC-AMS. Patient can be identified by name, id or time. The images/reports classified by modality types. When a patient was selected by an administrator as shown in left side GUI of Figure 7 (a) and (b), all users' accessing behavior on this patient's images/reports were showed in the right side of Figure 7 (a) and (b). The accessing types, to PACS server or RIS server, include examination order, image retrieve, preliminary reporting, final reporting, read reports, et al. These functions enable security officer of the hospital to audit user activities to assess compliance with security domain policies of the hospital, such as for users, which patients' PHI was accessed, and for patients PHI, which users accessed it.

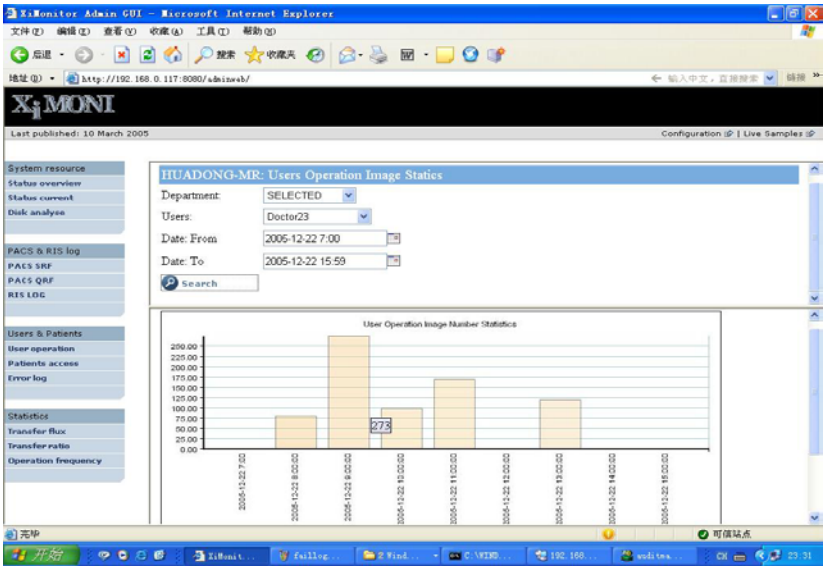

Figure 8. The total number of images was manipulated by users. The statistical calculation was performed once per day or per hour.

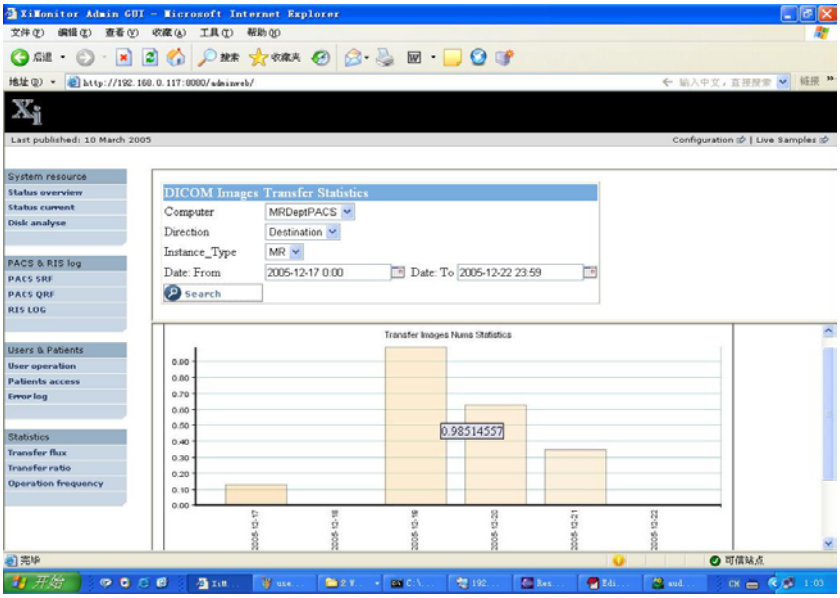

Figure 9. The amount of MR DICOM images transferred in PACS server calculated by HC-AMS. This statistic gives the performance of MR image dataflow in PACS server.

6. CONCLUSIONS

The HC-AMS was installed on top of a RIS-integrated PACS operating in a 800 beds Hospital successfully. The HC-AMS can not only monitor and control the entire PACS operation in real time, but also provide HIPAA compliant security services and management. These features make PACS administrators or security officers can manage and analyze the security status and data usages of RIS-integrated PACS from any where, and can take proper action if any failure happened in any PACS component, or can detect improper creation, access, modification and deletion of Protected Health Information.

7. ACKNOWLEDGEMENT

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REFERENCES

[1]. HIPAA, http://www.cms.hhs.gov/hipaa/hipaa2/general/background/p1_104191.asp.
[2]. DICOM Audit Trail Messages, ftp://medical.nema.org/medical/ dicom/supps/sup95_fz.pdf.
[3]. Jianguo Zhang, D. Wu, and R. Han, et al., "Automatic monitoring system for PACS operation and management", SPIE, Vol.4685, pp363-372, 2002

Integration of LDSE and LTVS Logs with HIPAA Compliant Auditing System (HCAS)

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ABSTRACT

The deadline of HIPAA (Health Insurance Portability and Accountability Act) Security Rules has passed on February 2005; therefore being HIPAA compliant becomes extremely critical to healthcare providers. HIPAA mandates healthcare providers to protect the privacy and integrity of the health data and have the ability to demonstrate examples of mechanisms that can be used to accomplish this task. It is also required that a healthcare institution must be able to provide audit trails on image data access on demand for a specific patient. For these reasons, we have developed a HIPAA compliant auditing system (HCAS) for image data security in a PACS by auditing every image data access. The HCAS was presented in 2005 SPIE. This year, two new components, LDSE (Lossless Digital Signature Embedding) and LTVS (Patient Location Tracking and Verification System) logs, have been added to the HCAS. The LDSE can assure medical image integrity in a PACS, while the LTVS can provide access control for a PACS by creating a security zone in the clinical environment. By integrating the LDSE and LTVS logs with the HCAS, the privacy and integrity of image data can be audited as well. Thus, a PACS with the HCAS installed become HIPAA compliant in image data privacy and integrity, access control, and audit control.

Keywords: HIPAA, Security, Integrity, Auditing, Access Control

1. INTRODUCTION

Health Insurance Portability and Accountability Act (HIPAA) [1, 2] Security Standards [3], has passed its official deadline on February 2005. HIPAA compliance in health data security becomes crucial for every healthcare provider in the U.S. now. The HIPAA Security Standards are aimed at the protection of privacy, integrity, and public availability of electronic health information against unauthorized use or disclosure. This is accomplished by utilizing administrative, physical, and technical safeguards. In particular, the technical safeguards consist of technical methods to assure security of the health data. Such technical methods proposed by HIPAA includes access control and audit control. The audit control specifically requires the on-demand generation of an audit trail that can record and examine information system activities such as data access of a particular patient. In general, the audit trails consists of following information for the health data access [4]:

- Identification of the person who accessed the data
- Identification of the accessed data
- Where the data was accessed
- Timestamp of when the data was accessed
- Types of access (eg, create, read, write, modify, delete)
- Status of access (eg, success or failure)

Because health data and information is such a broad area containing vast amounts of data types, this paper will focus on clinical imaging data that is generated and distributed through PACS.

Currently, to the extent of our knowledge, there are no systematic technical means available for a PACS be HIPAA compliant in image privacy and integrity, access control, and audit control. As a result, a HIPAA violation could be caused in a clinical PACS. For these reason, we have developed a HIPAA compliant auditing system (HCAS) [5-7] for protecting image data security in PACS. The HCAS can audit the image workflow of a PACS by collecting and analyzing the image data access events generated by PACS applications. The HCAS was presented in 2005 SPIE. This year, two new components, LDSE (lossless digital signature embedding) [8,9] and LTVS (patient location tracking and verification system) [10] logs have been developed and added to the HCAS. The two new components can provide HIPAA compliance in image data privacy and integrity, and audit control for a PACS.

2. SYSTEM ARCHITECTURE OF HCAS

The HCAS was designed as a two-layer system shown in Figure 1. The first layer (the lowest layer) is the Record layer, consisting of various logs generated by PACS components and two new components, LDSE and LTVS logs. The logs are the input data for the HCAS. By logically separating the logs from the other components in the HCAS, independence from PACS and portability can be achieved. The second layer is the Audit layer, which includes audit log collector, Syslog server, log data normalizor, centralized auditing database, audit analysis tool, monitor tool and role-based policy. These components are used to collect, preserve, and analyze the relevant information acquired from these various logs for generating audit trails and automatically monitoring the image data flow of the PACS [5-7]. By storing all image data access information in the centralized auditing database, HIPAA compliant audit trails can be generated for a particular patient anytime. The automatic monitor of the data flow of a PACS would greatly assist PACS management.

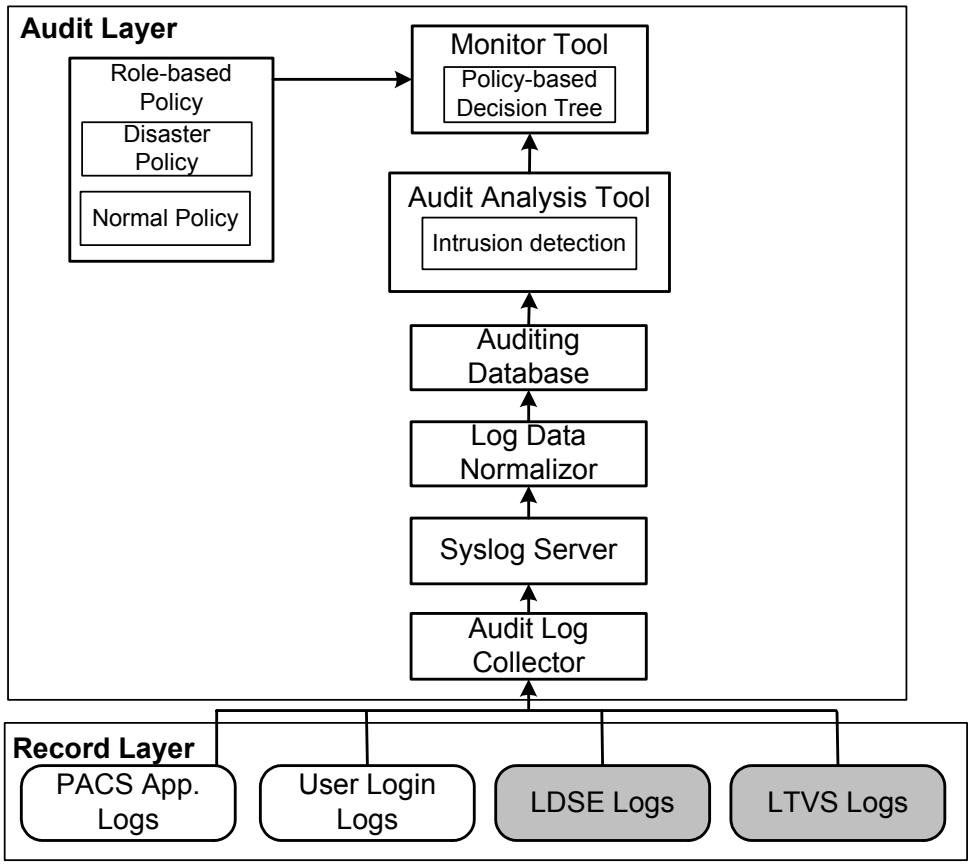


Figure 1 The two layer HCAS architecture for auditing of medical images in PACS showing various components for each layer: 1) Record layer, 2) Audit Layer. Shaded components represent the two new components.

3. INTEGRATION OF HCAS WITH LDSE AND LTVS

3.1 Relationships between HCAS and PACS, LDSE, and LTVS

The HCAS must be integrated with a PACS in order to collect image data access information from PACS logs. The information usually contains when, where, who, how, and what. The LDSE logs can be used to verify whether "what" (the image) is the original image data in the PACS. The LTVS logs can be used to verify whether the physical "who" is the authorized person accessing the PACS. Thus, HCAS, PACS, LDSE, and LTVS are inherently related and can be integrated seamlessly.

3.2 Integration of HCAS with PACS

The integration of HCAS with PACS is by installing a log collector of the HCAS in every PACS components and sending the relevant image data access information to the auditing database through the log collector [5-7]. The auditing database is then used to generate HIPAA compliant audit trails for a specific patient and monitor the image data flow of the PACS.

3.3 Integration of HCAS with LDSE Logs

The LDSE logs are generated by the LDSE processes, which can be used to assure the integrity of an image when it is in transit or stored in PACS archive. To integrate LDSE logs with the HCAS, the LDSE processes must be installed in the PACS first. Figure 2 shows the integration of the LDSE processes with the PACS. The LDSE Sign & Embed process is added to a black box connected to imaging modalities to insert the digital signature of the image into image pixels right after the image is generated in the modality. The signature embedded image is then sent to PACS for archiving and reviewing. The LDSE Extract & Verify process is added to PACS components, DICOM Gateway, PACS Controller, and Display workstation, to verify whether the image has been altered when the image is transferred through network or stored in each component. The integration of the LDSE processes with the PACS can completely assure the integrity of an image during its life time in the PACS.

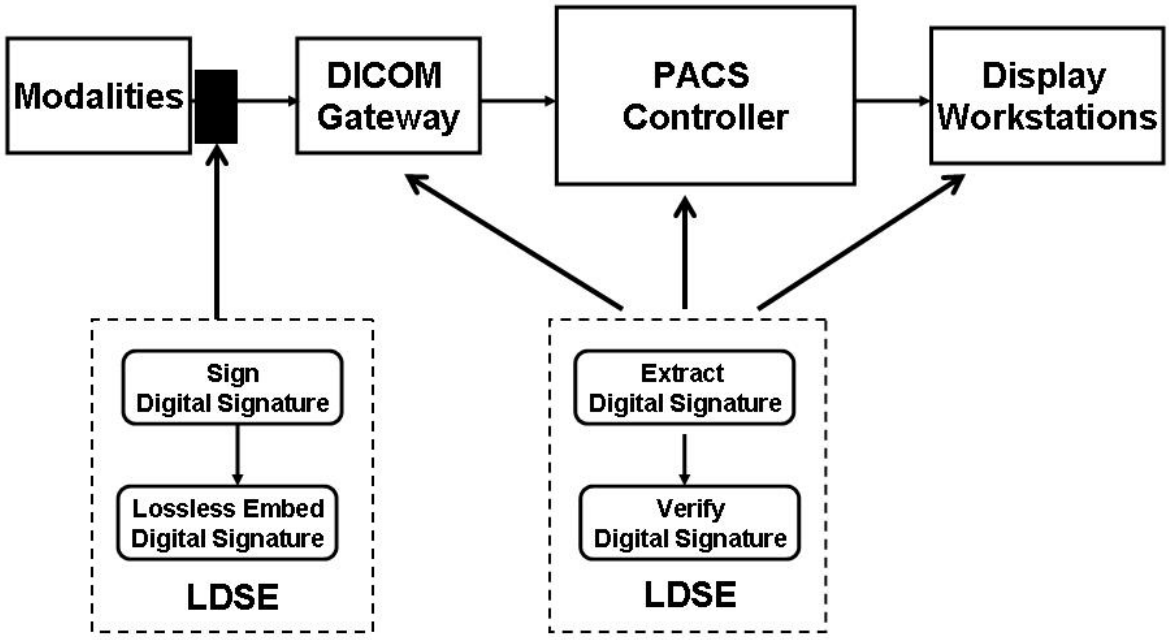


Figure 2 Integration of the LDSE processes with a PACS. The LDSE Sign & Embed process is added to a black box connected to imaging modalities, while the LDSE Extract & Verify process is added to DICOM Gateway, PACS Controller, and Display workstation for assuring the image integrity.

After the LDSE logs are generated in PACS components, the logs are collected by the HCAS log collectors in each PACS component, the same log collectors that collect the logs generated by PACS components. The relevant information are extracted from the LDSE logs and sent to the HCAS database for generating audit trails, therefore the HCAS with LDSE logs are seamlessly integrated together.

3.4 Integration of LTVS Logs with HCAS

The LTVS has been developed to track a patient location in clinical environment and verify the user who accesses the PACS by biometric facial recognition technology [10,11]. Figure 3 shows the system diagram of LTVS. LTVS consists of a LTVS server that includes a web server and a database for storing tracking and verification information, facial verification software, and a tracking system that includes wireless access points and tags.

To integrate the HCAS with LTVS logs, a log collector is installed in the LTVS server to collect relevant information from the LTVS database. The collected information is sent to the HCAS database for generating audit trails.

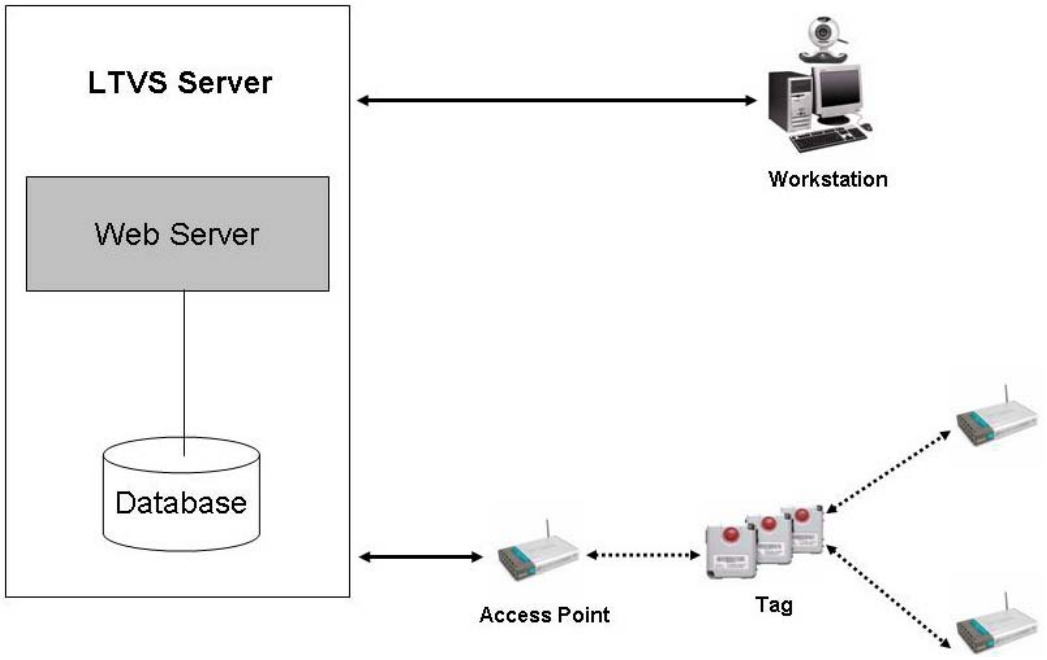


Figure 3 System diagram of LTVS (Patient Location Tracking and Verifying System).

4. RESULTS

4.1 Laboratory Evaluation Environment

The results were acquired from the laboratory evaluation performed in a PACS Simulator [12-14] at Image Processing & Informatics Laboratory, USC. The PACS Simulator (Figure 4) can simulate the image data flow of a typical clinical PACS.

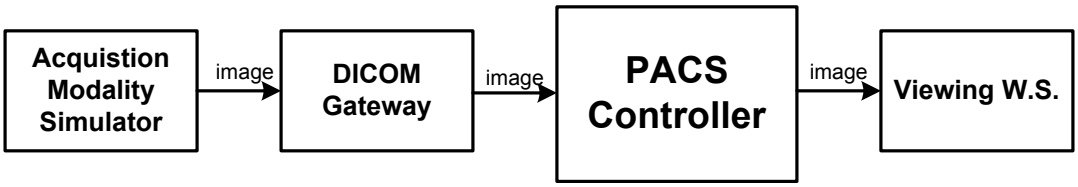
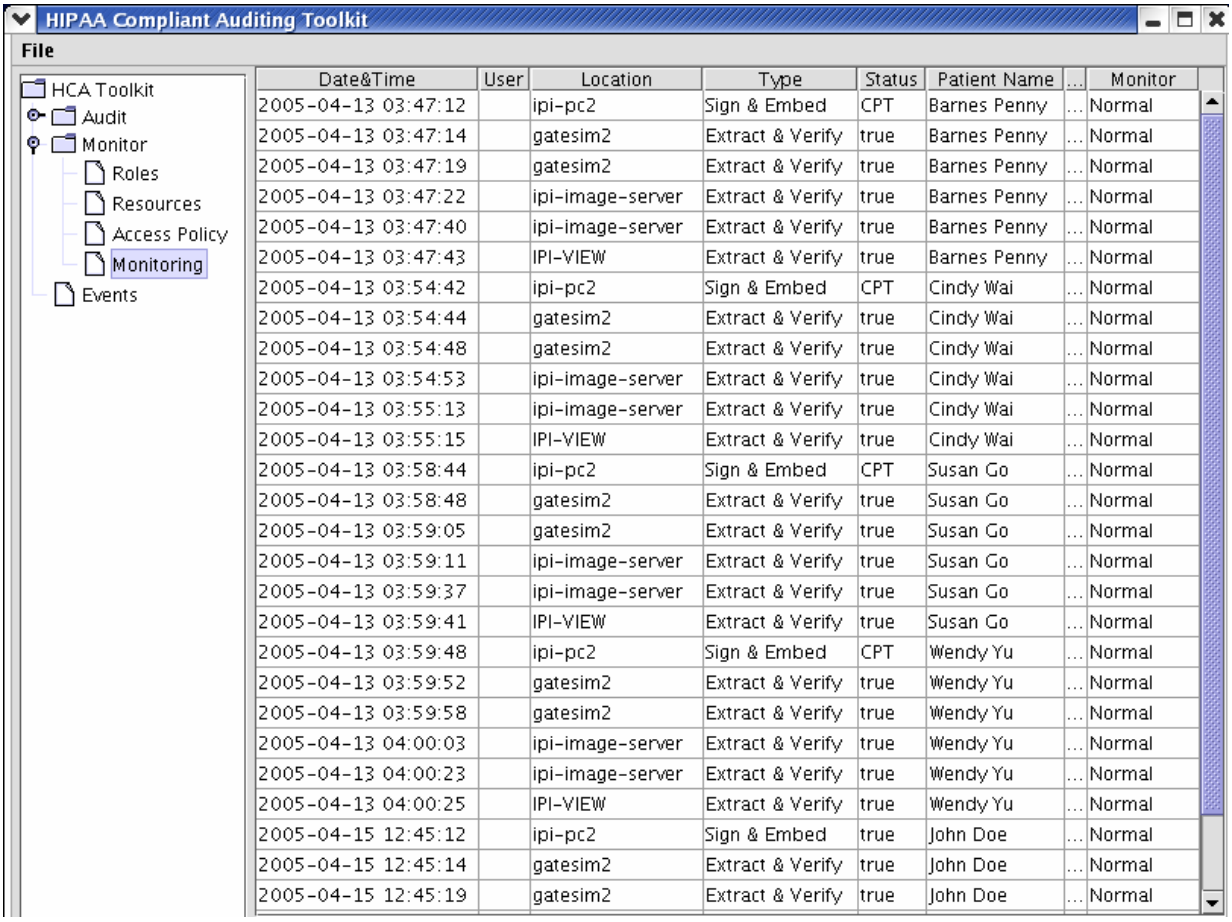


Figure 4 A laboratory based PACS Simulator for evaluation of the integration of HCAS with LDSE and LTVS.

4.2 Examples of Results

Two examples of results are shown in Figure 5and Figure 6

The first example shows HCAS searching the Auditing Database to generate a HIPAA compliant audit trail of image integrity for simulated patients. As shown in Figure 4, line 1 shows an example of LDSE Sign & Embed process for an image of a patient “Barnes Penny” at the modality simulator “ipi-pc2” on “2005-04-13 03:47:12”. Line 2 to Line 6 shows LDSE Extract & Verify processes for the same image when the signature embedded image goes through DICOM Gateway, PACS Controller, and Viewing Workstation. Notice that there are two Extract & Verify processes in both DICOM Gateway and PACS Controller at different time. These two processes are used to verify the integrity of the image in transmission from Modality Simulator to DICOM Gateway and in storage at DICOM Gateway. The same is for the PACS Controller. Also notice there is no user in these audit trails, because the LDSE processes are ran automatically in the background.



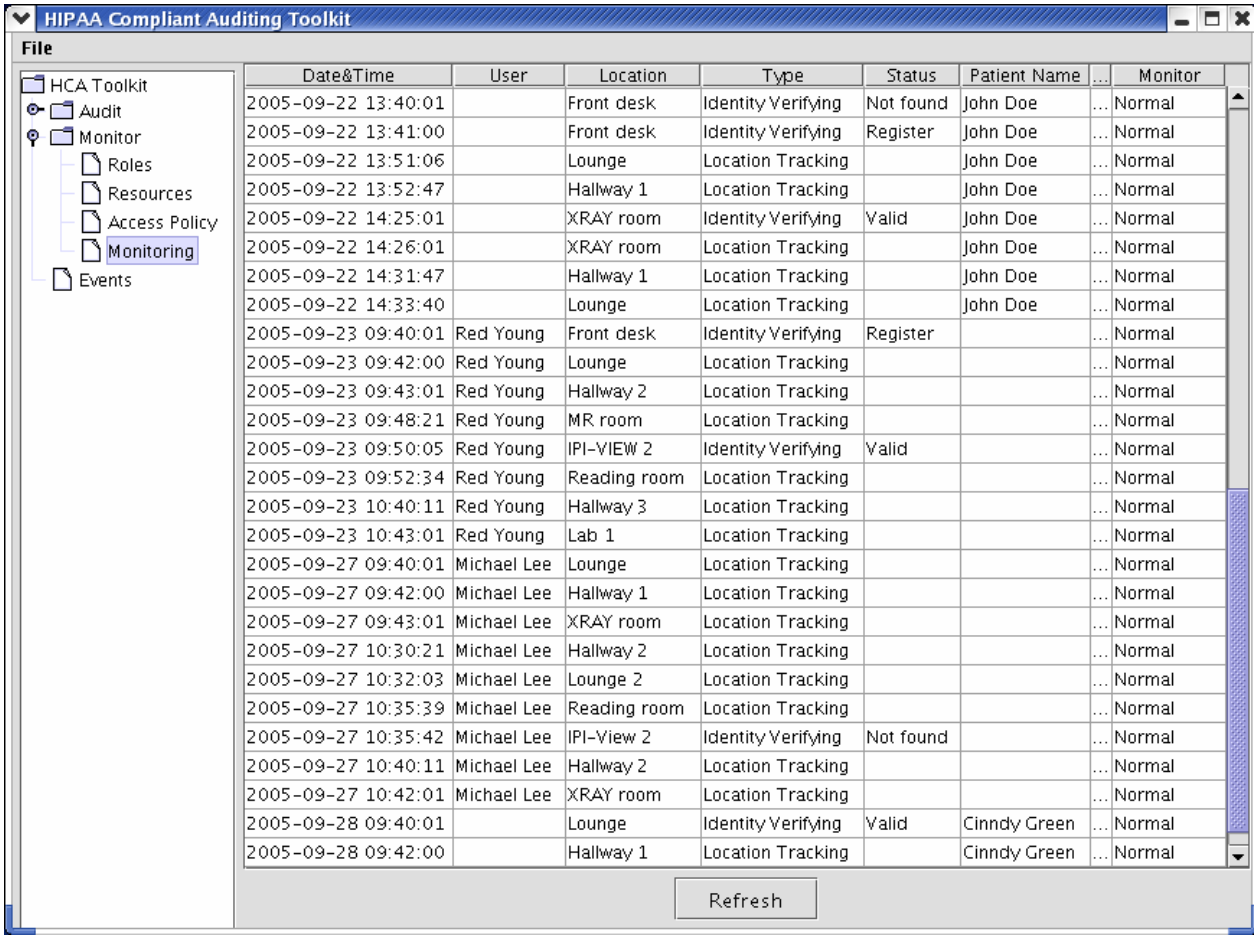
Date&Time	User	Location	Type	Status	Patient Name	...	Monitor
2005-04-13 03:47:12		ipi-pc2	Sign & Embed	CPT	Barnes Penny	...	Normal
2005-04-13 03:47:14		gatesim2	Extract & Verify	true	Barnes Penny	...	Normal
2005-04-13 03:47:19		gatesim2	Extract & Verify	true	Barnes Penny	...	Normal
2005-04-13 03:47:22		ipi-image-server	Extract & Verify	true	Barnes Penny	...	Normal
2005-04-13 03:47:40		ipi-image-server	Extract & Verify	true	Barnes Penny	...	Normal
2005-04-13 03:47:43		IPI-VIEW	Extract & Verify	true	Barnes Penny	...	Normal
2005-04-13 03:54:42		ipi-pc2	Sign & Embed	CPT	Cindy Wai	...	Normal
2005-04-13 03:54:44		gatesim2	Extract & Verify	true	Cindy Wai	...	Normal
2005-04-13 03:54:48		gatesim2	Extract & Verify	true	Cindy Wai	...	Normal
2005-04-13 03:54:53		ipi-image-server	Extract & Verify	true	Cindy Wai	...	Normal
2005-04-13 03:55:13		ipi-image-server	Extract & Verify	true	Cindy Wai	...	Normal
2005-04-13 03:55:15		IPI-VIEW	Extract & Verify	true	Cindy Wai	...	Normal
2005-04-13 03:58:44		ipi-pc2	Sign & Embed	CPT	Susan Go	...	Normal
2005-04-13 03:58:48		gatesim2	Extract & Verify	true	Susan Go	...	Normal
2005-04-13 03:59:05		gatesim2	Extract & Verify	true	Susan Go	...	Normal
2005-04-13 03:59:11		ipi-image-server	Extract & Verify	true	Susan Go	...	Normal
2005-04-13 03:59:37		ipi-image-server	Extract & Verify	true	Susan Go	...	Normal
2005-04-13 03:59:41		IPI-VIEW	Extract & Verify	true	Susan Go	...	Normal
2005-04-13 03:59:48		ipi-pc2	Sign & Embed	CPT	Wendy Yu	...	Normal
2005-04-13 03:59:52		gatesim2	Extract & Verify	true	Wendy Yu	...	Normal
2005-04-13 03:59:58		gatesim2	Extract & Verify	true	Wendy Yu	...	Normal
2005-04-13 04:00:03		ipi-image-server	Extract & Verify	true	Wendy Yu	...	Normal
2005-04-13 04:00:23		ipi-image-server	Extract & Verify	true	Wendy Yu	...	Normal
2005-04-13 04:00:25		IPI-VIEW	Extract & Verify	true	Wendy Yu	...	Normal
2005-04-15 12:45:12		ipi-pc2	Sign & Embed	true	John Doe	...	Normal
2005-04-15 12:45:14		gatesim2	Extract & Verify	true	John Doe	...	Normal
2005-04-15 12:45:19		gatesim2	Extract & Verify	true	John Doe	...	Normal

Figure 5 An example of audit trails of image integrity by integrating the LDSE logs with HCAS.

The Status "true" in these lines means that signature verification is successful, therefore the image integrity is assured. All these seven lines together show an example of a complete image integrity assurance for the image in the PACS. The results show that the LDSE processes can be traced through HCAS for demonstrating HIPAA compliant image integrity assurance in a PACS.

The second example (Figure 6) shows HCAS searching the auditing database to generate HIPAA compliant audit trails for patients or clinical staff location tracking and verification by integrating HCAS with LTVS logs. Line 1 shows patient biometric verification for a simulated patient "John Doe" at the front desk on "2005-09-22 13:40:01" during patient registration. Since this patient is a new patient in this case, the "Status" of biometric verification is "Not found". Line 2 shows the patient "John Doe" is registered in LTVS. Line 3 shows that LTVS starts to track the patient "John Doe" after he receives a tag at the front desk. Line 4 and 6 shows the continuous location tracking when the patient goes through "Hallway 1" to "XRay room". At "XRay room", the patient is verified again before he takes the X-Ray exam. The Status "Valid" shows he is the right patient to take the exam.

Figure 6 also shows the similar location tracking and biometric verification procedures for a simulated radiologist "Red Young". Notice that he is verified before he uses the viewing workstation to ensure that he is the authorized person to access the viewing station and patient exams.



Date&Time	User	Location	Type	Status	Patient Name	...	Monitor
2005-09-22 13:40:01		Front desk	Identity Verifying	Not found	John Doe	...	Normal
2005-09-22 13:41:00		Front desk	Identity Verifying	Register	John Doe	...	Normal
2005-09-22 13:51:06		Lounge	Location Tracking		John Doe	...	Normal
2005-09-22 13:52:47		Hallway 1	Location Tracking		John Doe	...	Normal
2005-09-22 14:25:01		XRAY room	Identity Verifying	Valid	John Doe	...	Normal
2005-09-22 14:26:01		XRAY room	Location Tracking		John Doe	...	Normal
2005-09-22 14:31:47		Hallway 1	Location Tracking		John Doe	...	Normal
2005-09-22 14:33:40		Lounge	Location Tracking		John Doe	...	Normal
2005-09-23 09:40:01	Red Young	Front desk	Identity Verifying	Register		...	Normal
2005-09-23 09:42:00	Red Young	Lounge	Location Tracking			...	Normal
2005-09-23 09:43:01	Red Young	Hallway 2	Location Tracking			...	Normal
2005-09-23 09:48:21	Red Young	MR room	Location Tracking			...	Normal
2005-09-23 09:50:05	Red Young	IPI-VIEW 2	Identity Verifying	Valid		...	Normal
2005-09-23 09:52:34	Red Young	Reading room	Location Tracking			...	Normal
2005-09-23 10:40:11	Red Young	Hallway 3	Location Tracking			...	Normal
2005-09-23 10:43:01	Red Young	Lab 1	Location Tracking			...	Normal
2005-09-27 09:40:01	Michael Lee	Lounge	Location Tracking			...	Normal
2005-09-27 09:42:00	Michael Lee	Hallway 1	Location Tracking			...	Normal
2005-09-27 09:43:01	Michael Lee	XRAY room	Location Tracking			...	Normal
2005-09-27 10:30:21	Michael Lee	Hallway 2	Location Tracking			...	Normal
2005-09-27 10:32:03	Michael Lee	Lounge 2	Location Tracking			...	Normal
2005-09-27 10:35:39	Michael Lee	Reading room	Location Tracking			...	Normal
2005-09-27 10:35:42	Michael Lee	IPI-View 2	Identity Verifying	Not found		...	Normal
2005-09-27 10:40:11	Michael Lee	Hallway 2	Location Tracking			...	Normal
2005-09-27 10:42:01	Michael Lee	XRAY room	Location Tracking			...	Normal
2005-09-28 09:40:01		Lounge	Identity Verifying	Valid	Cinndy Green	...	Normal
2005-09-28 09:42:00		Hallway 1	Location Tracking		Cinndy Green	...	Normal

Figure 6 An example of audit trails of patients or clinical staff location tracking and verification by integrating HCAS with LTVS logs.

4.3 Discussion

The integration of HCAS with LDSE and LTVS logs is loosely coupled through separating HCAS into a two-layer architecture, therefore any changes made to LDSE and LTVS, such as adopting new biometric technology or new digital signature algorithm, would not affect the work flow of HCAS. Any future changes to HCAS caused by changes of LDSE and LTVS logs would be reduced to minimum by extracting only the relevant information from the logs instead of using all information included in the logs and normalizing the extracted information before inserting the information into the auditing database.

The HCAS is currently limited in functions supporting sophisticated data analysis of the collected audit information, such as data mining. These functions can be used to detect anomaly image data access in a PACS and make automatic decision whether it is HIPAA violation for the anomaly image data access.

5. CONCLUSION

The advent of HIPAA greatly impacts medical imaging systems, such as PACS, and the entire health information systems. To be HIPAA compliant, every medical imaging system must satisfy the HIPAA requirement of audit control, access control, image integrity and privacy.

We have developed a HIPAA compliant auditing system (HCAS) for auditing medical images in PACS. The HCAS enables PACS to generate HIPAA compliant audit trails of image data access for a specific patient on demand. Two new components, LDSE and LTVS logs, were added to HCAS this year. The LDSE logs show the assurance of image integrity in PACS, while the LTVS logs verify whether the person accesses PACS components is the authorized person and track patient or clinical staff location. The integration of HCAS with LDSE and LTVS logs has two benefits:

1. Important information for what (image) and who (user) in HIPAA compliant audit trails of image access in a PACS.
2. The audit trails of LDSE and LTVS in HCAS can serve as the demonstration of HIPAA compliant access control and image integrity assurance in a PACS.

The integration has been evaluated in the laboratory environment. The evaluation is currently ongoing with promising initial data results.

ACKNOWLEDGEMENT

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REFERENCES

1. HIPAA, http://www.cms.hhs.gov/hipaa/hipaa2/general/background/pl104191.asp
2. HIPAA, http://www.rx2000.org/KnowledgeCenter/hipaa/hipfaq.htm
3. HIPAA Security Standard, 2003, http://www.cms.hhs.gov/hipaa/hipaa2/regulations/security/03-3877.pdf
4. Cao F., Huang H.K., Zhou X.Q., Medical image security in a HIPAA mandated PACS environment, *Computerized Medical Imaging and Graphics*, Vol. 27, Num. 2-3, pp. 185-196, 2003.
5. Z. Zhou, B.J. Liu, HIPAA compliant architecture for workflow auditing of medical imaging systems, *Computerized Medical Imaging and Graphics*, vol. 29, pp. 235-41, 2005.
6. Z. Zhou, B.J. Liu, H.K. Huang, J. Zhang, Educational RIS/PACS simulator integrated with the HIPAA compliant auditing (HCA) toolkit, *Proc. SPIE Medical Imaging*, vol. 6, pp. 491-500, 2005.
7. B.J. Liu, Z. Zhou, H.K. Huang, A HIPAA compliant architecture for securing clinical images, *Proc. SPIE Medical Imaging*, vol. 6, pp. 326-333, 2005.
8. Zhou Z., *Lossless Digital Signature Embedding for Medical Image Integrity Assurance,* Ph.D. Dissertation, Ch. 5-6, July 2005.
9. Zhou Z., Huang H.K., Liu B., *Digital Signature Embedding for Medical Image Integrity in a Data Grid Off-Site Backup Archive,* SPIE Medical Imaging, Vol. 6, pp. 306-317, 2005.
10. B. Guo, J. Documet, N. King, B.J. Liu, H.K. Huang, E. Grant, Patient Tracking and Facial Biometrics Integrated in a Clinical Environment for HIPAA Security Compliance, 2005 RSNA InfoRAD 9711 NT-i.
11. P.J. Phillips, A. Martin, C.L. Wilson, M. Przybocki, An Introduction to Evaluating Biometric Systems, *IEEE Computer*, February, pp. 56-63, 2000.
12. Law M.Y.Y., Zhou Z., New direction in PACS education and training, *Computerized Medical Imaging and Graphics*, Volume 27, pp. 147-156, 2003.
13. Z. Zhou, H.K. Huang, B.J. Liu, F. Cao, J. Zhang, M. Law, A RIS/PACS simulator with web-based image distribution and display system for education, *Proc. SPIE medical imaging*, vol. 5, pp. 372-381, 2004.
14. Zhou Z., Huang H.K., Cao F., Liu B.J. Zhang J. Mogel G.T., Educational RIS/PACS Simulator, *SPIE Medical Imaging*, Vol. 4, pp. 139-147, 2003.

SELECTED PEER REVIEWED REPRINTS AND PREPRINTS

Hutchinson Lecture of the 13th ISRRT World Congress

Challenges of radiography beyond the 4th dimension

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Abstract

This presentation echoes the theme of the 13th ISRRT World Congress "Radiography...beyond the fourth dimension". We first review the current roles of radiographers in the world scene. This is followed by a review of recent advances in medical imaging and how radiography could contribute to further this advancement. Parallelism is drawn between the roles of medical physicists (MP) 25 years ago versus now, and challenges radiographers to advance their profession by learning from the MP model. A work-in-progress example illustrates how a radiography department is taking up these challenges and moving toward this goal.

Key words: *Radiography, challenges, fourth dimension, medical imaging, imaging informatics*

Prelude

February 3-6, 2005 marked the dates of the 13th World Congress of the ISRRT at Hong Kong. Among other topics discussed such as virtual radiography, digital radiography, we heard the theme: the Fifth Dimension in Radiography, "Radiography...Beyond the Fourth Dimension" repeatedly during the Congress.

In Dr. Maria Law's, Chairlady of the Organizing Committee, opening speech, I quote "Radiography advances rapidly in the last two decades together with development of computers and information technology. Image reconstruction from projections adds the third dimension to the 2-dimensional imaging world of the past. The fourth dimension usually refers to as the time. ... Thus the x, y, z coordinates give the spatial domain while the fourth dimension provides the temporal extension. These are the imaging technology that we encounter daily. But, can we make a quantum jump to leap out of it and take possession instead of being driven by them?

So what is there beyond the fourth dimension?[1]"

In the Hutchinson Lecture and this follow up paper, I offer my perspective of "What is there beyond the fourth dimension in radiography?"[2]

1. Current roles of radiographers in the world scene

After the regular training, there are two traditional major categories of professional career in radiography. The first is to follow the main stream of radiography training to become a technologist (radiographer) in diagnostic imaging or in radiation therapy (RT). The promotion paths are to become a specialist to perform procedures in digital and computed radiography (DR and CR), ultrasonography (US), mammography (mammo), CT/MR, dosimetry, and RT treatment planning, or a red-dotted radiographer. Another career path is to become a radiological assistant (RA), who has a closer relationship with radiologists and covers additional clinical responsibility.

The second traditional professional career in radiography is to move to the administrative roles. This path can begin as the radiology department workflow manager, to department financial officer, department manager, and the hospital manager or director.

In this lecture, I would like to call your attention and challenge you to think outside of the box and consider possible new career paths in radiography which are none traditional. This possible opportunity arises from recent advances in medical imaging and radiation therapy research and development.

2. Recent advances in medical imaging technology and opportunity for radiography

During the past ten years, medical imaging, radiation therapy, and imaging informatics have advanced rapidly which have affected the professional training and career development in radiography. Table 1 shows five categories of technological advances including imaging modality, radiology procedure, radiation therapy, image processing, and imaging informatics.

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Table 1. *Five categories of medical imaging related advances*

Imaging Modality	Radiology procedure	Radiation Therapy	Image Processing	Imaging Informatics
Digital radiography	Intervention Radiology	Cyberknife	3-D Rendering	PACS
Digital mammography	Image-guided surgery	3-D conformal therapy	Computer-aided diagnosis (CAD)	Integrated HIS/CMS/ RIS/PACS/VR#
Multisliced CT • 3-D rendering • CT angiography		Intensity Modulated Radiotherapy	Image matching	Electronic Patient Record (ePR)
MR imaging Technique • Functional MRI • Diffusion tenor imaging (DTI) • MR spectroscopy (MRS)		Image-guided Radiotherapy	Image data mining	Electronic Medical Record (ePR)
High-field and Fast MRI • MR angiography • Fetal Imaging		DICOM RT objects		RT Information System
Breast imaging				
3-D US				

VR = voice recognition

2.1 Imaging modalities, radiology procedure, radiation therapy, and image processing

Figures 1 — 10 show the image quality and methods of some of the new imaging modalities and procedures used in diagnostic and therapy treatment. Figure 1 left shows a 4K x 5K digital mammogram, and the Right shows a magnification view. Figure 2 describes the principle of multi-slice CT, dependent upon available scanning modes, it can generate from 4, 16, ..., to 256 slices in one scan. The multi-slice capability opens the door for 3-D volume rendering, for example, to display skeletal fracture (Figure 3) and CT angiography (Figures 4 and 5). In high field strength MR angiography using a 3.0 Tesla magnet, the images quality can rival that of the conventional angiography (Figure 6). In sectional breast imaging, it may be able to distinguish between benign and cancerous tissues of the breast (Figure 7). In brain imaging, its image quality is so refined that it resembles an anatomical section (Figure 8). In fetal imaging, it can reveal the brain structure which could not be seen with US imaging techniques (Figure 9). In RT cyberknife, it could pin point the extension of treating a lesion using a six degree of freedom robotic arm delivering precise dosages to the cancerous tissues and avoiding damage to the surrounding health tissues (Figure 10).

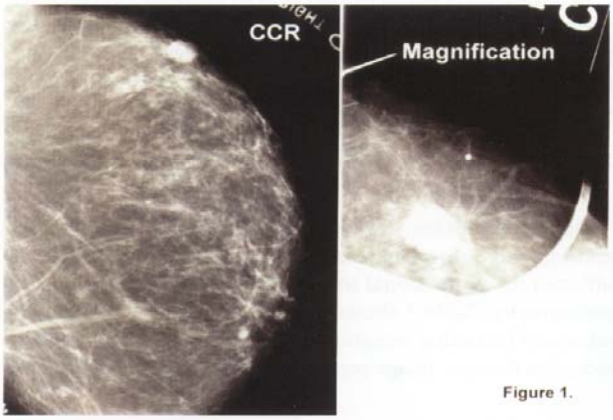

Figure 1. *Digital Mammography with 4K x 5K image size.*

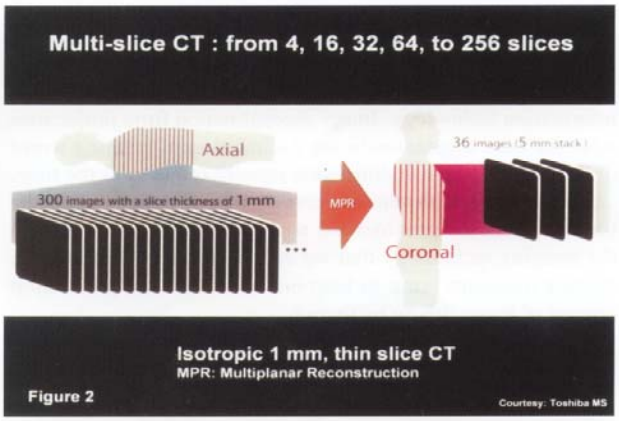

Figure 2. *Principle of multi-slice CT, one complete CT scan can yield from 4, 16, ..., to 256 slices. If the voxel size is the same in x, y, and z directions, it is called isotropic.* (Courtesy: Toshiba Medical Systems)

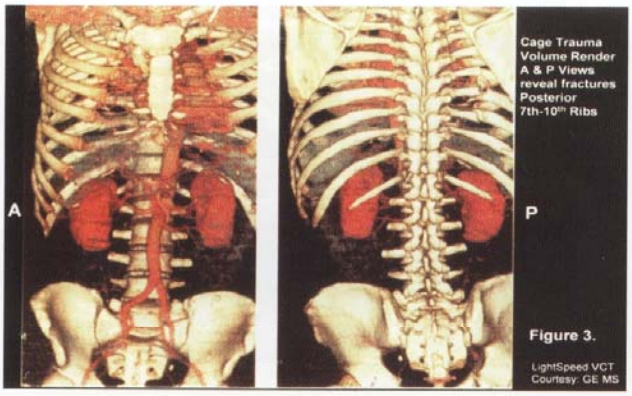

Figure 3. *3-D volume rendering of the thoracic cage from multi-slice CT images. A & P views reveal fractures at posterior 7th-10th ribs.* (*LightSpeed VCT Courtesy: GE Medical Systems*)

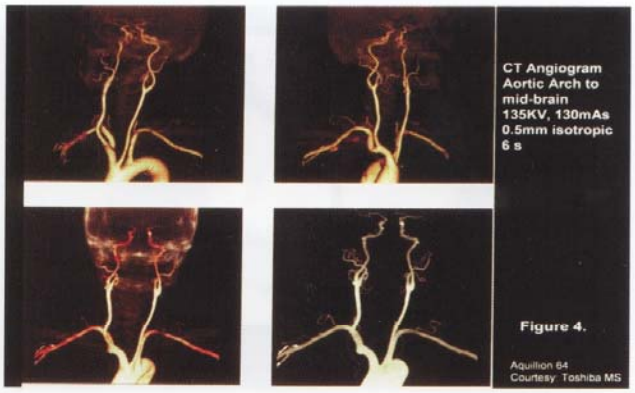

Figure 4. *CT Angiogram showing the Aortic Arch to mid-brain using multi-slice CT* (*Scanning conditions: 135KV, 130mAs, 0.5mm isotropic 6 seconds, Aquillion 64, Courtesy: Toshiba Medical Systems*)

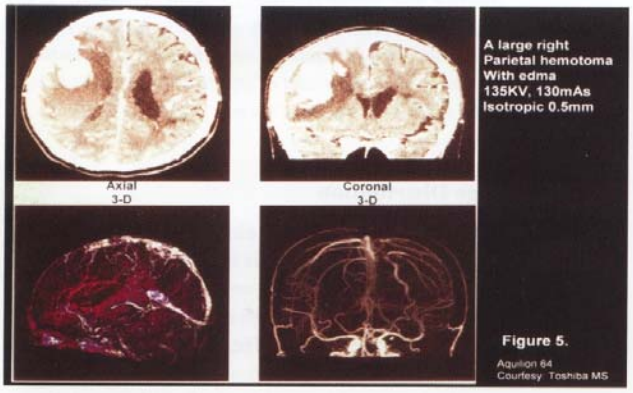

Figure 5. *A large right Parietal haemotoma with oedema* (*Scanning conditions: 135KV, 130mAs, Isotropic 0.5mm, Aquilion 64, Courtesy: Toshiba Medical Systems*)

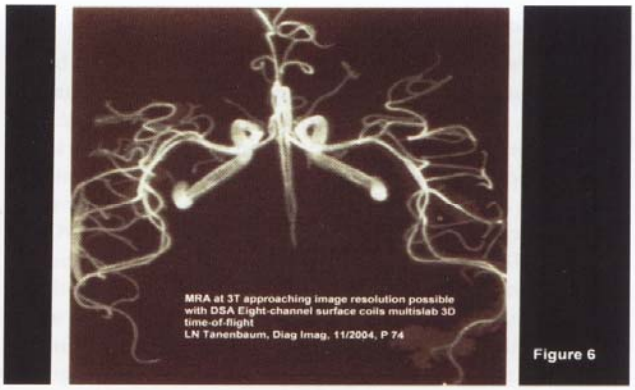

Figure 6. *MRA at 3T approaching image resolution possible with DSA. Eight-channel surface coils multislab 3D time-of-flight.* (*Courtesy: LN Tanenbaum, Diag Imag, 11/2004, P 74*).

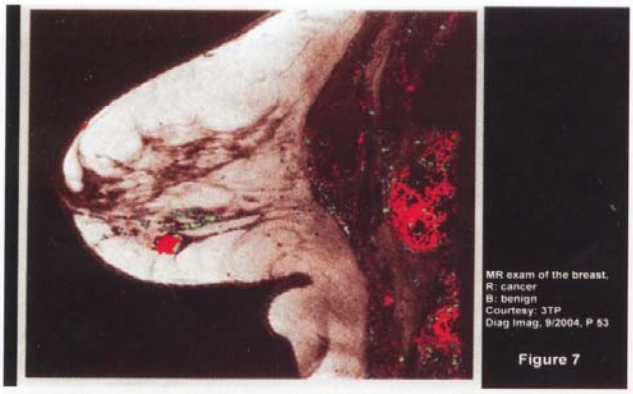

Figure 7. *3T MR exam of the breast, R: cancer, B: benign* (*Courtesy: 3TP Diag Imag, 9/2004, P 53*).

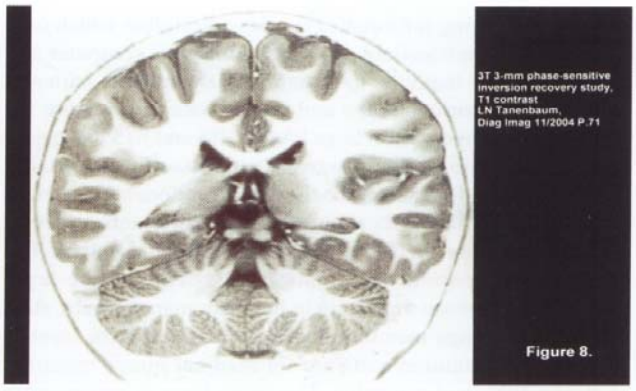

Figure 8. *3T 3-mm phase-sensitive inversion recovery study, T1 contrast* (*Courtesy: LN Tanenbaum, Diag Imag 11/2004 P.71*)

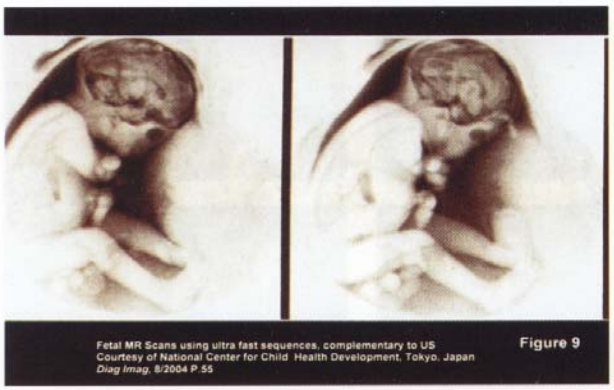

Figure 9. *3T Fetal MR Scans using ultra fast sequences revealing brain structures, complementary to US (Courtesy: National Center for Child Health Development, Tokyo, Japan Diag Imag, 8/2004 P.55).*

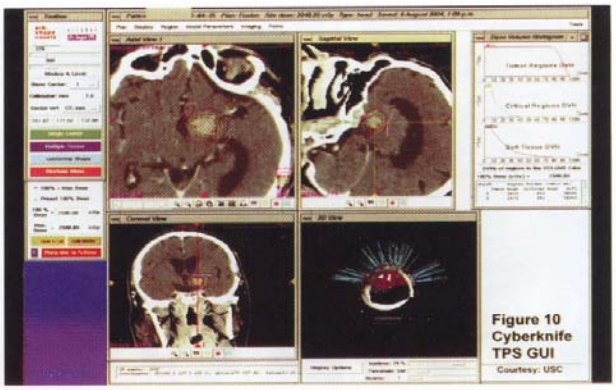

Figure 10. *Functions of the Cyberknife used in Radiation Therapy. It is an image-guided system for RT treatment. It consists of a multi-jointed robotic arm with six degrees of freedom with sub-millimeter dose delivery accuracy. It is excellent for treating irregular shape lesions and can treat multi-lesions during the same treatment plan. Graphic User Interface (GUI): Both upper and lower left windows show structures and dosage distributions. Lower right: positions of multiple treatment beams with high precision. (Courtesy: Oncology USC)*

2.2 Imaging Informatics[3, 4]

During the past years, the need of collecting and distributing large amount of image data due to advances of imaging modalities, developing innovative radiology procedures and radiation therapy methods, and analyzing and processing image for knowledge discovery, imaging informatics has gradually emerged as an independent field of specialty. Among the many novel concepts and development, PACS, integrated HIS/CMS/RIS/PACS/VR (voice recognition), ePR, eMR, and RT information system have great influence to the potential of further radiography profession career development. The use of PACS and integrated HIS/CMS/RIS/PACS/VR has been well recognized and become daily operating routines in radiography profession. This section highlights the concept of medical imaging informatics, ePR with image distribution, and the RT Information System which provide gateways for future radiography career development.

Concept of Imaging Informatics

Medical imaging informatics is a new discipline which uses computer software technology along with other computer and communication methods to systematically analyze patient's current and historical image and related data information for knowledge discovery from large PACS, HIS and RIS databases. Results from knowledge discovery could facilitate research protocols, provide new approaches in education, and improve clinical service. The medical imaging informatics infrastructure is shown in Figure 11. The lower layer is the data sources. The second layer contains informatics tools. The middle layer consists of database and knowledge base management, data mining, and image matching techniques. The fourth layer is composed of common software for medical image research, clinical service and education. The upper layer is user specific application software.

ePR with Image Distribution

Electronic patient record (ePR), or electronic medical record (eMR, emphasizing medical records) is the ultimate information system in a healthcare enterprise. In an even broader sense, if the information system includes health record of an individual, then it is called the eHR (Electronic Health Record). Although the development of a universal ePR as a commercial product is still years away, its eventual impact to the healthcare delivery system should not be underestimated. Most current ePR systems lack an imaging component, but when the ePR includes medical image distribution, it would impact the radiography profession greatly because the integration of HIS/CMS/HIS/RIS/VR becomes necessary. Figure 12 shows the major components of PACS-based ePR with image distribution. The ePR server can be a standard ePR system with selected images transmitted from the PACS image database and archive where clients can access ePR data as well as selected images from PACS. Since the radiography profession is most familiar with medical imaging than any other healthcare professions, this factor opens up golden opportunity for radiography to enrich its profession profile.

A Web-based DICOM RT ePR System[5]

Radiation Therapy (RT) is an image-based treatment. It requires images from projection X-rays, computed tomography (CT), magnetic resonance (MR), positron emission tomography (PET), and linear accelerator for tumor localization, treatment planning and verification of treatment plans. In the process, it needs patient information to plan a treatment; image registration

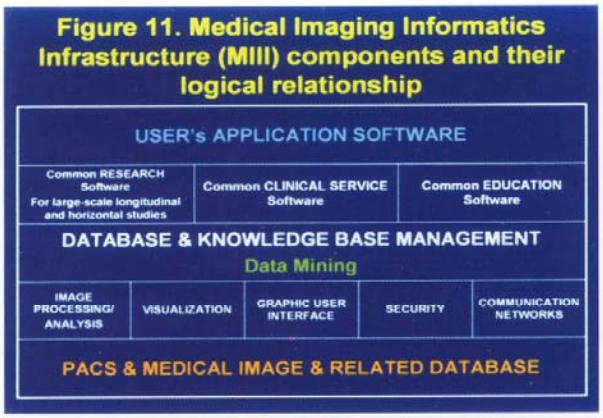

Figure 11. *Medical Imaging Informatics infrastructure (MIII) components and their logical relationship. See Figure 12 for its connection to the PACS database.*

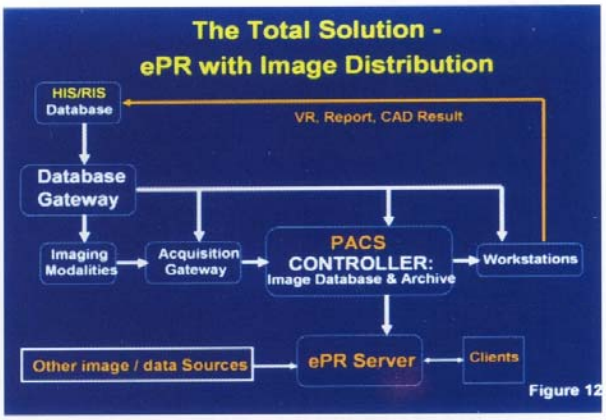

Figure 12. *The concept of ePR server with image distribution using selected images from PACS. The MIII can be located in the ePR server.*

to identify regions to be treated, and markers to align images; image fusion to best delineate pathological abnormalities from different imaging modalities, anatomy to identify the shape, size, and location of the targets and radio-sensitive vital organs; and dose computation to ensure the delivery of uniform high dose to the target but avoiding critical normal anatomical structures. In addition, carefully monitoring treatment, optimization and dose calculation are essential for successful patient outcome. In these processes, PACS and imaging informatics technologies are used extensively. However, they are not integrated as a complete radiation treatment information system. Most of the current RT imaging information systems can only provide incomplete information of the patient at individual image or information system component in the Radiation Oncology department. Figures 13 — 15 describes an innovative concept and prototype of a Web-based DICOM RT ePR system. Figure 13 defines the seven ratified DICOM RT objects which are the standard in RT information systems. Figure 14 depicts the five major components and workflow of the Web-based DICOM RT ePR prototype system. Figure 15 presents a GUI Window (graphic user interface) in the DICOM RT Web-based ePR system. Most RT management systems provide only patient summary (Lower right), some RT modalities provide RT related images in piecemeal fashion (Middle rows with images). The DICOM RT Web-based ePR prototype can provide all information of the patient related to the treatment plans and history in one single GUI window (Far right). Each cell in the Window can be further queried linking to more detailed information for instant display.

The DICOM RT Web-based ePR prototype utilizes the most up-to-date imaging informatics technology, the success of which would change the method of operation and workflow distribution of the Radiation Oncology department. The concept of this RT Web-based ePR would provide opportunities for radiography to expand their professional and career development paths.

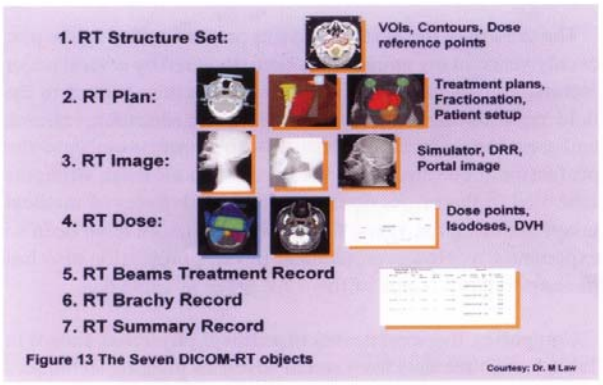

Figure 13. *The seven DICOM-RT objects (radiation therapy) which can be used as standard for RT information integration among many information systems used in radiation therapy.*

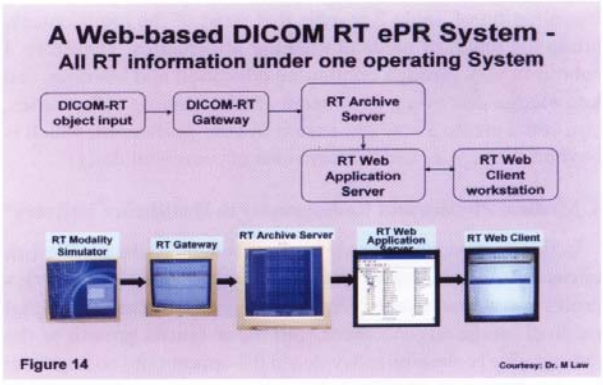

Figure 14. *The workflow in a Web-based DICOM RT ePR system. All RT information is under one operation system which would facilitate patient information communications within the RT department and in the hospital wise ePR system.*

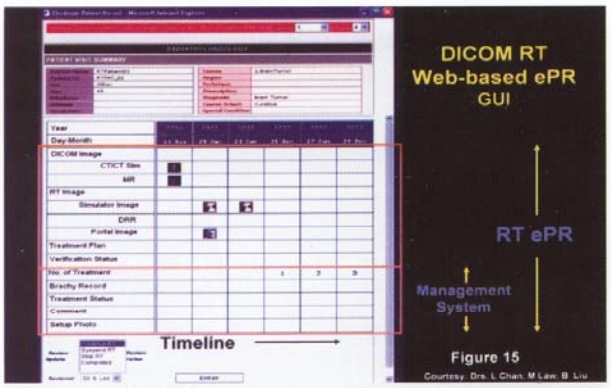

Figure 15. *A GUI Window (graphic user interface) in the DICOM RT Web-based ePR system. Most RT management systems provide only patient summary (Lower right), some RT modalities provide RT related images in piecemeal fashion (Middle rows with images). The DICOM RT Web-based ePR can provide all information of the patient related to the treatment plans and history in one single GUI window (Far right). Each cell in the Window can be further queried linking to more detailed information and displayed instantly.*

3. Opportunities in Radiography: New Demands from Advance Technologies and Strengthens of Radiography

The aforementioned recent advances in medical imaging technologies create new demands of healthcare profession to take advantages of them for better patient care. Some of these requirements are shown in Table 2. If we pause and contemplate the strengths of the radiography profession as shown in Table 3, we see the fit between the requirements and the strengths. Therefore I propose to you, as the radiography profession, that requirements given in Table 2 are your opportunity of professional career enhancement and growth. But how do radiographers prepare themselves to accomplish the requirements given these strengthens they possess? A careful examination of Table 2 reveals that most of the requirements are in the realm of medical imaging informatics. Therefore, I submit to you, through continuing education and learning, and knowledge discovery of concepts from imaging informatics, you could create a new dimension in your profession, which is beyond the x, y, z, and t dimensions encountered daily.

4. Medical Physics and Radiography in Healthcare Delivery[α]

In this section, an example is given related to the parallelism between the successful career growth of medical physics profession started twenty years ago triggered by the then digital medical image advancement, and the potential growth of the radiography profession today due to the opportunity arising from the emergence of imaging informatics.

[α] *Professor Huang was the Director of the Biomedical Physics Graduate Program, School of Medicine, University of California, Los Angeles from 1982-1992.*

Table 2. *New requirements from advance imaging technologies*

• More Images from Different Modalities
• More Patient and modality related information
• Increasing Complexity in Patient Imaging and Therapy
• Fused images with information
• Visualization
• System Integration
• Workflow Management
• Knowledge Discovery
• Efficient Health and Patience Care Operation
• Outcome Assessment

Table 3. *Strengths in Radiography*

• Imaging Techniques
• Patient handling and Care
• Liaison with Different Clinical Specialties
• Departmental and Hospital Workflows
• Digital Technology
• Radiation Treatment Planning
• Concept of Informatics

Before the CT era, the roles of medical physicists mostly centered in dosimetry, medical imaging equipment calibration, nuclear medicine equipment, radiation treatment planning, medical imaging equipment purchase, equipment site planning, and radiation biology. However, after the development of CT, US, DR, CR, MRI and other highly sophisticated medical imaging equipment, the medical physics profession has grown exponentially in terms of the prestige of the profession, quality of the new recruits, academic and industry employment opportunity, and income. In addition to their traditional career paths, medical imaging advances have brought the medical physics profession new subspecialties and career opportunity; some of them are shown in Table 4. The current status of medical physicists in the healthcare can be summarized in Table 5.

The growth of the medical physics profession during the past twenty years, in my opinion, has been triggered by several major factors, among them are the quality of the new comers to the field, rigorous training programs, continuing education, research and development mind setting in the profession, and the professional culture. However, even with all these strengths inherited in the profession, without the advances of medical imaging during the years, the growth would not have been so exponentially. However, medical physics profession also has its shortcomings, some of them are given in Table 6.

Comparing the weaknesses of medical physicists shown in Table 6, requirements from recent advances imaging techniques described in Table 2, and the strengths of radiography profession

Table 4. *Selected medical physics profession subspecialties and career opportunity*

• Image reconstruction
• Image source and detector technology
• Imaging modality R & D
• Display technology R & D
• Radiation therapy modality R & D
• Treatment planning and dose computation
• Computer-aided diagnosis
• and others

Table 5. *Current status of medical physicists in the healthcare field*

• Recognition in the fields of Medicine, Physics, and Engineering
• Career development paths are continuously growing
• Holding leading positions in Academic, Medicine, Healthcare, and the Private Industry

Table 6. *Traditional shortcomings of Medical Physicists*

• System integration
• Informatics
• Patient contacts and care
• Physician liaison
• Imaging and treatment procedures
• Patient and hospital workflow
• Operation efficiency
• Healthcare outcome assessment

shown in Table 3, it is not difficult to draw conclusion that, radiography profession can learn from the medical physics successful model to shape its own growth paths. My dear radiography colleagues, this to me, is your challenges beyond the 4th dimension!

5. A Work-in-progress case study — How does a Radiography Department prepare to meet this challenge?

The Story

In this section, I would like to give an example of how a radiography group took destiny to its own hands, and crossed the boundary of traditional radiography training to develop new career growth paths beyond the 4th dimension.

In 1999, the radiography group with both medical imaging and radiation therapy specialties in the Department of Optometry and Radiography, the Hong Kong Polytechnic University (PolyU) under the leadership of Professor and Head, Dr. Maurice Yap, and Chair Professor and Dean, Dr. George Woo, initiated a five year strategic plan to nurture young faculties in the group by carving out a new career direction in radiography (Figure 16). The plan is shown in Table 7. The goals are to embark in a new direction in medical imaging informatics and to enrich the

Table 7. *Department of Optometry and Radiograph — A five year strategy and the progress*

1999: Mandatory of a Doctoral Degree of all Faculty members
1999: Recruitment of a Chair Professor of Medical Informatics
2000- Current:
• Research and clinical PACS
• Develop Imaging Informatics Infrastructure
• Encourage innovative research concepts
• Obtain extra-mural & intra-mural funds
• Research collaboration with leading local and international universities
• Present and publish research results at international congress and peer-review journals
• Enter international science and technology competition

Table 8. *Five year progress of the Radiography Group from 2000 to February, 2005*

	Before 2000	February 2005
Faculty	13	11
W/ Doctoral	3	9
Ph.D. Candidate	4	2
Research Personnel	0	21
Research Personnel W/ Doctoral	—	3 (1 Ph.D, 2 MD)
Pursuing Ph.D. in Informatics	—	2 with MD

Table 9. *Doctoral degree of the faculty in the Radiography Group*

Education	1
Applied mathematics	1
Ultrasound	2
Dosimetry	1
Image processing	1
Informatics	1
Medical legal & ethics	1
Radiation Therapy	1

radiography profession along this discipline. Table 8 shows the change of the Radiography Programme from Year 2000 to 2005 in terms of its faculty body, qualification, Ph.D. candidates, and the quality of research staff. Table 9 shows the doctoral degrees of the faculty in 2005. Table 8 demonstrates the rapid growth of the quality of the faculty. Counting the faculty members with a doctoral degree, of the eleven, the number has grown from 3 to 9, and the other two are also Ph.D. candidates graduating within a year or so. The research personnel has grown from none to 21, of these, two are with an M.D. degree and one with a Ph.D. Table 9 shows the diversified specialties of the faculty with a doctoral degree which is the direct result of the strategic plan. The concept was clear in the beginning of the strategic plan, that radiographers, in addition to their inherent strengths, the faculty members were encouraged to select a new discipline to supplement individual's traditional professional training.

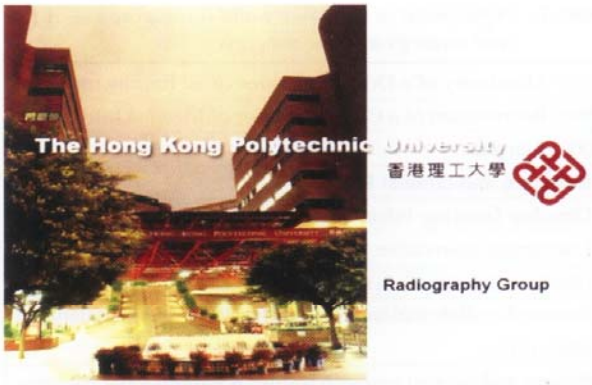

Figure 16. *The Hong Kong Polytechnic University where the radiography group belongs to.*

If we observe the successful growth model of the medical physics profession, the PolyU example has followed three of the important criteria in the model, two of them are the quality of the faculty (profession) and the new recruits (research staff). The third one is to receive prestigious research and development awards. During the past three years, the PolyU radiography group has received several major international awards; among them is the Silver Award in 2004, Brussels Eureka, 53rd World Exhibition of Innovation, Research and New Technology as shown in Figure 17.

This example narrates the early stage of a successful story of a radiography group. The factors needed which lead to the possibility are: leadership from the senior management; the preparation, determination, hard work, and the "can do" spirit of the group; and taking advantage of opportunity arisen from the recent advances of medical image informatics.

My dear radiography colleagues, these are your challenges beyond the 4th dimension.

Epilogue

The radiography group at the PolyU has found a new home, the Department of Health Technology and Informatics (HTI) a recently formed department at PolyU with three specialties: Biomedical Engineering, Medical Laboratory Sciences, and Radiography in 1st July, 2005. The novel Medical Imaging Informatics expertise now possessed by the radiography group rightly justifies their representation in the new department and will form corner stones for the informatics synergy of the three specialties. The group has worked hard and has found novel, exciting, and bright career paths to further their professional enrichment.

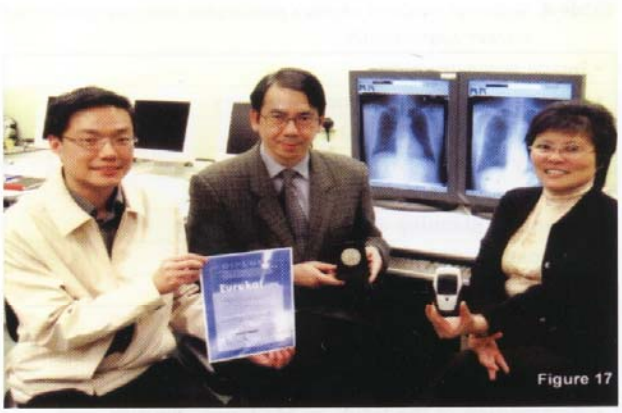

Figure 17. *Three winners of the Silver Award in Brussels Eureka, 53rd World Exhibition of Innovation, Research and New Technology from the Hong Kong Polytechnic University Radiography Group. Title: "Mobile Image Distribution in Medical Picture Archiving and Communication System". From left to right: Dr. Lawrence Chan, Dr. Fuk Hay Tang, and Dr. Maria Law.*

6. The future is bright

In this lecture we discussed the current roles of radiography in the world scene. How the rapid advances in medical imaging technologies has opened up opportunity for the radiography profession to grow beyond the 4th dimension. We saw the success growth of medical physics profession during the past twenty years as a challenge to the radiography profession. We also looked at an example of how the radiography group at the Hong Kong Polytechnic University initiated a five year strategic plan to propel themselves beyond the 4th dimension, and their accomplishments. I submit that this is the challenge to the radiography profession to reach the 5th dimension.

References

1. Law MYY. Opening speech, 13th ISRRT World Congress, Hong Kong, 3-6 February, 2005.
2. Huang HK. Challenges of radiography beyond the 4th dimension—Hutchinson Lecture, 13th World Congress of the ISRRT, Hong Kong, 3-6 February, 2005
3. Huang HK. PACS and image informatics: basic principles and applications. Hoboken, NJ: John Wiley & Sons, 2004.
4. Huang HK. Medical imaging informatics research and development trends — An Editorial. Comput Med Imaging Graph. 2005; 29: 91-3.
5. Law MYY. A model of DICOM-based electronic patient record in radiation therapy. Comput Med Imaging Graph. 2005; 29:125-36.

Data Grid for Large-Scale Medical Image Archive and Analysis

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ABSTRACT

Storage and retrieval technology for large-scale medical image systems has matured significantly during the past ten years but many implementations still lack cost-effective backup and recovery solutions. As an example, a PACS (Picture Archiving and Communication system) in a general medical center requires about 40 Terabytes of storage capacity for seven years. Despite many healthcare centers are relying on PACS for 24/7 clinical operation, current PACS lacks affordable fault-tolerance storage strategies for archive, backup, and disaster recovery. Existing solutions are difficult to administer, and often time consuming for effective recovery after a disaster. For this reason, PACS still encounters unexpected downtime for hours or days, which could cripple daily clinical service and research operations.

Grid Computing represents the latest and most exciting technology to evolve from the familiar realm of parallel, peer-to-peer, and client-server models that can address the problem of fault-tolerant storage for backup and recovery of medical images. We have researched and developed a novel Data Grid testbed involving several federated PAC systems based on grid computing architecture. By integrating grid architecture to the PACS DICOM (Digital Imaging and Communication in Medicine) environment, in addition to use its own storage device, a PACS also uses a federated Data Grid composing of several PAC systems for off-site backup archive. In case its own storage fails, the PACS can retrieve its image data from the Data Grid timely and seamlessly. The design reflects the Globus Toolkit 3.0 five-layer architecture of the grid computing: Fabric, Resource, Connectivity, Collective, and Application Layers. The testbed consists of three federated PAC systems, the Fault-Tolerant PACS archive server at the Image Processing and Informatics Laboratory, the clinical PACS at Saint John's Health Center, and the clinical PACS at the Healthcare Consultation Center II, USC Health Science Campus.

In the testbed, we also implement computational services in the Data Grid for image analysis and data mining. The federated PAC systems can use this resource by sharing image data and computational services available in the Data Grid for image analysis and data mining application.

In the paper, we first review PACS and its clinical operation, followed by the description of the Data Grid architecture in the testbed. Different scenarios of using the DICOM store and query/retrieve functions of the laboratory model to demonstrate the fault-tolerance features of the Data Grid are illustrated. The status of current clinical implementation of the Data Grid is reported. An example of using the digital hand atlas for bone age assessment of children is presented to describe the concept of computational services in the Data Grid.

Categories and Subject Descriptors

[Multimedia Medical Image Retrieval Design]: multimedia archive and retrieval system, medical image, picture archiving and communication system, data grid, and computing grid.

General Terms: Design

Keywords: PACS, Grid Computing, data grid, fault-tolerance archive, image analysis, image data mining, bone age assessment of children, computational services

1. INTRODUCTION

We start our discussion with a clinical large-scale imaging system PACS (Picture Archiving and Communication system), its requirements for fault-tolerance archive, and clinical image recovery after disaster. These characteristics are the precursors of the development of the Data Grid.

1.1 Picture Archiving and Communication systems (PACS)

A PACS is a system integration of computers, servers, workstations, communication networks, and software to form a system for radiological image information archive, distribution, and display. It consists of the following components:

- A data acquisition gateway connected to the Radiology Information System (RIS) and the Hospital Information system (HIS) for patient and examination related data,
- Several image acquisitions gateways connected to various radiology modalities including film digitizer, CR (computed radiography), DR (digital radiology), DM (digital mammography), US (ultrasonic), CT (computed tomography), and MRI (magnetic resonance image),
- A PACS Controller and Archive Server including various storage devices, and
- Image display workstations (WS).

MM'05, November 6-11, 2005, Singapore.

These components are integrated together by digital networks, communication protocols, and software shown in Figure 1. PACS is an integrated component in a total healthcare delivery system for daily 24/7 clinical diagnosis. PACS uses Digital Imaging and Communications in Medicine (DICOM) standard for data communication protocol and image data format.

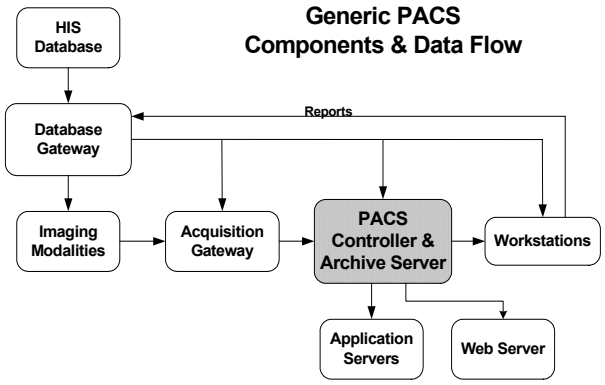

Figure 1. PACS and its basic components. This paper discusses the PACS Controller and Archive Server (shaded box) related to the Data Grid.

1.2 Clinical Image Recovery after Disaster

PACS, developed originally to smooth the operation of hospital radiology departments, has evolved into the most commonly found computing tool of a mission critical nature in the modern hospital. The component technologies of PACS have matured over the past several years, from the image acquisition devices to display workstations, archive servers, networks and, perhaps most significantly, the DICOM standard and IHE (Integrating Healthcare Enterprise), dataflow profiles. Among the components shown in Figure 1, the PACS controller and the archive server serve as the image data archive system consisting of arrays of hard disks, RAID, and DLT (Digital Linear Tape). This component archives all clinical images for seven years, as mandated by the recently adopted Health Insurance Portability and Accountability Act (HIPAA). [1] For an average 300–500 bed hospital in USA, this translates to about 40 terabytes of storage without image compression; but simply possessing the storage capability is not enough to assure compliance as no single image in this archive can be lost under any circumstances.

Fault Tolerance, long a necessity in most other applications of mission critical computing, is now expected in medical applications; however, practical field experience demonstrates that PACS archive servers can and do go down without warning. [21, 22] Once down, the malfunction cripples the clinical operation and dramatically affects the quality of healthcare services. Currently, most PAC systems use a backup archive solution for image data recovery. This not-so-fool-proof solution is entirely inadequate given its expense, in dollars and man-hours, as well as its slowness in recovering the image data, which has a negative impact on healthcare delivery. [2-4] New approaches to this problem are greatly desired.

2. GRID TECHNOLOGY

2.1 Grid Technology and the Globus Toolkit 3.0

Grid computing is the integrated use of geographically distributed computers, networks, and storage systems to create a virtual computing system environment for solving large-scale, data-intensive problems in science, engineering, and commerce. [5-11] A grid is a high-performance hardware and software infrastructure providing scalable, dependable and secure access to the distributed resources. Unlike distributed computing and cluster computing, the individual resources in grid computing maintain administrative autonomy and are allowed system heterogeneity; this aspect of grid computing guarantees scalability and vigor. Therefore, the grid's resources must adhere to agreed-upon standards to remain open and scalable. A formal taxonomy, composed of five layers (as shown in Fig. 2) has been defined by the Globus Toolkit 3.0 of grid computing to assure this standardization. [7]

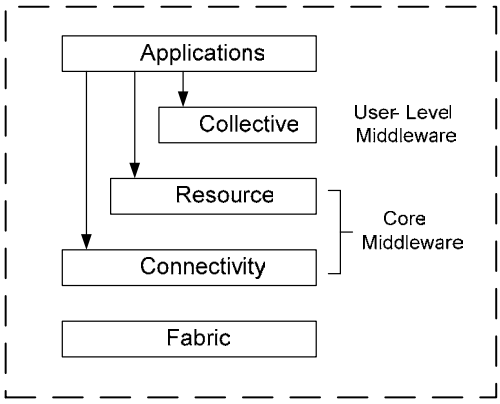

Figure 2. The five layers of the grid computing technology based on Globus Toolkit 3.0

At its core, grid computing is based on an open set of standards and protocols - e.g., the Open Grid Services Architecture (OGSA) [9, 10].

In this paper, we address the computational services and the data services of the Globus Toolkit 3.0. [6-8]

a. *Computational Services* support specific applications on distributed computational resources, such as supercomputers. A grid for this purpose is often called a Computational Grid (see Section 4).

b. *Data Services* allow the sharing and management of distributed datasets. A grid for this purpose is often called a Data Grid. (See Sections 3 and 4)

We use the Globus 3.0 toolkit co-developed by ANL and ISI, USC as the guide for implementing the Data Grid architecture [18]. (Globus 4.0 is now available for Alpha test)

2.2 Use of SAN Technology in PACS and Data Grid

A current data storage trend in large-scale archiving is Storage Area Network (SAN) technology, and PACS is no exception in this trend [12]. With this new configuration, the PACS server

will still have a short-term storage solution in local disks of the display workstations containing unread patient studies. However, for long-term storage, the PACS data is stored in a SAN. This SAN is a stand-alone data storage repository with a single Internet Protocol (IP) address. File management and data backup can be achieved with a combination of digital media (e.g., RAID and DLT.) smoothly and with total transparency to the user. In addition, the SAN can be partitioned into several different repositories each storing different data file types. The storage manager within the SAN is configured to recognize and distribute the different clients' data files and store them to distinct and separate parts of the SAN. Figure 3 shows an example of a SAN configuration where three different clients, PACS server, IT server and Data Grid, store their data to the SAN. They each access the same IP address and make a request for data storage or retrieval. The SAN is pre-configured such that the storage manager knows which client is requesting storage service and where the data should be stored within the SAN. In the case where a client requests data to be retrieved from the SAN, the storage manager again knows which client is requesting data and where that data needs to be retrieved from within the SAN. In addition, the SAN can be partitioned in a heterogeneous fashion where the different volume sizes can be scaled to either the data file sizes of the different clients or the total volume of data needed for storage by a particular client as compared to another.

In the Data Grid system to be described in Section 3, both clinical PAC systems use one partition in its respective SAN for its own long-term archive. The Data Grid uses the second partition in each respective PACS' SAN for the back up image data of other federated PACS. The resource allocation method based on the Globus 3.0 toolkit is discussed in Section 3.

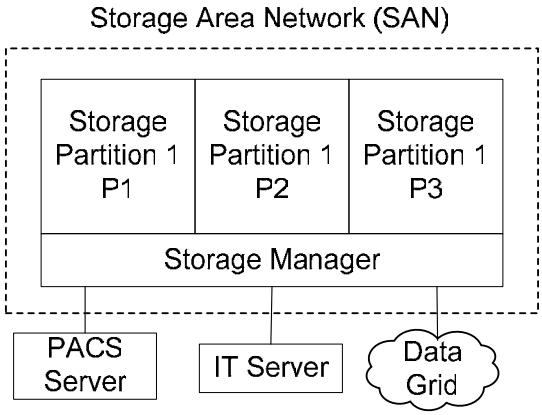

Figure 3. SAN Technology integrated with a clinical PACS. The SAN can be partitioned for orthogonal types of data storage such as an Information Technology server (e.g., email) or used as a resource for the proposed Data Grid. In this example, the data from the PACS server is sent to the storage manager within the SAN and then configured to be stored in partition 1 (P1). Likewise, data from an IT server is stored in partition 2 (P2). Finally data from the proposed Grid would be stored in partition 3 (P3). Each partition is separate and distinct.

3. DATA GRID ARCHITECTURE

3.1 Data Grid for PACS Archive Application

The Data Grid testbed consists of three sites. The first site is the IPI (Image Processing and Informatics Laboratory) where the major resources are the PACS Simulator and the DICOM Fault-Tolerant backup archive. Both components are the resources in the Data Grid. The second and the third sites are the Saint John's Health Center (SJHC) and the Healthcare Consultation Center II (HCC II) at USC/HSC. Both sites have a clinical PACS with a SAN archive system. A partition of each SAN, which does not handle the site's clinical PACS image data, is used as backup archive resources in the Data Grid. It is important to note that the SAN partitions belonging to each of the two sites are completely independent and the data stored in these partitions are orthogonal and separate from the clinical data partitions that are integrated with each of the respective clinical PACS. From these available resources in this testbed, we have developed the five layers based on the Globus Toolkit 3.0 (GT) and some PACS DICOM resources shown in Figure 4.

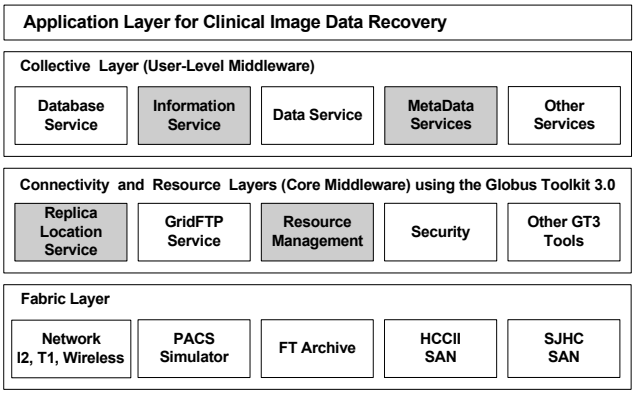

Figure 4. Five-layer architecture and the contents of the Data Grid in the testbed. For shaded boxes, see Section 4.

1. **Fabric Layer**: This layer consists of a DICOM compliant fault-tolerant (FT) backup Archive Server and a PACS simulator at IPI; two SANs (Storage Area Network) at two PACS clinical sites – HCCII, USC (Healthcare Consultation Center 2, University of Southern California Health Science Campus), and SJHC (Saint John's Health Center, Santa Monica, CA); and communication network systems including LAN (local area network), Internet 2 and broadband WAN (wide area network - T1).

2. & 3. **Connectivity and Resource Layers (Core Middleware) using the Globus Toolkit 3.0** [13-17]. This layer consists of a set of services in the Globus Toolkit 3.0 (GT3) developed at the Argonne National Laboratory, and ISI (Information Science Institute), USC. GT3 is an open and free toolkit based on Open Grid Service Architecture (OGSA) [11, 18, 19] mechanisms, which has the same five layer grid architecture. GT3 provides a set of services, such as Grid Security (GSI), remote job submission and control using the Grid Resource Allocation and Management (GRAM), high-performance secure data transfer (GridFTP), Replica Location Service (RLS)

and other core tools for building the Core middleware layer. GT3 is common amongst a large user community in Grid research and applications.

4. **Collective Layer (User-Level Middleware)** This layer consists of services to interact between the User Applications and the services in the Core Middleware, such as database service (to find the best available database in the Data Grid), information service (to monitor the current active services in the Data Grid), and data service (to find the physical address of the logical data) as well as other services. In this layer, GT3 has only the Information Service (Fig. 4 shaded), all others, such as Database, Data, Metadata, and Other Services are currently not available (Fig. 4). We are developing these services in conjunction with our image data recovery application.

5. **Data Grid Application Layer:** This layer consists of several applications, such as the recovery of clinical PACS image data.

3.2 A Three-site Testbed and Its Major Image Data Storage Resources

Figure 5 shows the configuration of the testbed Data Grid including the three sites mentioned above. A clinical PACS workstation outside of the Data Grid is able to access the grid for services.

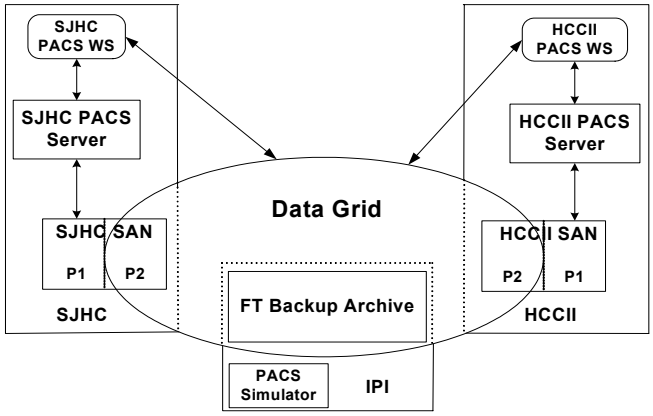

Figure 5. Configuration of three sites data storage systems that comprises of image data storage resources in the Data Grid. Workstations outside of the Data Grid can still access the grid for particular services. In this configuration, P1 at each site is used for clinical data pertinent to it PACS, whereas P2 becomes a shared resource of the Data Grid.
SJHC: Saint Johns Healthcare Center
HCCII: Healthcare Consultation Center II, University of Southern California (USC)
IPI: Image Processing and Informatics Laboratory, USC

The SAN architecture of the two sites is heterogeneous which provides a good basis for a more robust testbed development and evaluation. In both cases, the SAN is utilized as long-term storage of clinical PACS data. Each of the PACS servers has short-term storage, or, it can be considered as an unread buffer of clinical PACS studies. However, with each of the long-term storage solutions, there are major differences within the SAN architecture. Figure 6 shows the major differences between the two SAN architectures that are used as part of the Data Grid resources. In the case of the SJHC SAN (Architecture A), the RAID is only a temporary holding place for the data before it is transferred to the main storage area, which is the digital tape library holding 13.5 TB. Therefore, the RAID is only a small amount (270 GB) of data storage volume. In the case of HCCII's SAN the RAID is used as the primary storage area and therefore data volumes are larger (7.2 TB). In addition, the RAID capacity is scalable up to 52 TB. The digital tape library (14.4 TB), in this case, is only used as disaster recovery/backup to the RAID. Therefore, the tape read/write throughput is much slower as compared to the read/write throughput of SJHC's digital tape library within its SAN. Table 1 lists the backup storage resources, which are allocated from each PACS and Archive Server in the Data Grid.

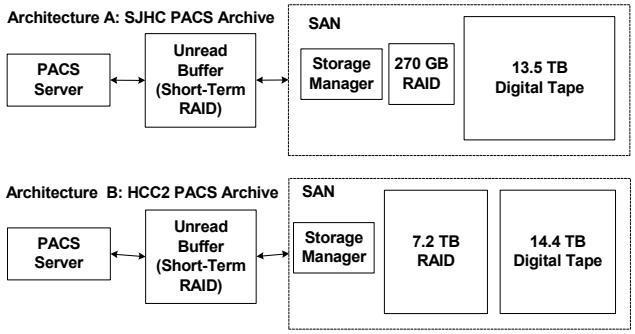

Figure 6. Two different SAN architectures that are utilized within the proposed Data Grid.

Table 1. Backup Storage Resources in the Data Grid Testbed

Resource	Location	Types (Capacity)
IPI FT Backup Archive	IPI	RAID (300 GB), DLT (1.6 TB)
SAN (P2)	SJHC	RAID & DLT (1.3 TB)
SAN (P2)	HCCII	RAID & DLT (2 TB)

3.3 The Backup Image Data Storage in the Data Grid [20-23]

Clinical images generated in the three sites, IPI, SJHC, and HCCII can be backed up by the Data Grid using the following protocol shown in Table 2. There are always two backup copies of the image data acquired from any site in the Data Grid. For example, image data acquired from SJHC PACS will have two backup copies in the Data Grid. One is stored in HCCII SAN (P2), and the second in the IPI FT backup archive. Similarly, image data acquired from HCCII PACS will be backed up in the SJHC SAN (P2) and IPI FT backup archive [20], and data from

IPI PACS Simulator will be backed up in the SJHC SAN (P2) and HCCII SAN (P2). The IPI PACS Simulator has a connection to the clinical PACS at USC for clinical image data. A database in the Data Grid based on the PACS data model is used to track every patient comes in contact with the Data Grid. Figure 7 illustrates an example of the backup procedure.

Table 2. Backup Policy in the Data Grid

Site	Clinical Image Data	Backup Copy 1	Backup Copy 2
SJHC	SJHC SAN (P1)	HCCII SAN (P2)	IPI FT Backup Archive
HCCII	HCCII SAN (P1)	SJHC SAN (P2)	IPI FT Backup Archive
IPI PACS Simulator	PACS Simulator Archive	SJHC SAN (P2)	HCCII SAN (P2)

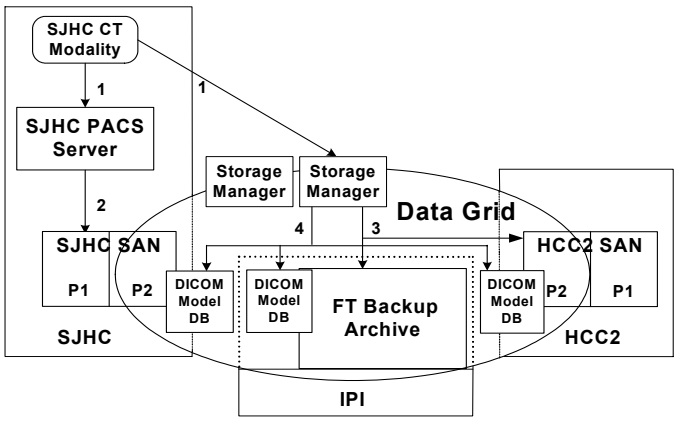

Figure 7. The backup procedure of image data from SJHC CT Modality to two storage sites (IPI FT Backup Archive and HCCII SAN (P2) in the Data Grid).

Follow the numerals described in Figure 7:

1. After an examination is completed at the SJHC CT scanner, it sends out two copies of the image data, one to the SJHC PACS Server, and the second to the Data Grid for backup.
2. The SJHC PACS Server receives the first copy of the image data and stores it in the SJHC SAN (P1) as its own archive.
3. The Data Grid activates one service Storage Manager to receive the second copy of the image. The Data Grid monitors the status of Storage Manager service and can activate a second one if the first Storage Manager fails. After receiving the image data, the Storage Manager automatically sends two copies, one to the IPI FT Backup Archive and the second to the HCCII SAN (P2). Since two copies are distributed to two different storage sites by the Data Grid, a single-point-of failure can be avoided. After the image data has been successfully archived in the two storage sites, the physical location will be added to the Replica Location Table of the Data Grid. The Replica Location Table keeps the physical storage information of each copy of image data.
4. The Storage Manager adds the patient information of the image data (not the image data itself) to a DICOM Data Model database in the Data Grid which makes three copies distributed to the FT backup Server at IPI, the SJHC SAN (P2), and the HCC SAN (P2). Three copies are used to avoid the single-point-of-failure of the database.

3.4 Interfacing the PACS and Data Grid

The utilization of Data Grid for PACS applications are mainly in DICOM Image Store and Query/Retrieve (Q/R), and Computational Services. In this section we use two examples of DICOM image Store, and DICOM image Q/R to demonstrate the fault tolerance features of the Data Grid based on three sites (see Figure 5 and Table 1). Section 4 describes the computational service. Figure 8 shows a DICOM WS using the Data Grid for image store. Under normal operation condition (solid lines), the image is sent from the DICOM client to the Data Grid through the Grid Access point 1. Two copies of the image are stored in two Grid Storage Resource 1, and 2 respectively. Suppose the Grid Access Point 1 fails (cross lines), as shown in Figure 9, the Data Grid has the intelligence to find Grid Access Point 2 (dotted line) from there it finds (dotted lines) Grid Storage Resource 1, and 2 for archive.

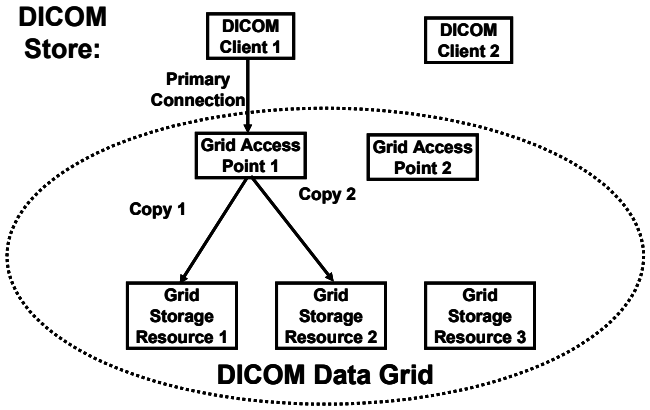

Figure 8. Normal DICOM Store (solid Lines).
The three Storage Resources are those shown in Figure 5 and Table 2.

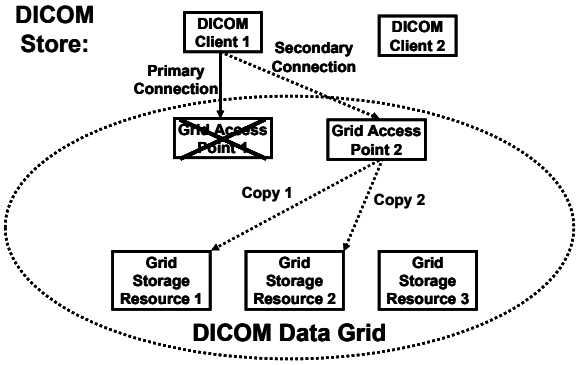

Figure 9. If Grid Access Point 1 fails, the Data Grid automatically switches to Grid Access Point 2 to complete the DICOM Store process (dotted lines)

Figures 10 and 11 show the second example which is for DICOM Q/R. Under normal operation condition (solid lines), the Q/R processes go through Grid Access Point 1 to find the required information at Grid Storage Resource 1. The information is retrieved and sent to the DICOM Client. Suppose the Grid Storage Resource 1 fails during the Q/R (cross lines), the Grid Access Point 1 finds the Grid Storage Resource 2 which contains the required information, Resource 2 then fetches the information and sends to the DICOM Client 1 (dotted lines).

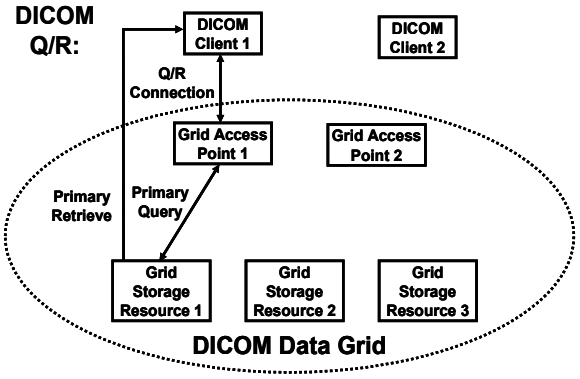

Figure 10. Normal DICOM Query/Retrieve (Q/R) (solid lines)

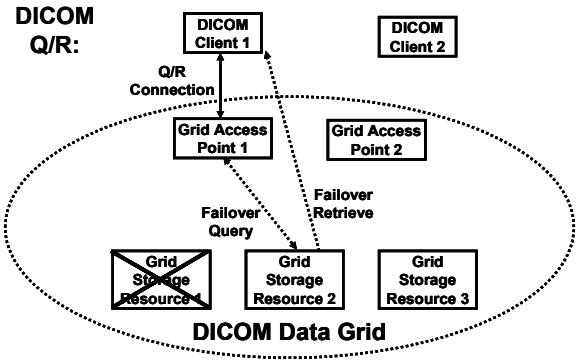

Figure 11. If Grid Storage Resource 1 fails, Data Grid automatically switches to Resource 2 and completes the Q/R process. (dotted lines)

3.5 EXTENSION OF THE DATA GRID SERVICE TO MORE PAC SYSTEMS

This paper discusses the data grid model which incorporates three PACS sites. When the data grid grows with more than three heterogeneous PAC systems, the Data Grid concept can be extended without much difficulty because only storage resource (see Fig. 5, 7 and 8) which is not used by each of the PAC systems is involved.

4. COMPUTATIONAL SERVICES IN THE DATA GRID FOR IMAGE ANALYSIS

A computational service infrastructure in the Data Grid provides dependable, consistent, pervasive, and inexpensive access to computational capabilities. Globus toolkit [13] described earlier includes core and user-level middleware services (refer to Fig. 4 shaded boxes) that enable users to obtain information about the services available, component software, data files, and the execution environment. The Grid execution environment includes computing and storage services with diverse capabilities. [24] We develop four computational services using the Globus toolkit in the Data Grid infrastructure. We first describe the basic infrastructure and then in Section 4.2, we apply this infrastructure to bone age assessment. [25]

4.1 Computational Services Architecture in the Data Grid

In Grid environment, an application component can be implemented in different source files; each complied to run in a different type of target architecture. Exact replicas of the executable file can be stored in many locations, which helps reduce execution time. Data files can also be replicated in various locations. Each file has a description of its contents in terms of application-specific metadata. The Metadata Service including Catalog Service, see Figure 4, responds to queries based on application-specific metadata and returns the logical names of files containing the required data, if they already exist. Given a logical file name that uniquely identifies a file without specifying a location, the Replica Location Service (RLS), see Figure 4, can be used to find physical location for the file on the Grid.

A specific application may require a certain type of resource for execution. Figure 12 shows the operation architecture of the computational services. First, the client requests resources from MDS (Monitoring and Discovery System) server (Fig. 12, Numeral 1), which manages the resources and distributes the jobs to the computational services. The index service finds resources appropriate to the requirements of application components and notifies the client to send the application to the Grid Resource Allocation and Management (GRAM) service (Fig. 12, Numeral 2). The GRAM service acknowledges MDS after it receives the application. (Fig. 12, Numeral 3). After the GRAM service receives the application, jobs that completely specified for execution are sent to schedulers that manage the resources and monitor execution progress. Execute acknowledges MDS server the completion of the job (Fig. 12, Numeral 3) which in turn notifies the client (Fig. 12, Numeral 4).

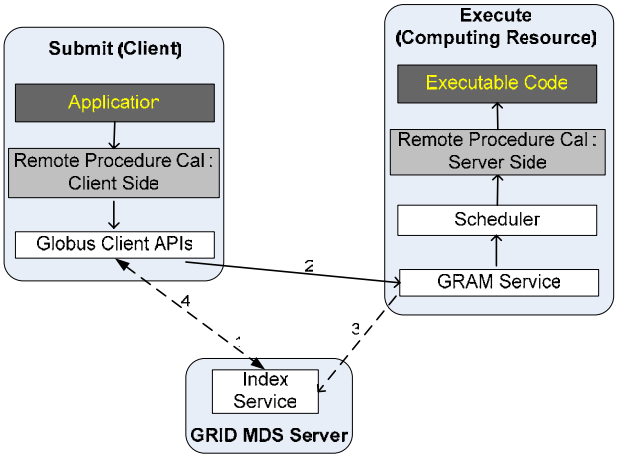

Figure 12. Operation architecture of a computational grid. Numerals represent the workflow.

4.2 Computerized Bone Age Assessment

We use the bone age assessment (BAA) of children as an example to illustrate how the computational services in the Data Grid can be used in BAA application. Bone age assessment is a procedure performed in pediatric patients to evaluate parameters of maturation and growth of the child from a left hand and wrist radiograph (Figure 13).

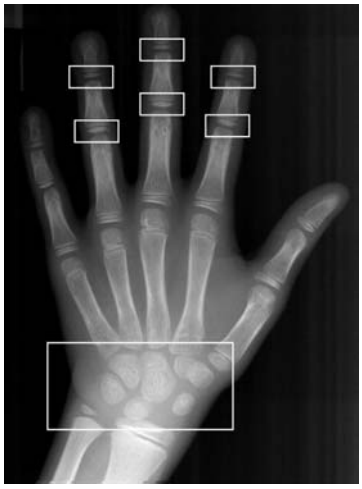

Figure.13. A left hand and wrist radiograph with seven regions of interest (ROI). Top: Six epi-metaphyseal ROIs; Bottom: Carpal bones ROI

Recent works in the field of computerized approach to BAA have already been completed from our previous work. [26] We have acquired a total of 1,080 digitized hand images of normally developed children, 5 images for each group of children (0 - 9 years old) and 10 images for children (10 -18 years old) from the Childrens Hospital Los Angeles, evenly distributed from boys and girls of European, African, Hispanic and Asian descent. The images in our collection have been subjected to fully automatic procedure of image processing yielding a vector of features for each successfully processed region of interest (ROI). There are seven ROIs (Fig. 13) which provide evidences of bone growth.

The overall image processing procedure is broken down into 3 software layers shown in Figure 14: pre-processing, region of interest analysis, and high-end application. The hand image processing and analysis starts with background removal based on a histogram analysis. Then the hand object is identified with the phalangeal axes along digits II, III and IV. The six epi-metaphyseal joints and carpal bones ROIs are segmented out as separate subimages, shown in Figure 13, for further analysis.

An overview of medically accepted diagnostic method indicates that epi-metaphyseal ROIs appear to be the most sensitive area reflecting the skeletal development stage. At the early stage of skeletal development, the epiphysis is separated from the metaphysis. 11 distance-related features, which form the feature vector of a ROI of a phalange, are extracted using the Gibbs random fields. In later stage (starting from 9 to 12 years old), the gap between epiphysis and metaphysis becomes radiographically inapparent. The ROI is subject to wavelet decomposition in order to assess the stage of fusion. Carpal bones part is another important ROI in bone age assessment. The inclusion of number, size, and shape features of carpal bones can be used to augment epi-metaphyseal ROIs to obtain higher accuracy of bone age assessment. The separation of carpal bones is most advantage to be used for bone age assessment for children of ages 0-5 (female) or 0-7(male), and the amount of bone overlapping can be used as an indication of ages 5-12 (female) or 7-12 (male).

The features from the six epi-metaphysis ROIs and the carpal ROI are integrated to estimate the bone age of a child from the hand radiograph by using a fuzzy logic system.

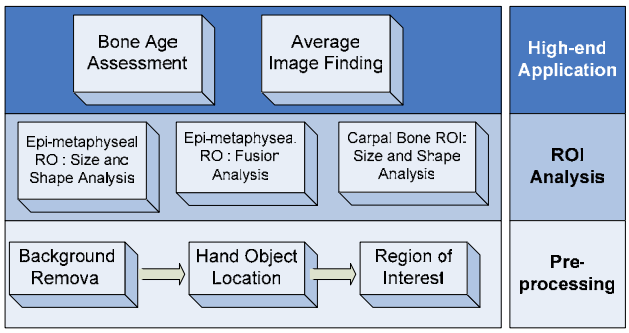

Figure 14. Three-layer procedure of computerized BAA

As data including the image, features extracted from each ROI, along with growth factors in textual form, are augmented and organized for each normal subject for all 1,080 subjects in a large-scale database, a digital atlas can be formed. Two high end applications can be implemented. One is to assess the bone age of a child from a hand radiograph based on image analysis using the digital atlas discussed earlier. The other is the "average" reference image in the digital atlas which can be selected for each of the groups of normal developed children with the best representative skeletal maturity based on specific bony features using image mining technique. Figure 15 shows an example of the average image of African American girls' category from 1 to 12 years old in the digital atlas. [27]

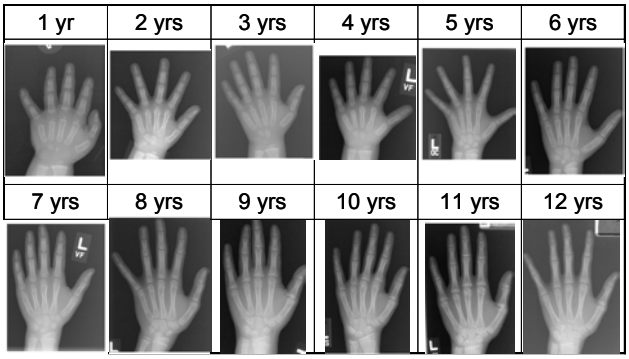

Figure 15. The average images for age groups (1-12 years) of African American girls (size not in scale). Each average image is obtained by image mining from all normal images based on their feature vectors in the same category (for example, ethnic origin and gender) in the digital hand atlas.

4.3 Use of Data Grid for Bone Age Assessment

The already developed BAA methodology has one disadvantage which is the computational requirements in identifying the ROIs, feature extraction from each ROI, and the use of fuzzy logic for bone age assessment. The Data Grid with computational services can be used to speed up the computational requirements. In order to accomplish that, we modified the current methodology in BAA shown in Figure 14 to facilitate the computational services in the Data Grid shown in Figure 4 and Figure 12 by subdividing the entire hand image into multiple regions of interest, including six epi-metaphyseal ROIs of three phalanges and the carpal bones ROI. These ROIs are processed by remote grid resource nodes; later, all results are merged together through the Data Grid MDS (Monitoring and Discovering System) server.

Let us assume the user submit a patient's hand image to the Data Grid with BAA computational services, the overall operation workflow of bone age assessment is shown in series (1, 2, 3) in Figure 16.

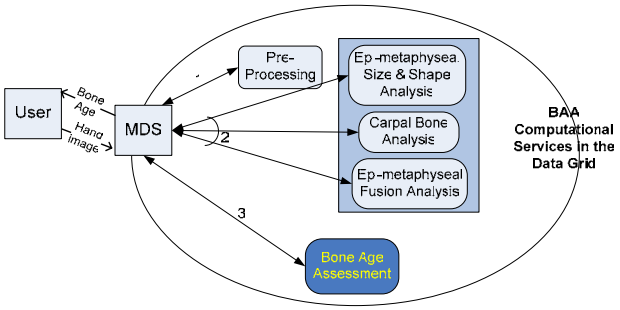

Figure 16. Operation workflow of BAA computational services. The MDS allocates the computation requirements according to the available resources in the Data Grid. Numerals represent the workflow.

4.4 Advantages of Computational Services in the Data Grid for Bone Age Assessment

The advantages of developing the computational services in the Data Grid for BAA versus using the conventional method are:

1. It utilizes the existing Data Grid technology which saves the job distribution and computation time.
2. It does not require to significant rewrite the image processing codes, this approach has resulted in substantial acceleration of the data analysis speed.
3. It facilitates the upgrading of the segmentation and feature extraction methodology easily.
4. With an ever-expanding digital hand atlas, such an object-oriented designed system can assure a continuous accrual of the best representations of the "average maturity" of a normal population by using a systematic image analysis method.

5. CONCLUSION

Grid computing is a powerful tool for large-scale computation and storage requirements. In this paper we present a novel concept of Data Grid for medical image application, in particular, for daily clinical PACS on-site archive, off-site backup, and disaster recovery. The Data Grid utilizes the SAN technology, and imbeds the DICOM standard as an integrated system. A testbed with two clinical sites and one research site is being implemented to evaluate the performance of the Data Grid. The allocation and distribution of resources at each site is described. The backup procedure during disaster is presented with dataflow using the DICOM Store and DICOM Query/retrieval functions.

Taking advantage of the Data Grid infrastructure, we also implemented computational services in the Data Grid for bone age assessment of children. A large-scale digital atlas containing over 1,000 digital hand radiographs of normal children from age 0 to 18, male and female, and four ethnic origins has been developed in an organized database. Each radiograph has seven computer extracted regions of interest (ROI), and each ROI has a feature vector containing pertinent information of bone age indicators. These feature vectors in the atlas are used to assess the bone age of a child when his/her radiograph is submitted. A feature vector is extracted from the radiograph and compared with those in the digital atlas by using Fuzzy logic. This conventional computation procedure has been modified and implemented in the computational services of the Data Grid. Evaluation of the Data Grid method versus the conventional computation methods in terms of computational effectiveness and efficiency is being conducted.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] Cao F, Huang, HK, Zhou XQ. 2003 Medical Image Security in a HIPAA Mandated PACS Environment. *Comp Med Imag & Graphics* V27, Issues 2-3, 185-196.

[2] Huang HK. 2003. Enterprise PACS and Image Distribution, *Comp Med Imaging & Graphics* V27, Issues 2-3, 241-253.

[3] Liu BJ, Cao F, Zhou MZ, Mogel G, 2003 Trends in PACS image Storage and Archive. *Comp Med Imaging & Graphics* V27, Issues 2-3, 165-174.

[4] Huang HK, Cao F, Zhang JG, Liu BJ, Tsai ML 2000. Fault tolerant Picture Archiving and Communication System and Teleradiology Design. In Reiner B, Siegel EL, Dwyer SJ*: Security Issues in the Digital Medical Enterprise, SCAR, Chapter 8,* 57-64.

[5] What is grid computing, http://www-1.ibm.com/grid/about_grid/what_is.shtml

[6] Grids and Grid technologies for wide-area distributed computing, Mark Baker, etc. *SPIE,* 2002.

[7] The Grid: A New Infrastructure for 21st Century Science, http://www.aip.org/pt/vol-55/iss-2/p42.html,

[8] Computational Grids, *The Grid: Blueprint for a New Computing Infrastructure*, Chap 2, Morgan-Kaufmann, 1999.

[9] The Physiology of the Grid: An Open Grid Services Architecture for Distributed Systems Integration. I. Foster, C. Kesselman, J. Nick, S. Tuecke, Open Grid Service Infrastructure WG, *Global Grid Forum*, June 22, 2002.

[10] The Anatomy of the Grid: Enabling Scalable Virtual Organizations. I. Foster, C. Kesselman, S. Tuecke. *International J. Supercomp Applications*, 15(3), 2001.

[11] Grid Services for Distributed System Integration. I. Foster, C. Kesselman, J. Nick, S. Tuecke. *Computer*, 35(6), 2002.

[12] SAN Technology: http://www.storage.ibm.com/ibmsan/whitepaper.html

[13] Globus Toolkit 3, http://www.globus.org/toolkit/gt3-factsheet.html

[14] The Globus Striped GridFTP Framework and Server. W. Allcock, J. Bresnahan, R. Kettimuthu, M. Link, C. Dumitrescu, I. Raicu, I. Foster. *Proceedings of Super Computing* 2005 (SC05), November 2005.

[15] Security for Grid Services. V. Welch, F. Siebenlist, I. Foster, J. Bresnahan, K. Czajkowski, J. Gawor, C. Kesselman, S. Meder, L. Pearlman, S. Tuecke. *Twelfth International Symposium on High Performance Distributed Computing (HPDC-12)*, IEEE Press, to appear June 2003.

[16] Grid Information Services for Distributed Resource Sharing. K. Czajkowski, S. Fitzgerald, I. Foster, C. Kesselman. *Proceedings of the Tenth IEEE International Symposium on High-Performance Distributed Computing (HPDC-10)*, IEEE Press, August 2001.

[17] Grid Resource Management. J. Nabrzyski, J.M. Schopf, J. Weglarz (Eds). Kluwer Publishing, Fall 2003.

[18] Globus Toolkit 3 Core White Paper, http://www-unix.globus.org/toolkit/documentation.html

[19] Open Grid Services Infrastructure (OGSI) Version 1.0. S. Tuecke, K. Czajkowski, I. Foster, J. Frey, S. Graham, C. Kesselman, T. Maguire, T. Sandholm, P. Vanderbilt, D. Snelling; *Global Grid Forum Draft Recommendation*, 6/27/2003.

[20] Liu BJ, Huang HK, Cao F, Zhou MZ, Zhang J, Mogel GT. 2004, A Complete Continuous -Availability PACS Archive Server Solution, *Radiographics*, 1203-1209.

[21] Huang HK, Liu BJ, Zhou Z. 2004, A CA Server for Medical Imaging Application, *Academic Radiology*, V.11, No.7 767-778.

[22] Huang HK, 2005, Medical Imaging Informatics Research and Development Trends – An Editorial. *Comp Med Imaging & Graphics* V.29, Issues 2-3, 91-93.

[23] Huang, HK, 2004. *PACS and Image Informatics: Basic Principles and Applications*. 703 pages, Cloth. John Wiley & Sons, Hoboken, NJ

[24] Jim Blythe, Ewa Deelman, Transparent Grid Computing: a Knowledge-Based Approach. *Fifteenth Innovative Applications of Artificial Intelligence Conference* (IAAI-03),Acapulco, August 12-14 2003.

[25] Performance Analysis of the Globus Toolkit Monitoring and Discovery Service, MDS2. X. Zhang and J. Schopf. *Proceedings of the International Workshop on Middleware Performance (MP 2004), part of the 23rd International Performance Computing and Communications Workshop (IPCCC)*, April 2004.

[26] E. Pietka, S. Pospiech, A. Gertych, F. Cao, Integration of Computer Assisted Bone Age Assessment with Clinical PACS, *Computerized Medical Imaging and Graphics*, 1-12, 2002.

[27] A. Zhang, et al. Data mining and visualization of average images in a digital hand atlas. *Proceedings of SPIE Medical Imaging*, Vol. 5748, pp65-72, February 2005

Invited Lecture — 13th ISRRT World Congress

Living with PACS

Part 1: Implementation strategy

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Abstract

The implementation process of a PACS within a clinical environment can be a sometimes daunting process with many issues and challenges. This paper, divided into two parts, presents an overview of experiences gained during various PACS implementations at various health care institutions following from the initial planning stages to the final Acceptance Testing (AT) and system turnover. This part (Part 1) focuses on the implementation strategy which includes risk assessment, targeting high-return areas, phasing the implementation, work flow study, training of personnel, and implementation planning.

Keywords: *PACS, implementation, risk assessment*

Introduction

As more and more health care institutions move towards a filmless environment, the implementation process of PACS becomes crucial for a successful installation. The following are key fundamental concepts for considering a PACS implementation process:

- PACS is an enterprise-wide system that impacts the entire healthcare enterprise.
- Buy-in from key areas crucial for success: 1) Hospital Administration; 2) Radiology Department; 3) Information Technology (IT) Department; 4) High Profile Customers of Radiology (e.g. orthopedics, surgeons, etc.).
- The need for a champion(s).
- PACS is a system of multiple components.
- The need for an implementation risk assessment based on site survey.
- Target high-return areas to obtain the "low-hanging fruits of success".
- Phase the implementation
- PACS is disruptive technology: workflow and training development are crucial.

In this paper, the last four concepts will be elaborated further to better describe the implementation methodology.

The need for an implementation risk assessment

In the Risk Assessment of a healthcare institution planning to implement a PACS, there are a few key areas to focus on when performing a site survey to help determine potential stumbling blocks:

- **Network infrastructure supporting PACS:** More and more PACS solutions are evolving into a client-server architecture. Therefore, the network bandwidth and performance become even more crucial for acceptance by Radiologists and Physicians. It is important to configure or upgrade a network if the current bandwidth is not suitable. Most vendors can advise on what network requirements are needed for the PACS to operate efficiently.

- **Modality integration with PACS:** A healthcare institution may have legacy modalities that will need to be upgraded to DICOM or if that is not possible, they may require a DICOM black box. This process can be time-consuming and should be addressed as soon as possible. In addition, DICOM worklist is an important workflow tool for the modalities since it eliminates the need for Radiographers to manually type in patient demographics and introduce potential human error. Some modalities already feature DICOM modality worklist but it may need to be configured. Others may require a software upgrade. Finally, it is important to consider a Quality Control (QC) workstation for complex high-volume modalities that require manipulation of the study prior to sending to PACS. For CT and MR modalities, this QC workstation will help to streamline the presentation of the PACS studies and improve overall workflow.

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- **Physical space for PACS equipment:** Since space is always a premium within a healthcare institution, proper space planning becomes an important planning strategy. Workflow will need to be considered to streamline the process between acquiring a PACS study to the diagnosis of the PACS study and how the Radiographers interact with the Radiologists. Since Radiologists will be working with computer equipment almost continuous and daily, ergonomic issues need to be considered (e.g. tables, chairs, cubicles, mouse, keyboard, monitors). Sometimes construction is needed to expand or redesign rooms where film was once the workflow focus. This physical disruption may sometimes overshadow the inherent fears of a new system that humans will interface with. In addition, the construction may take a while to complete and should be considered to begin almost immediately.

- **Resource Availability:** In-house support is key to successful implementation and operation of a PACS. Therefore, proper personnel should be identified during the initial stages of the implementation process and they should be involved from the beginning. Many institutions attribute PACS to the various other IT-related systems within a healthcare institution. However, because PACS involves the diagnostic workflow process of a Radiologist, it is necessary for not only IT-related personnel to be involved in the PACS implementation but also personnel with a clinical background within the department (e.g. Radiographers, File Clerks, etc). This clinical background will become extremely useful during workflow and training development as well as future support of PACS.

Target high-return areas

Another key concept for a successful implementation is target areas where PACS has the highest likelihood of success and acceptance. These areas are usually clinics that have the highest film volumes and a low rate of film returns to the Radiology Department (e.g. Critical Care Areas, Orthopedics, Surgery). This will help continue drive the implementation to full completion and serve as a springboard to other areas where PACS will eventually be implemented. In addition to determining which clinical areas to implement first, modality type PACS studies also has its own set of benefits and challenges. These are usually broken down into two types:

1) Implementation of CR with PACS first.
2) Implementation of digital modalities (CT, MR, US) with PACS first.

CR is easier to implement first because it takes less lead time to integrate since it is DICOM ready and there is no need to address legacy modalities. In addition, CR studies are less complex due to less number of images and the types of studies which will allow the Radiologist to get acclimated to the new PACS workstations. This also allows for time for the other digital modalities to be integrated and to gather historical data for when they are ready to go live with PACS. However, one of the challenges is that transitioning from analog film to a CR system can be quite complex because the Radiographer will need to operate and support multiple computer devices that belong to the CR system. If the Radiographers have never been exposed to computer equipment, this can be a challenging task for them.

On the other hand, digital modalities do not require this transition from film, since the Radiographers have already been trained to operate the modality and are familiar with it. Instead of printing the PACS study to film, the Radiographer merely sends the study to PACS through the network. However, integration of digital modalities can be challenging especially if some of the modalities are legacy equipment and do not feature DICOM worklist. Because there are larger volumes of image data coming from these digital modalities, navigation of these data on a PACS workstation is more complex and challenging. In addition, the workflow protocols at the modality scanner may need to be adjusted to ensure that the PACS study is in proper order and presentable to the Radiologist. A QC workstation may help to streamline this workflow by allowing the Radiographers to adjust the PACS study on the workstation prior to sending it to PACS for the Radiologist to read. Finally, historical data are almost always a requirement for a Radiologist to read a new study. Therefore, careful planning is needed to migrate historical studies either from historical data media from the modality scanner archive or to collect a historical data set in PACS before going live.

Along with these above factors, the low risk/high return areas will help to drive the implementation strategy and the implementation phased timeline. Ultimately, it is always beneficial to have a successful first push of the implementation process especially since PACS is inherently disruptive in nature.

Phase the implementation

The following is the recommended Implementation Phase timeline for a PACS installation.

- **Phase I includes:**

1) PACS network infrastructure;
2) HIS/RIS/PACS interfaces;
3) Archive and archive server;
4) Diagnostic and clinical workstations;
5) CR or digital modalities based on the risk assessment.

- **Phase II Includes:**

1) Additional diagnostic and clinical workstations;
2) CR or digital modalities based which one was chosen for Phase I.

- **Phase III Includes:**

1) Enterprise-wide distribution solution (e.g. Web Server);
2) Archive server and upgrade (if necessary).

Each of the phases would have distinct timelines and go live dates. In addition, it is recommended to perform an Acceptance Test for each of the implementation phases since they will change the overall system characteristics. The time between phases can be as little as a few months depending on the overall PACS timeline.

PACS is disruptive technology

Because of its disruptive nature, PACS will affect and change every aspect of the Radiology Department. Therefore, workflow, training/education are crucial in mitigating this disruptive effect. There is a direct correlation between the amount of workflow/training development effort and the length of chaotic period that occurs after the department has gone live with PACS which is: Lesser effort results in increased time of chaos after the PACS go live date.

Workflow study

For workflow development, it is important to develop the baseline workflow prior to implementing PACS. This is important because the baseline workflow will help to anchor and streamline existing processes that are currently unnecessary even before PACS is implemented. Understanding the baseline workflow in the department helps to pave the way for the future impact of the new PACS technology. When developing the baseline workflow, the entire imaging continuum from acquisition to diagnosis needs to be considered. This means that all Radiology staff who should be involved in the workflow (e.g. Radiographers, Film Clerks, Film Librarians, Radiologists). The goal is to first develop the baseline workflow and then begin to add and change parts of the baseline workflow that will be affected by implementing PACS. This new workflow may be an iterative process since issues may arise that requires further research. Figure 1 shows a portion of the new Clerical workflow with PACS in flowchart form. Note that historical studies on film are digitized with a laser film scanner and stored in PACS, which may be necessary to implement in Phase I.

In addition to the clinical workflow, it is also important to understand the data workflow of the PACS to be implemented at a site. Figure 2 shows one example of PACS data workflow. Based on the knowledge of both the clinical workflow and the data workflow, contingency plans can be developed to address PACS failures which result in downtime. Contingency plans are beneficial especially during times of crisis when scenarios are already planned for and even practiced as drills. Contingency plans can be multi-tiered geared for both short downtimes of hours (e.g. PACS component failure) to long downtimes of days (e.g. disaster scenarios).

Training program

The development of a Training Program for PACS will also help to mitigate the disruptive nature of PACS. The general perception that Radiologist are the main target of training usually falls short of providing successful acceptance of PACS throughout the department. Similar to workflow development, the training program should focus on the entire imaging continuum of not only Radiographers, film clerks and librarians, Radiologists, but also clinical area nurses, referring physicians, PACS system administrator and other PACS IT support personnel. To develop and administer the training program, a PACS training team is formed. Members of this training team can be departmental staff members who show interest in PACS which enhances the effectiveness of the training program. Although vendors usually provide training materials, they are not tailored to the specific sites needs and most of the time, include too much information. The training team can help to develop additional materials that will be used during the training period. Finally, the training team serves as a feedback mechanism for PACS users. Because the training team is expected to be the in-house experts on the PACS components, members of the team can naturally evolve into PACS support personnel. The training program utilizes the "train the trainer" methodology which is to identify superusers who will attend training courses provided by the vendor and become experts in the particular PACS applications. These superusers then train other in-house clinical staff and identify other superusers within particular areas throughout the healthcare enterprise called PACS Local User Support (PLUS) representatives. In order to administer the training program, three key points need to be addressed:

1) Identify User and User Groups: Examples include — Radiologists, Radiographers, Clerks, Referring Physicians, Nursing Staff, System Administrators.
2) Identify PACS components necessary for training each user group.
3) Develop User Groups Grid of necessary and unnecessary workstation functionalities.

Finally, during the training program period all user input should be recorded and documented. Training users can be difficult due to conflicting and busy schedules. One method is to develop a checklist where the trainer can evaluate and determine whether a user is properly trained to use a PACS component before signing off and allowing that user to perform daily clinical tasks on the PACS component. This provides for an accountability mechanism to ensure that users will take the time to receive the proper training before using the system.

PACS implementation planning

The following are three fundamental concepts for successful PACS implementation planning:

- Development of Implementation Workgroups crucial especially for large-scale implementations.
- Identify resources for the implementation process.
- Incorporate implementation planning tools.

Implementation workgroups can be broken down into subgroups as follows:

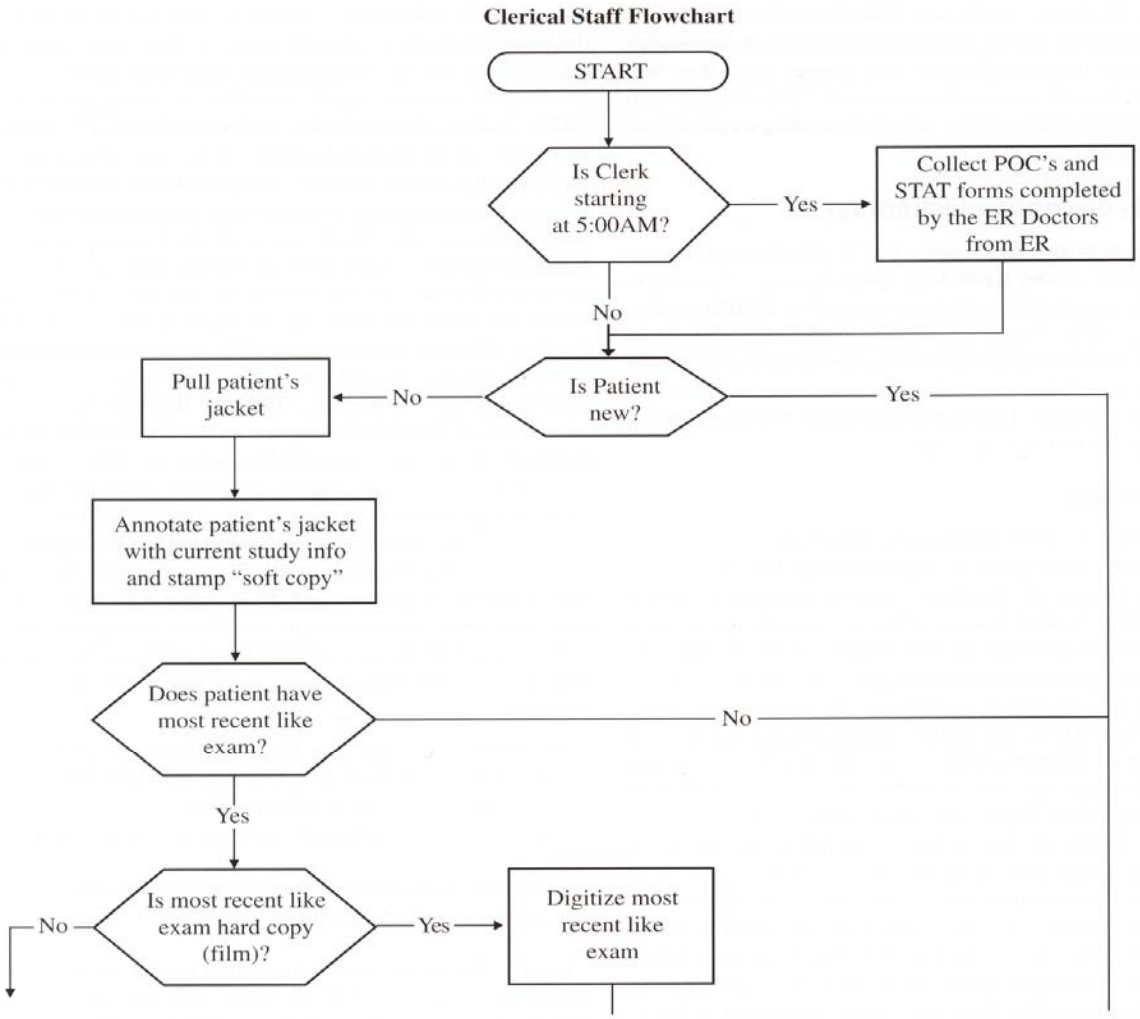

Figure 1. *An example of a portion of the new clerical workflow with PACS in flowchart form.*

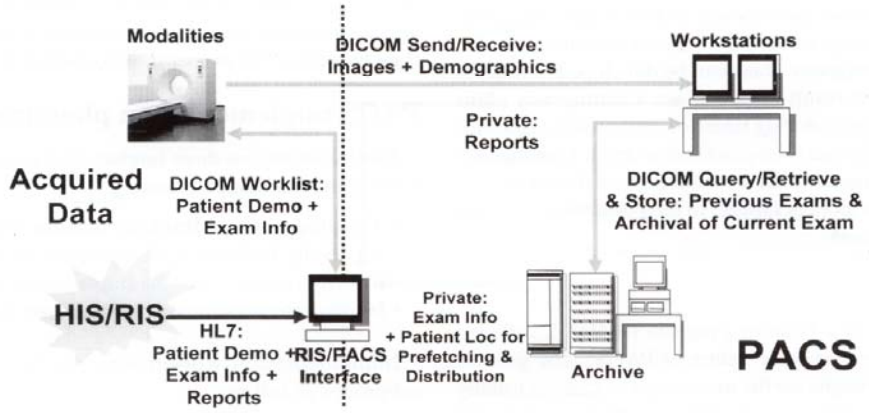

Figure 2. *An example of PACS data workflow*

UCLA PACS Implementation Project
Phase I Implementation Checklist
2/2/2005

Done	When	Who	WG	Event
xxxx	w.o 5/14/02	Brent	2	Review Modality Integration List
xxxx		Sandy	4	Review Locations for QC and Film Librarian workstations
xxxx		Brent	5	Review Reading Roondy
xxxx		Sandy	5	Identify & Schedule Appts with Radiology Section Heads
xxxx		Ric	5	Identify Physicians Customer List
xxxx		Sandy	5	Complete Demo/Survey of PACS monitors
xxxx		Kinchi	6	Follow up with new Network Device Purchases
xxxx		Kinchi	6	Setup UCLA Network Simulation with Demo Equipment
xxxx		Doug	All	Schedule Kickoff Meeting with GE: July 9th 1PM

Figure 3. *An example of a portion of a schedule and implementation checklist*

PACS Clinical Workstations

Clinical Area	Workstation Location	# of Monitors	Contact Person Info(Name, Phone #, E-mail, Position)	Scheduled Walkthru Date	Need Power?	Need Net.Drop?	PACS Rep	Training Rep	Comments
CHS. Riser B2 near O elevator. Across from B2-210.	**Riser B7-290. West Wing Elevator**								24Fibers to each riser.
ER Resusc. Site	BE-252	1B	Art Milberger, 57398 ER Coordinator		OK, but need **UPS** for Emergency Power	2 cables, 1 used, 1 open OK	Sandy		Adj. Console area has 4 cables, 3 used, 1 open. **DD: Together w/ ER Radiology Workstation Rollout**
ER Trauma Rm #14	BE-244	1B	Art Milberger, 57398 ER Coordinator		OK, but need **UPS** for Emergency Power	Add 4 new cables.	Sandy		**DD: Together w/ ER Radiology Workstation Rollout**

Figure 4. *An example of a portion of a grid to deploy clinical workstations.*

1) RIS/PACS interface and testing — Responsible for integration/testing for RIS/PACS interfaces including modality worklist.
2) PACS modalities and system integration — Responsible for technical integration of modalities with PACS and implementation of all PACS components.
3) PACS acquisition workflow and training — Responsible for developing workflow and training for clerical and Radiographer staff members. Responsible for any construction needed in the clinical areas.
4) PACS diagnostic workflow and training — Responsible for developing workflow and training for Radiologists and Clinicians. Responsible for any construction needed in the clinical diagnostic areas (e.g. Reading Room designs).
5) PACS network infrastructure — Responsible for all design and implementation of network infrastructure to support PACS.

These five workgroups can meet on a regular basis as needed and schedule any necessary meetings to develop the workflow and training program. From these five workgroups, one point person from each workgroup will form the core of the PACS Implementation Team. This team can contain additional members including the Project Manager, the Medical Director, the Administrative Director, IT representative, and Engineering/ Facilities representative. From this team, it shows how much PACS requires skills from various areas of expertise which no one single person can cover. This team should meet on a regular basis of at least every two weeks to update and status items and be made aware from the workgroups whether there are any potential stumbling blocks. In addition, these team meetings allow a forum for High-Level Administrators to observe the progress of the implementation.

Once the workgroups have been established, resources need to be identified to fill each of the roles. The following are some areas within the clinical environment to draw resources from:

- Radiographer Supervisor of each modality (e.g. CT, MR, US, and CR) — They are experts in the Radiographers workflow.
- Clerical Supervisor — The expert in clerical workflow.
- Film Librarian/Film Clerk — The expert in film distribution workflow.
- RIS Support Personnel — The expert in RIS for designing and performing interface testing.
- IT Network Support — The expert in the IT network infrastructure.

Because the PACS implementation covers a wide variety of expertise and skills, it is important to select the right people for the right job. Teamwork becomes extremely important all working towards the same goal. The success of a PACS ultimately rests more on the in-house staff support and ownership than it does on making the right vendor choice.

Because PACS implementation planning can be quite complex, implementation planning tools should utilized throughout the process. One key tool is the development of a schedule and implementation checklist. In this checklist, items such as task description, scheduled date for task, task owner, and mark for task completion should be included. Figure 3 shows an example of a portion of a schedule and implementation checklist. This template checklist allows for finer granularity to protect against overlooked implementation tasks and input from the PACS team can be documented. In addition, the checklist can be used to create subtask checklists (e.g. Workflow development, Training development, Go-Live) necessary for larger tasks.

An additional tool for large-scale implementation is a Workstation Deployment Grid. This grid allows for important information to be recorded and reviewed prior to the deployment of the workstation in its respective clinical area. This is especially important if there are a large number of workstations to be deployed. Within the grid, such key information such as clinical locations of workstation to be deployed, actual workstation locations, number of monitors, contact person, schedule deployment date, power, network, PACS and Training Representative assigned to the workstation and any additional comments can be entered and reviewed. Figure 4 shows an example of a portion of a workstation deployment grid. This grid was used to deploy workstations within the clinical areas of the entire hospital.

One of the most important parts of implementation planning is the development of an acceptance test plan to insure that the customer has received what has been promised by the vendor. The acceptance testing design methodology will be described in Part 2 (p.xxx) of the "Living with PACS" series.

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Invited Lecture

Living with PACS

Part 2: Acceptance test design methodology

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Abstract

Prior to system turnover of the PACS, one important key piece is the Acceptance Testing (AT) of a PACS. 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. 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. Together with proper planning and a robust AT plan of a PACS installation site, both can increase the utilization and satisfaction of a successful implementation of a PACS product that benefits both vendor and customer.

Key words: *PACS, Acceptance Test*

Introduction

It is difficult to judge how successful a particular implementation is within a healthcare institution 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.

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

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

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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 Radiographer/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 particularly 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) 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:

i) Archive Server
ii) Short-Term Archive Storage
iii) Long-Term Archive Storage
iv) DICOM Gateway or Image Acquisition Gateway
v) Diagnostic Workstations
vi) Review Workstations
vii) RIS/PACS Interface
viii) Web Server
ix) 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.

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:

i) Sharpness — The ability to identify high frequency structure within an image (e.g. interstitial lung markings, renal filling defects, bony trabecular markings)
ii) Brightness — The ability to display high brightness while maintaining best grayscale dynamic range
iii) Flicker — Perception of raster lines while viewing image (in CRT monitors)
iv) Angle of View — The ability to view an image at extreme side angles
v) 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 workstations 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 (e.g. radiographer, RIS support personnel, clerk). Verification of all necessary RIS and PACS data that are captured and stored in PACS (e.g. 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 (e.g. 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 vendors' 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:

i) Display of entire PACS exam from worklist selection.
ii) Query/Retrieve from short-term archive and ready for display on workstation.
iii) Query/Retrieve from long-term archive and ready for display on workstation.
iv) Multiple users query/retrieve from archive simultaneously.
v) Query/Retrieve multiple exam types from archive.
vi) 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 Care (SJHC) in Santa Monica, CA, USA. 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]

Table 1. *Performance Measurements for SJHC PACS.*

	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

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.

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:

i) Archive server: Stand-Alone vs. Client-Server
ii) Archive storage: RAID, Digital Tape, or MOD
iii) DICOM or acquisition gateway
iv) RIS/PACS Interface
v) Network Devices
vi) Web Server: Single vs. Clustered
vii) 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 (e.g. 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.

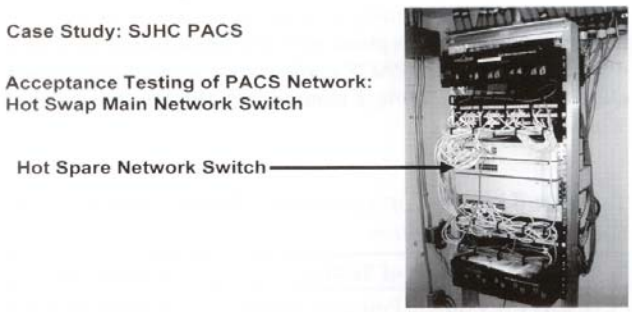

Figure 1. *Technical Testing of the Hot Spare Switch for SJHC PACS AT Plan.*

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:

i) Test description and method of testing
ii) Pass/Fail criteria and any additional comments
iii) Who performed the test
iv) 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 (e.g. 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.

6) 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.

Table 2. *Summary of Acceptance Testing Timeline and Implementation*

	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

Case Studies

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]

In another Case Study for the PACS implementation at University of California Los Angeles Medical Center, Los Angeles, CA, USA (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

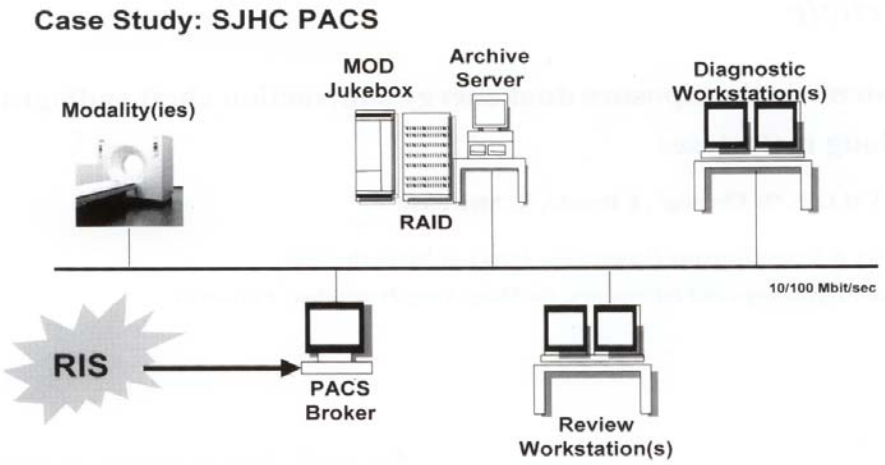

Figure 2. *PACS configuration for Saint John's Health Center in Santa Monica.*

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.

Conclusion

Together with Part 1 of this series of Living with PACS, this paper describes an overview of key PACS implementation strategy and development as well as the Acceptance Testing design and methodology. From the customer side, a carefully planned PACS implementation strategy and 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 PACS implementation strategy and 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. However, ultimately, the success of any PACS implementation rests on the in house staff development and planning efforts, training and support programs, and ownership of the PACS within the clinical environment.

References

1. Liu BJ, Huang HK, Cao F, Documet L, Sarti DA.Implementation of PACS and informatics in a community-sized hospital: making real-time radiology a reality, SPIE Medical Imaging, 4323-11, Feb. 2001.
2. Liu BJ, Documet L, Sarti DA, Huang HK, Donnelly J. PACS archive upgrade and data migration: clinical experiences, B. J. Liu, L. Documet, D.A. Sarti, H.K. Huang, J. Donnelly, SPIE Medical Imaging, 4685-14, Feb. 2002.
3. Liu BJ, Cao F, Zhou MZ, Mogel G, Documet L. Trends in PACS image storage and archive, Comput Med Imaging Graph. 2003; 27: 165-74.

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A HIPAA-Compliant Architecture for Securing Clinical Images

Brent J. Liu, Zheng Zhou, and H. K. Huang

The Health Insurance Portability and Accountability Act (HIPAA, instituted April 2003) Security Standards mandate health institutions to protect health information against unauthorized use or disclosure. One approach to addressing this mandate is by utilizing user access control and generating audit trails of the various authorized as well as unauthorized user access of health data. Although most current clinical image systems [e.g., picture archiving and communication system (PACS)] have components that generate log files for application debugging purposes, there is a lack of methodology to obtain and synthesize the pertinent data from the large volumes of log data generated by these multiple components within a PACS. We have designed a HIPAA-compliant architecture specifically for tracking and auditing the image workflow of clinical imaging systems such as PACS. As an initial first step, we developed HIPAA-compliant auditing system (H-CAS) based on parts of this HIPAA-compliant architecture. H-CAS was implemented within a test-bed PACS simulator located in the Image Processing and Informatics lab at the University of Southern California. Evaluation scenarios were developed where different user types performed legal and illegal access of PACS image data within each of the different components in the PACS simulator. Results were based on whether the scenarios of unauthorized access were correctly identified and documented as well as on normal operational activity. Integration and implementation pitfalls were also noted and included.

KEY WORDS: HIPAA, security, auditing, monitoring

INTRODUCTION

Health Insurance Portability and Accountability Act (HIPAA)[1,2] of 1996, Public Law 104-191, was officially instituted on April 14, 2003 to enforce healthcare providers to be compliant by April 2005 deadline. The major goal and focus of HIPAA is to set and enforce broad standards in the attempt to protect the privacy and security of health data throughout the patient care environment. To date, there are four types of standards in HIPAA:

1) Transaction and code set standards
2) Identifier standards
3) Privacy standards
4) Security standards

In this paper, we focus on the fourth standard type—security. HIPAA Security Standards[3] are aimed at the protection of confidentiality, integrity, and public availability of electronic health information against unauthorized use or disclosure. This is accomplished by utilizing administrative, physical, and technical safeguards. In particular, the technical safeguards consist of technical methods to assure security of the health data. One such technical method proposed by HIPAA is the on-demand generation of an audit trail that can record and examine information system activities such as data access of a specific patient. Specifically, HIPAA-compliant audit trails require the following information for the health data access:[4]

- Identification of the person who accessed the data
- Identification of the accessed data
- Where the data were accessed
- Timestamp of when the data were accessed

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- Types of access (e.g., create, read, write, modify, delete)
- Status of access (e.g., success or failure)

Because health data and information is such a broad area containing vast amounts of data types, the major focus of this research is on clinical imaging data that are generated and distributed through picture archiving and communication system (PACS).

Some efforts have been achieved by developing HIPAA-compliant auditing tools for general health information systems.[5–7] These auditing tools generate audit trails by recording the health data transactions or changes in logs and extracting the pertinent auditing information from these logs on demand. This method is applicable for health information systems that have all the data transactions or data flow controlled by a centralized server, such as radiology information system.[8] However, the data flow is much different in integrated medical imaging systems, such as PACS. There is no single component that controls and records the data flow of all the multiple components within PACS. This makes it very difficult for these auditing tools to record all the data transactions and changes in PACS. For example, the PACS archive server, even within client–server architecture, has no control of the workflow of the CT modality and vice versa. Additionally, there are various other components within a PACS that require a system-wide architecture instead of a single component-based approach. Most current clinical imaging systems have no such ability to generate HIPAA-compliant audit trails, although they generate activity logs. Furthermore, although pertinent auditing information can be extracted from these logs to create audit trails, it requires tedious if not manual methods to produce the requested audit information and analysis. There is a lack of a formal methodology to interpret the potential large volumes of these log data and generate these HIPAA-compliant audit trails. Therefore, a HIPAA-compliant auditing architecture for integrated medical imaging systems needs to be tailored to the complex workflow.

In this research, we present the design and development of a HIPAA-compliant architecture specifically for tracking and auditing the image workflow of clinical imaging systems such as PACS. The architecture is designed to facilitate the generation of HIPAA-compliant audit trails of image data access for a specific patient so that various types of audit queries can be performed on demand. It also provides the mechanisms to automatically monitor the data flow of PACS and to facilitate the detection of unauthorized image access and other abnormal activities. As an initial first step, HIPAA-compliant auditing system (H-CAS) was developed based on parts of this HIPAA-compliant architecture. This initial H-CAS was implemented and evaluated within a test-bed PACS simulator located in the Image Processing and Informatics (IPI) lab at the University of Southern California.[9] Evaluation scenarios were developed, and results were based on whether the scenarios of unauthorized access were correctly identified and documented as well as on normal operational activity.

METHODS AND MATERIALS

Design Criteria

To apply the HIPAA-compliant architecture for auditing and tracking clinical images to various PACS generating different format log files, it must be independent from any individual PACS architecture or manufacturer. For this reason, we define the necessary architecture criteria as follows:

(1) HIPAA compliant. The ability to facilitate generation of the HIPAA-compliant auditing trail report in terms of who accesses it, when, where, what are accessed, access status, and access types.
(2) Open and extensible. Provide interfaces for integration of new auditing or monitoring techniques and the ability to support current HIPAA auditing requirements and accommodate new HIPAA additions in the future without affecting already existed components.
(3) Portable. Not tied down to any individual PACS or PACS architecture.
(4) No interruption of clinical PACS workflow. Any interruption on the workflow of PACS is avoided.

HIPAA-Compliant Architecture Design

Based on the criteria described above, the HIPAA-compliant architecture was designed as a four-layer system shown in Figure 1. The first layer (the lowest layer) is the record layer, consisting of various logs within PACS components. By logically separating PACS logs from other logs and layers, independence from PACS and portability can be achieved. The second layer is the audit layer, which includes a centralized auditing database and other audit data analysis and interpretation tools. HIPAA-compliant audit trails can be generated

based on the auditing database. This layer also enables us to automatically monitor the data flow of PACS, which greatly assists PACS management. The third layer is the notification layer, which has a notification component sending warning or alert messages of abnormal events to end users, such as PACS administrators. Finally, in the fourth layer, end users can decide to take certain actions against these abnormal events. These layers will be described in more detail in the following paragraphs.

Record Layer

This first layer is the data resource layer, including but not limited to the various types of log data shown in Figure 1. PACS application logs are event logs generated by the individual PACS applications. For example, an image query/retrieve event in PACS archive server may include such information as time, local host name, Digital Imaging and Communications in Medicine (DICOM) application entity title, patient information, and query/retrieve status. In addition, PACS "user logs" record any login events of users for each individual PACS component. Other computer system logs generated in PACS components, such as application access logs, can also provide supplement information.

Because of the flexibility of this architecture, new logs can also be added to this layer. For example, an image integrity log can be added to record image data integrity verification events. Data integrity, as one requirement of HIPAA Security Standards, refers to protecting image data from being altered or destroyed by unauthorized users. A lossless digital signature embedding (LDSE) method has been developed to ensure the data integrity of medical images at IPI laboratory.[10] By recording signature verification time, local machine, and signature verification status in the integrity log, the LDSE method can provide logs to generate HIPAA-compliant audit trails on the data integrity of image.

To extract and interpret the pertinent information from thousands of log events requires proper methodology, which will be addressed in the second layer, the audit layer.

Audit Layer

As shown in Figure 1, the audit layer is the heart of the architecture. It collects the audit data from distributed PACS components and stores the data in a centralized auditing database. The database is then used for audit analysis and automatic monitoring. Currently, there are seven components in this layer: audit log collector, syslog server, log data norlmalizer, auditing database, audit analysis tool, role-based policy, and monitor tool.

Audit Log Collector. Because the audit data are scattered within large volume of logs, a collector was designed to extract the pertinent data from logs and send the data to the centralized auditing database. PACS logs may be stored with different

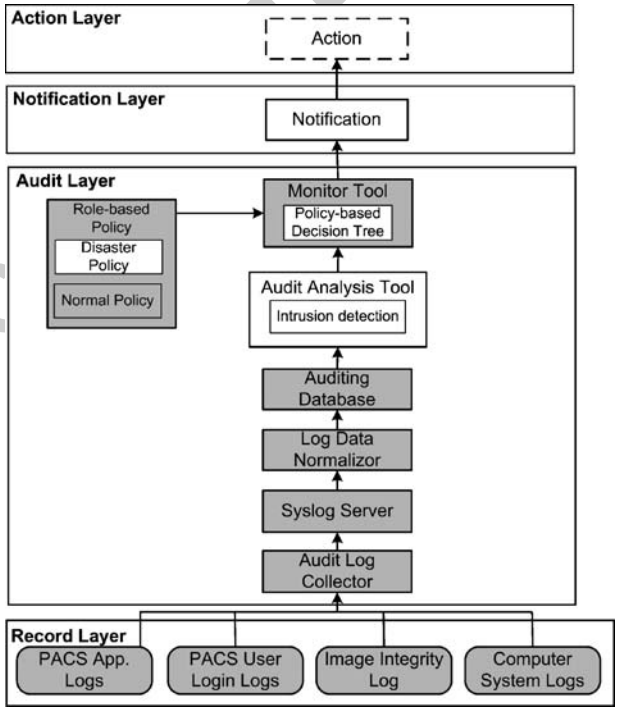

Fig. 1. The four-layer HIPAA-compliant architecture for auditing of medical images in PACS showing various components for each layer: (1) record layer, (2) audit layer, (3) notification layer, and (4) action layer. Shaded components represent already developed components of H-CAS.

formats, such as database tables or textual files. The collector should be designed to support the various types of logs.

System Log (Syslog) Server. The pertinent data extracted from PACS logs are distributed in different PACS components connected by digital networks. To store them in the centralized auditing database, a transmission mechanism is needed.

Currently, syslog[11] is a de facto standard for transport and storage of event notification messages in UNIX and Windows-based systems, network devices, and network applications. Syslog is a client–server mechanism. The clients can be configured to locally store event messages or directly send event messages to the server without local storage. Syslog uses user datagram protocol to transfer event messages. This feature can be utilized to reduce the overhead added to the image transmission in PACS caused by event message communication because PACS uses DICOM protocol and transmission control protocol. For this advantage, syslog technology was adopted as the architecture standard to transfer pertinent log data. The data are converted to syslog format by the syslog client in each PACS component. The client then sends the data to syslog server, which will forward the data to the log data normalizer.

Log Data Normalizer. The pertinent data extracted from PACS components might have different terminologies for the same object. For example, the name "film librarian" in the CT modality might be named as "clerk" in an MR modality. For this reason, a log data normalizer was designed to normalize the data into common terms and then add them to the auditing database. The current dictionary contains some of these object classifications and is designed to be scalable to support additional objects in the future.

Auditing Database. To generate HIPAA-compliant audit trails in a short time, a centralized database was designed to preserve all the obtained auditing data. The structure of database was designed based on the requirement of HIPAA-compliant audit trails, including who, when, where, what, how, and status. Patient information, such as name and id, and other relevant information are also included in the database. The advantages to use database technology to preserve the log data are as follows:

- No loss of historical logs. Because all the logs generated in PACS components are obtained and stored in the database everyday, there is no loss of log data when these logs are updated by PACS components.
- Centralized management of data access information. The image data access events for an individual patient usually happen in multiple PACS components. For example, an event that a CT image is generated in a CT modality and another event that the same CT image is retrieved to viewing workstation for clinical review are related to the same patient. But these two events were recorded in two different logs at two separate PACS components. This pertinent information will need to be extracted from these two components every time HIPAA-compliant audit trails of image access for this patient are desired. Therefore, a centralized database design enables us to quickly generate audit trails in one centralized location where data are stored.

The auditing database design contains three tables: event, patient, and study. The relationship among them is shown in Figure 2.

- The event table contains seven columns: Event_No, Event_Type, Event_Location, Event_Time, Event_Status, Event_User, and Patient_No. The Patient_No column is a link that connects to the Patient_No column in the second table, the patient table.
- The patient table contains five columns: Patient_No, Patient_Name, Patient_ID, Patient_Sex, and Patient_Age.
- The study table contains five columns: Study_No, Study_InstanceUID, Accession_Number, Modality, and Patient_No, which is a link between the study table and the patient table.

The relationship between the patient table and the event table is 0 or 1 to 0 or more because a single patient can be associated with multiple events that access the data of this patient. The same relationship is between the patient table and the study table because a single patient can contain multiple studies. Whenever an event occurs where a study is accessed in PACS, the auditing database records the information to these three tables accordingly.

Audit Analysis Tool. Most current PACS lack a mechanism to dynamically monitor the data flow, which results in PACS management mostly relying on the experience of PACS administrators. A monitoring tool that can automatically analyze the data to find abnormal patterns and make decisions

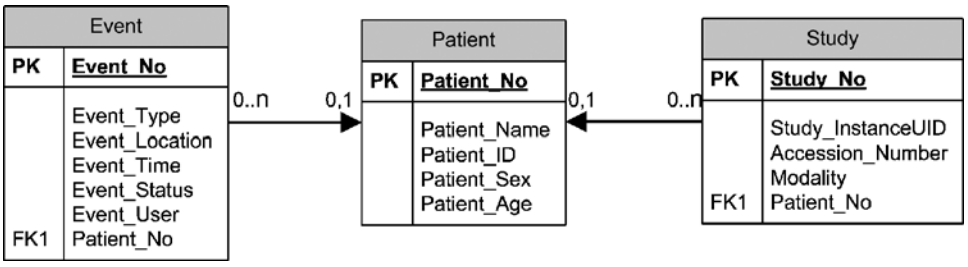

Fig. 2. E–R model of the auditing database in the audit layer of the HIPAA-compliant architecture. Three tables and their relationships are shown: (1) event table; (2) patient table; and (3) study table. PK: primary key. FK: foreign key.

on the patterns would make PACS management much easier. To develop such a tool, the information of data flow of PACS needs to be collected and analyzed in real time. With audit data collected in the auditing database, the HIPAA-compliant architecture can provide this ability using some data analysis techniques, such as intrusion detection technology.[12] Audit analysis tool is the component to perform such data analysis functions.

Monitor Tool. After the audit analysis tool finds abnormal patterns in the data flow of PACS, a monitor tool was designed to monitor the pattern and make decisions whether it is an unauthorized data access for the abnormal pattern based on the role-based policy. Any pattern that violates the policy would automatically cause a warning or alert result. For example, audit analysis tool discovers an abnormal pattern of image query/retrieve by a PACS user "A", belonging to the role of "Clerk", which was defined to have no image query/retrieve right in the policy. The monitor tool automatically makes a decision that this is an unauthorized image query/retrieve and gives a warning message.

Role-Based Policy. The role-based policy defines the roles for PACS users based on the roles they performed in the clinical environment, such as clerk, PACS manager, and radiologists, and the image access rights for each role. Two types of policies, normal policy and disaster policy, are defined for two different conditions. Normal policy is for daily operation, whereas disaster policy is defined for the emergency situations, such as earthquake, when normal policy can be bypassed.

Notification Layer

Notification layer consists of a notification component, which receives the warning or alert messages from the audit layer and notifies PACS end users of the unauthorized image data access and other abnormal activities.

Action Layer

Action layer is designed for PACS end users to take actions, such as access control, against the unauthorized image access and other abnormal activities. This four-layer architecture enables PACS to generate HIPAA-compliant audit trails of image data access for a specific patient on demand. Meanwhile, it can automatically monitor the data flow of PACS facilitating PACS management. With an open and extensible design, the architecture can also easily incorporate new data analysis and monitoring techniques and be extended to support future HIPAA requirements.

PRELIMINARY RESULTS AND DISCUSSION

A H-CAS has been developed for automatic monitoring of the data flow of PACS based on partial components of the audit layer in the architecture. The H-CAS and its graphic user interface (GUI) were installed in a LINIX machine. H-CAS currently includes such components as audit log collector, syslog server, auditing database, monitor tool, and role-based policy (normal policy). These components are represented by the shaded boxes in Figure 1. H-CAS can monitor the dynamic data flow of PACS. First, it collects pertinent auditing data from PACS application logs, PACS user login logs, and other computer system logs. It then stores the log data in the auditing database. Next, a comparison is made of the user name in every record in the auditing database and the user name in the policy table. If a match occurs, further comparison is made with the application name in the database record and the application name in the policy table. If any comparison fails, the H-CAS gives out a warning message of unauthorized image data access in its GUI. Otherwise, a normal message is given out. In addition, H-CAS can generate HIPAA-compliant audit trails of image data access for a specific patient.

Integration with PACS Simulator in a Laboratory Environment

To evaluate the impact of H-CAS in PACS, a laboratory-based PACS simulator[13,14] was implemented with the toolkit to simulate the data flow of clinical PACS. The simulator can simulate the complete data workflow of clinical PACS from patient registration to exam ordering and to image generation, image archive, and display. The clinical images used for simulation are replenished continuously through a clinical PACS connection but with the patient information in the DICOM header of the image removed. Figure 3 shows the integration of H-CAS with the PACS simulator for evaluation.

The log collector clients are installed in every component to receive event messages of each image data access activity generated by these components. Log messages generated are automatically collected and inputted into the H-CAS via the syslog server. The log data include what, when, and where images are accessed. In addition, user login logs and computer system logs are collected. All pertinent log information are collected and stored in the centralized auditing database. As with any PACS, log data can be

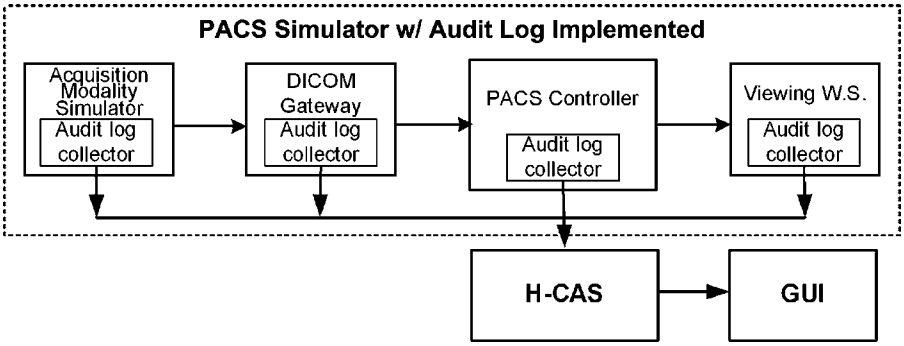

Fig. 3. H-CAS implemented with the PACS simulator in the laboratory environment showing log collector clients at each of the PACS simulator components.

stored in different formats. For example, the log data of the acquisition modality simulator (AMS) are stored in the Microsoft access database, whereas the log data of the PACS controller are stored in the Oracle database. The user login information and application access information from the computer system logs of the DICOM gateway and viewing workstations were also collected and can be from different operating systems such as Windows and UNIX. An interface is developed to extract each of the different log data and integrate it within the H-CAS SQL auditing database. All data logs are sent to the centralized H-CAS where analysis is performed. A user-friendly GUI application was developed in conjunction with H-CAS to understand the HIPAA audit trails concept by searching H-CAS for data access events on a specific patient or user. In addition, it also provides a set of features allowing users to configure the role-based policy and dynamically monitor the image data flow of the PACS simulator based on the policy.

Evaluation Methodology

Test Scenario Design

Test scenarios for laboratory evaluation of the H-CAS are anchored around creating a clinical simulation of the PACS workflow from exam generation to the retrieval of exams for clinical review. According to the perspective of clinical end users, two categories of test scenarios were designed for the evaluation.

- Category 1: Background scenarios
- Category 2: On-demand scenarios

Category 1 background scenarios are basically automatic storage functions, such as DICOM gateway sending images to PACS archive server, whereas category 2 on-demand scenarios are requests issued by end users, such as image query/retrieve at viewing workstations. To simulate clinical 24/7 image automatic storage, a loop process was designed to repeatedly send various types of modality images, such as CT, MR, CR, and ultrasound images, to DICOM gateway, which automatically forwards the images to PACS controller. One example of a category 2 test scenario is performing an on-demand query/retrieve from the viewing workstations.

Experiment Description

During the laboratory experiments, H-CAS was tested with five CT exams, five MR exams, and five CR exams. Table 1 tabulates the test data. Three scenarios were performed in the experi-

t1.1 **Table 1. Exams tested in the laboratory experiments**

t1.2		CT exams	MR exams	CR exams	Total
t1.3	No. of exams	5	5	5	15
t1.4	Total images	186	288	11	485
t1.5	Average no. of images per exam	37.2	57.6	2.2	
t1.6	Data size (MB)	93.9	53.0	83.3	230.2

ments: (1) AMS simulates generation of an exam; (2) DICOM gateway automatically forwards the exams to the PACS controller; and (3) the viewing workstations query/retrieve the exams for clinical review. Scenarios 1 and 3 are in the active category 2, whereas scenario 2 is a passive category-1-type scenario. Most of the experiments were performed with all three scenarios in the order of 1, 2, and 3. Some experiments only included one or two scenarios performed in random order. The experiments were conducted over a 6-month period.

Examples of Results

Two examples of results are shown in Figures 4 and 5.

The first example shows H-CAS searching the auditing database to generate a HIPAA-compliant audit trail based on a given patient name "Jim Johnson." Two operations need to be performed to generate the audit trail for a patient. First, search the patient in the database with "Patient Name" or "Patient ID". In this case, "Patient Name" was chosen. The GUI supports wildcard searching; therefore, a "J" was typed in the search field to search the patient with the first name starting with "J". A list of patients matching the search criteria was returned in a new popup window. Next, the patient name "Jim Johnson" was selected. A HIPAA-compliant audit trail is then generated as seen in Figure 4. As shown in Figure 4, line 1 shows an example of scenario 1, where the user "PACS" performed a MR exam generation at the modality simulator "ipi-pc2" on "2004-11-15 15:40." Line 2 shows an example of scenario 2, where the DICOM gateway stored the exam in the PACS controller. Line 4 shows an example of scenario 3, where the user "Tech" performed a DICOM query/retrieve of the exam at the viewing workstation "IPI-VIEW."

Figure 5 shows a second example of results of dynamic monitoring of the image data flow of the PACS simulator. Two types of results, "Normal" or "Warning," were given for each data access event based on the role-based policy.

The role-based policy is defined and configured prior to using the monitoring function and is based

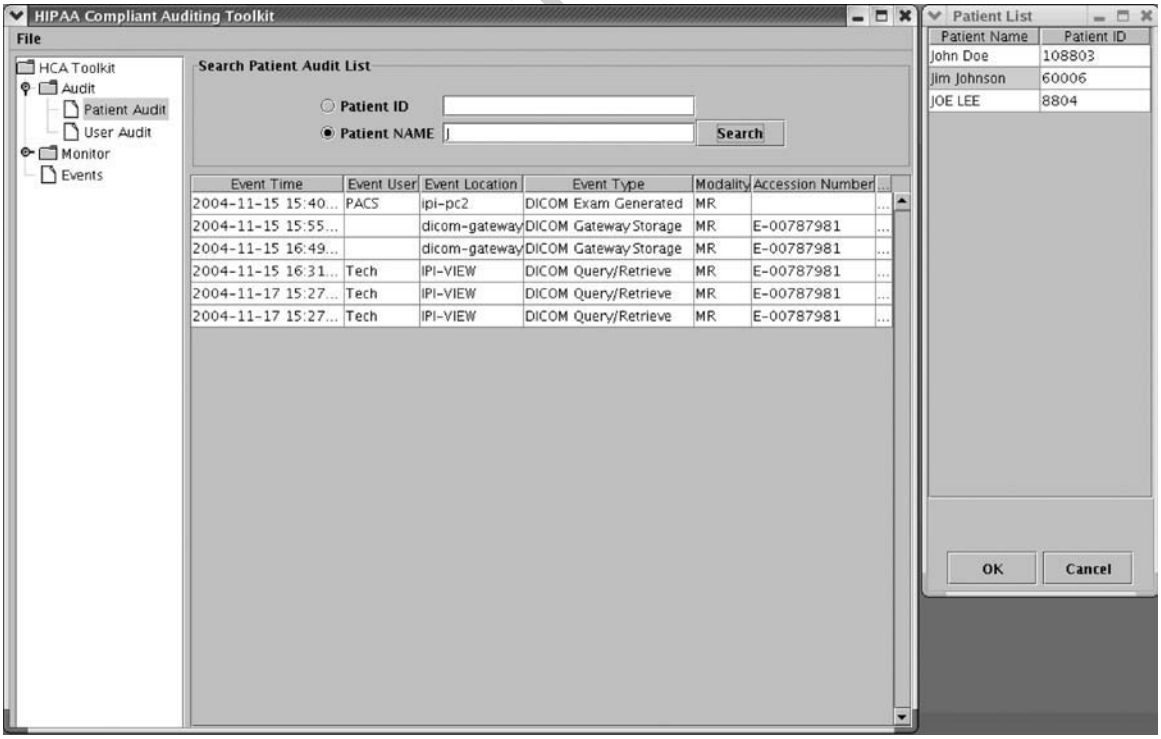

Fig. 4. Example of generating the HIPAA-compliant audit trails for a patient "Jim Johnson", who is shaded in the list on the right.

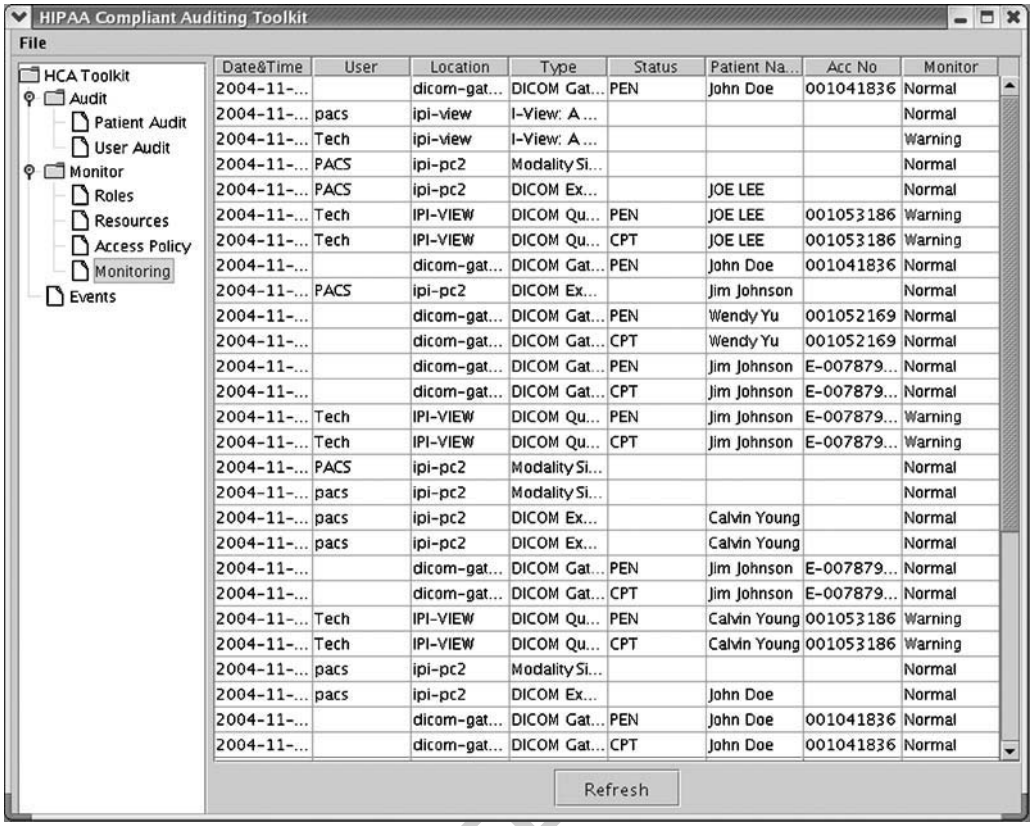

Fig. 5. Example of the dynamic monitoring of the image data flow of the PACS simulator based on the role-based policy.

on each institution's own access policy. The GUI of the toolkit provides users an interface called "Access Policy" to add, modify, or delete the role-based policy. Table 2 lists an example policy used in the experiments. In this case, user "Pacs" was defined as "PACS administrator" with the right to perform all the applications in the PACS, whereas user "Tech" was defined as "Technician" with the right to perform the exam generation in the modality simulator. For this particular experiment, it would be a violation of the policy if user "Tech" performed the exam query/retrieve at the viewing workstation designated only for radiologists. The "Warning" in the sixth row in Figure 5 indicates that a violation occurred when user "Tech" retrieved an exam with patient name "JOE LEE." Because it is sometimes necessary at a particular institution for a user "Tech" to perform query/retrieve at the radiologist's workstation, the role-based policy is flexible to accommodate each institution's own particular access policy to allow such a function for the user "Tech."

Table 2. Example of a role-based policy table where "all" indicates access to all components within the PACS simulator

User name	Role name	Resources
Pacs	PACS administrator	All
Clerk	Film clerk	Viewing workstation
Rad	Radiologist	All
Tech	Technician	AMS

The events shown in Figure 5 are all examples of the three scenarios developed. For example, line 1 is an example of scenario 2, line 2 is an example of scenario 3, and line 5 is an example of scenario 1.

Discussion

Three testing scenarios have been developed for the laboratory evaluation of the H-CAS integrated with the PACS simulator. For the evaluation of the function of generating HIPAA-compliant audit trails, the results from active category 2, scenarios 1 and 3, are more important than the ones from passive category 1, scenario 2, because of the

increased likelihood of HIPAA security violation when humans are involved. On the other hand, all three scenarios are almost equally important for the dynamic monitoring because any unreported event may indicate a failure in the image data flow. The three scenarios developed are the most typical data flow in PACS and can represent most of the processes in PACS. However, one important process, image storage or archive, was not included in the testing. The image storage is very important to both evaluated functions of H-CAS because the stored image data could be compromised without detection. By integrating image integrity logs at the record layer, this image storage issue can be solved.[10]

To give an approximate estimate of the number of records that can be collected by the H-CAS, we assume that a community-sized hospital generates about 150,000 imaging studies per year. In addition, assuming each exam is accessed an average of five times (once at the modality, once at the PACS server, once in the diagnostic reading workstation, once in the reviewing workstation for the referring physician, and once as a historical review), there will be a total of 750,000 records in the event table, 150,000 records in the study table, and, assuming an average of two exams per patient, 75,000 records in the patient table yearly.

The current H-CAS functionality of dynamic monitoring is still limited. A more sophisticated monitoring system can be developed using intrusion detection technology and policy-based decision tree approaches. The role-based policy can also be improved to a multiple-factor-based policy instead of a single role-based one. In addition, robust and well-formatted logs generated by PACS and imaging modalities would greatly enhance H-CAS functions.

CONCLUSION

The advent of HIPAA greatly impacts medical imaging systems, such as PACS, and even the entire health information systems. To be HIPAA-compliant, every medical imaging system must satisfy the HIPAA requirement of audit trails.

In this research, we presented a HIPAA-compliant architecture for auditing medical images in PACS. The architecture enables PACS to generate HIPAA-compliant audit trails of image data access for a specific patient on demand. It also enables PACS to automatically monitor the image flow in the system, including detection of unauthorized usages of image data and other abnormal activities. As an initial first step, a H-CAS has been developed partially based on the audit and record layers of this architecture. H-CAS can automatically monitor the image flow in PACS and the ability to generate HIPAA-compliant audit trails. A PACS simulator was integrated with the H-CAS for laboratory evaluation. An evaluation methodology was developed, and test scenarios were designed accordingly to perform the evaluation. Evaluation is currently ongoing with promising initial data results.

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REFERENCES

1. HIPAA, http://www.cms.hhs.gov/hipaa/hipaa2/general/background/pl104191.asp
2. HIPAA, http://www.rx2000.org/KnowledgeCenter/hipaa/hipfaq.htm
3. HIPAA Security Standard, 2003, http://www.cms.hhs.gov/hipaa/hipaa2/regulations/security/03-3877.pdf
4. Cao F, Huang HK, Zhou XQ: Medical image security in a HIPAA mandated PACS environment. Comput Med Imaging Graph 27(2–3):185–196, 2003.
5. HIPAA audit, http://www.datamirror.com/products/liveaudit/
6. HIPAA audit tool, http://www.axolotl.com/press/20021113/
7. HIPAA audit tool, http://www.peacefulpackers.com/it_solutions/hs2.htm
8. Huang HK: PACS: Basic Principles and Applications. Wiley-Liss, p 291
9. Zhou Z: Lossless Digital Signature Embedding for Medical Image Integrity Assurance, Ph.D. Dissertation, Chap. 5–6, July 2005
10. Zhou Z, Huang HK, Liu B: Digital signature embedding for medical image integrity in a data grid off-site backup archive. SPIE Med Imaging 6:306–317, 2005
11. Syslog, http://www.loriotpro.com/Products/SyslogCollector/SyslogDataSheet_ENv3.php
12. White GB, Fisch EA, Pooch UW: Computer System and Network Security. Boca Raton, FL: CRC Press, 1996
13. Law MYY, Zhou Z: New direction in PACS education and training. Comput Med Imaging Graph 27:147–156, 2003
14. Zhou Z, Huang HK, Cao F, Liu BJ, Zhang J, Mogel GT: Educational RIS/PACS simulator. SPIE Med Imaging 4:139–147, 2003

Fuzzy clustering in CAD of multiple sclerosis*,

*Article in press in journal: E & I Elektrotechnik und Informationstechnik, by Springer

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Summary. Segmentation methodology of magnetic resonance images is developed to assist radiologists during the detection of demyelination lesions in multiple sclerosis. The results of automatically performed analysis may be adjusted. A 3D visualization is available for a fast examination. The solution may also be implemented in e-learning and case study repository.

1 Introduction

Multiple sclerosis (MS) is an inflammatory demyelinating disease of the central nervous system. It is characterized by multiple plaques of demyelination in the white matter of the brain and spinal cord. The primary lesions are found in the prevascular space along penetrating veins. As white matter lesions increase over the time, the disease frequently becomes chronically progressive. Accumulating neurological deficits ultimately lead to permanent disability. Northern Europe and the northern United States have the highest prevalence with more than 30 cases per 100 000 people. The clinical diagnosis is based on magnetic resonance image analysis.

In MR imaging the multiple sclerosis lesions appear with high signal intensity on FLAIR, PD-WI, and T2-WI sequences. Low signal intensity appears on T1-WI, yet they may also show a hyperintense border. Lesions in MS can be small, large, or confluent.

Automated methods of MR brain segmentation have already been developed. Volume measures the global white matter lesion [1], as well as segmentation of plaques in MS [2], [3] employ both fuzzy and non-fuzzy approaches. However, none of the system permits for correction of the segmentation results.

In the current study a fuzzy clustering method with median modification have been implemented in order to segment out the lesion. After an adjustment performed interactively the area is measured. If 3 mm continuous slices are

acquired, a volume measure can also be accessed. Remote access framework has been discussed.

2 Fuzzy clustering

Classical methods implemented in the segmentation of lesions yield crisp edges which usually can not be adjusted by the user at the diagnostic process. Since the appearance of plaques may differ, users interaction is required. Thus, a fuzzy clustering approach has been implemented in order to allow a user to easily modify selected elements of the partition matrix corresponding to certain lesions.

2.1 Fuzzy c-means clustering

Fuzzy c-means method ([4]) partitions a set of observed data vectors $\mathbf{x}_k$ into c-clusters. Each cluster is represented by its prototype $\mathbf{v}$.

Let $\mathbf{x}_k = (x_i, \ldots, x_n)$ be an observed data vector of $\{\mathbf{x}_k\}_{k=1}^N$ data set in feature space $\mathbf{F}^n$.

Standard FCM is derived to minimize the objective function:

$$J(\mathbf{U}, \mathbf{V}) = \sum_{i=1}^{c} \sum_{k=1}^{N} u_{ik}^m ||\mathbf{x}_k - \mathbf{v}_i||^2 \qquad \mathbf{x}_k, \mathbf{v}_i \in \mathbf{F}^n \tag{1}$$

with respect to the partition matrix element u_{ik} and the centre of the i-th cluster – $\mathbf{v}_i$ and for a given fuzzyfication level m ($1 \leq m < \infty$).

Values u_{ik} are positive and fulfil: $\sum_{i=1}^{c} u_{ik} = 1 \forall k$, $u_{ik} \leq 1$.

The FCM clustering is performed iteratively, starting with a set of c initially given prototypes and fuzzyfication level m. In each step a new matrix of $\mathbf{U}$ is created. For samples that belong also to the set of prototypes, values of u_{ik}, that minimize the corresponding part of cost function are:

$$u_{ik} = \begin{cases} 1, \mathbf{x}_k = \mathbf{v}_i \\ 0, \text{ otherwise} \end{cases} \tag{2}$$

And for the remaining partition matrix elements:

$$u_{ik} = \frac{||\mathbf{x}_k - \mathbf{v}_i||^{\frac{-2}{m-1}}}{\sum_{j=1}^{c} \left(||\mathbf{x}_k - \mathbf{v}_j||^{\frac{-2}{m-1}} \right)} \tag{3}$$

The membership matrix $\mathbf{U}$ is later employed to compute a new set of prototypes as a weighted mean of points and corresponding membership function values:

$$v_i = \frac{\sum_{k=1}^{N} u_{ik}^m \, \mathbf{x}_k}{\sum_{k=1}^{N} u_{ik}^m} \text{(centre of i-th cluster)} \tag{4}$$

The procedure is repeated until the desired accuracy of $\mathbf{V}$ is obtained, i.e. $max(|\mathbf{V}_i' - \mathbf{V}_i|) < \epsilon$.

In an image processing, a lack of spatial context of information in a grey-level-based FCM reduces its robustness in a presence of noise. Outliers influence both membership function and prototypes calculations. Although an introduction of pixel coordinates improves the clustering accuracy, the overall complexity of the process increases. Moreover, similar structures of different regions of an image may be partitioned into different clusters.

2.2 Median modification

Chen and Zhang [5] have modified the objective function of FCM (eq. 1) by introducing an element, that depends on the mean value of neighbouring pixels. Thus:

$$J(\mathbf{U}, \mathbf{V}) = \sum_{i=1}^{c} \sum_{k=1}^{N} u_{ik}^m ||\mathbf{x}_k - \mathbf{v}_i||^2 + \alpha ||\tilde{\mathbf{x}}_k - \mathbf{v}_i||^2 \tag{5}$$

where $\tilde{\mathbf{x}}_k$ is a mean of pixels within a predefined neighbourhood $\mathbf{x}_k$, and α controls the 'strength' of modification.

Since the modification propagates features of a mean filtered image into the clustering results, blurred edges are one of the most important disadvantage of the method.

In order to reduce the drawbacks, the mean estimator in eq. 5 has been replaced by a median estimator.

In the image processing procedure, an implementation of the median running-window filtering replaces each data sample by its spatial neighbourhood function, defined as:

$$MEDF(x; Z) = median(S), \tag{6}$$

where $S = neighbourhood(x, Z)$, and Z is the size of the mask.

Median of a set $\{x_1, \ldots, x_n\}$ is an M-estimator of location. Its cost function is given as [6]:

$$J(\Psi) = \sum_{i=1}^{N} |x_i - \Psi| \tag{7}$$

i.e. $median(\{x_1, \ldots, x_N\}) = \widehat{\Psi} = \arg \min_{\Psi} J(\Psi)$.

Median of an ordered data set $A = \{x_1', x_2', \ldots, x_N'\}$ is defined as:

$$median(A) = \begin{cases} x'_{(k+1)/2}, & k = 1, 3, 5, \dots \\ 0.5(x'_{k/2} + x'_{k/2+1}), & k = 2, 4, 6, \dots \end{cases} \tag{8}$$

An implementation of the median component into eq. 1 results in:

$$J(\mathbf{U}, \mathbf{V}) = \sum_{i=1}^{c} \sum_{k=1}^{N} u_{ik}^m ||\mathbf{x}_k - \mathbf{v}_i||^2 + \alpha ||MEDF(\mathbf{x}_k; Z) - \mathbf{v}_i||^2 \tag{9}$$

$$\tag{10}$$

A local minimum is obtained if (cf. eq. 3, 4):

$$u_{ik} = \frac{(||\mathbf{x}_k - \mathbf{v}_i||^2 + \alpha ||\mathbf{y}_k - \mathbf{v}_i||^2)^{\frac{-1}{m-1}}}{\sum\limits_{j=1}^{c} \left((||\mathbf{x}_k - \mathbf{v}_j||^2 + \alpha ||\mathbf{y}_k - \mathbf{v}_j||^2)^{\frac{-1}{m-1}} \right)} \tag{11}$$

$$v'_i = \frac{\sum\limits_{k=1}^{N} u_{ik}^m (\mathbf{x}_k + \alpha\, \mathbf{y}_k)}{(1+\alpha) \sum\limits_{k=1}^{N} u_{ik}^m} \tag{12}$$

where $\mathbf{y}_k$ denotes $MEDF(\mathbf{x}_k; Z)$.

In summary, the algorithm can be described as:

1. fix c $(1 < c < N)$, $m \in [1, \inf)$. Initialize $V^0 \subset \mathbf{F}^n$. Initialize $j = 0$
2. $j = j + 1$
3. calculate $U^{(j)}$, using eq. 11 and $V^{(j-1)}$
4. update $V^{(j)}$, using eq. 12 and $U^{(j)}$
5. if $||V^{(j)} - V^{(j-1)}|| > \epsilon$, then go to 2

3 Interactive adjustment

The graphical user interface with a 3D-rendering ([7]) has been designed for two different working modes: fully automated and interactive. The automated mode starts the image analysis and the results are shown to the user as a sequence of slices with highlighted lesions. Then, the interactive mode can be selected. It permits for the adjustment of the segmentation of the plaques.

3.1 The automated mode

In the automated mode the following steps are performed. First, the brain tissue is segmented out of the MR images. At this stage a two-class-FCM clustering approach is applied. The clustering results are subjected to morphological operations of erosion and filling holes followed by an automatic decision process which preserves the largest object.

Then, the plaques segmentation is performed by a median modified FCM clustering procedure. Demyelination lesions are recognised if the element of the membership matrix exceeds 0.5. Next, the unwanted segmented areas are discarded based on location and size. At this stage small artefacts at the edge of white/grey matter and CSF are removed.

Finally, the extracted plaque edges are subjected to a content based analysis. A median of the plaque edge is found and used as a local threshold value. It sharpens the lesion edges and removes pixels belonging to the surrounding brain tissue.

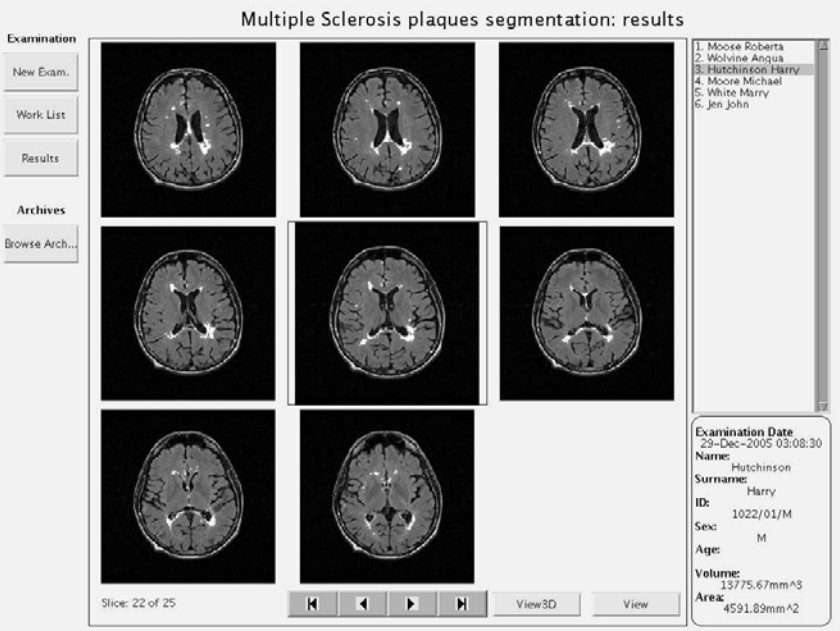

Fig. 1. Automated mode

The results are displayed as shown in fig. 1. The extracted lesions are colour-coded. The total area and volume measures are computed and displayed.

3.2 The interactive mode

In this mode a user is able to view and correct each slice separately (fig. 2). Two versions of each slice are displayed. One original, shown as a reference image and the second with superimposed, automatically extracted plaques.

The user is able to enhance the original slice are increase or decrease the size of each lesion by adjusting the local threshold value. Corrections described in Section 3.1 may be turned off.

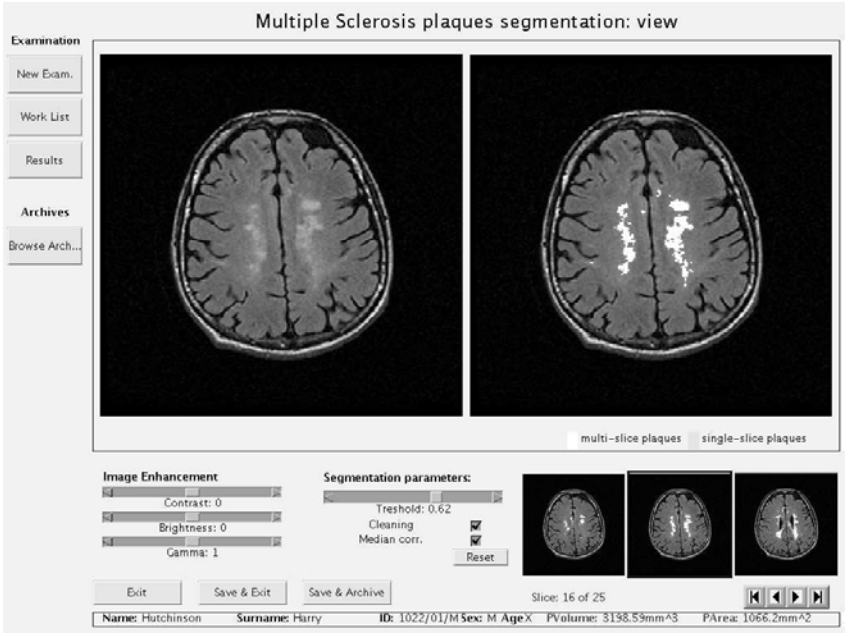

Fig. 2. Interactive mode

The area and volume measures are corrected on-line according the introduced changes.

A user is able to navigate through the entire series of slices. Neighbour slices are shown for reference.

4 Remote access

Original images together with the validated processing results have a significant educational value. Teaching activities yield for a remote access to a case study. Carefully virtualized patient and study data together with medical images could therefore be accessible through a web-interface.

Moreover, an organization of a repository centre may also benefit from this solution. Interesting and rare case studies may be web-wide accessed by physicians for preview and consultation.

Virtualization results is a full anonymization with generation of false patient and study identity. False identity should later be used consequently, when data are accessed by an unauthorized user.

Medical images accessible through a world wide web should be provided in lightweighted version. 2D image data are to be converted into lossy graphic compression format (eg. JPEG). For more demanding users progressive compression should be implemented to more effectively use the available bandwidth. 3D lesions visualization data may be presented as a non-interactive animated graphic sequences (eg. GIF or PNG) or described in terms of VRML.

5 Results

Ten FLAIR sequences of 3 mm continuous MR brain slices have been subjected to the analysis. Clustering has partitioned each slice into six classes ($c = 6$), the fuzzyfication level has been set to $m = 2$, and the accuracy $\epsilon = 0.01$. Median filtering has been performed with a 3×3 window. Modification strength (α) of median-modified FCM has been set to 0.8. Thresholding level for each fuzzy partition matrix of the cluster reflecting the lesions has been set to 0.5.

In 12% slices small lesions have required enlargement, whereas, in 16% slices large lesions have been decreased. A comparison of the overall volume of the demyelinated structure shown per study measured automatically and corrected interactively indicate the accuracy ranging between 1% and 2.5%.

Methodology, developed in this study, performs an automated segmentation of demyelination lesions acquired at the MR FLAIR serial images. The result is then presented to the user for further analysis. The adjustment can be done manually when the automated analysis happened to over- or underestimate the size of the lesion.

References

1. Alfano B, Brunetti A, Larobina M, et al. (2000) Automated segmentation and measurement of global white matter lesion volume in patients with multiple sclerosis. Journal of Magnetic Resonance Imaging 12:799–807
2. Zijdenbos A.P, Forghani R, Evans A.C (2002) Automatic "pipeline" analysis of 3-D MRI data for clinical trials: Application to multiple sclerosis. IEEE Trans. on Medical Imaging 21(10):1280–1291
3. Kikinis R, Guttmann C.R, Metacalf D, et al. (1999) Quantitative follow-up of patients with multiple sclerosis using MRI: Technical aspects. Journal of Magnetic Resonance Imaging 9:519–530
4. Bezdek J.C (1981) Pattern Recognition with Fuzzy Objective Function Algorithms. Plenum Press, New York
5. Chen S, Zhang D (2004) Robust image segmentation using FCM with spatial constraints based on new kernel-induced distance measure IEEE Trans. System, Man, and Cybernetics–Part B. 34:1907–1916

6. Kalluri S, Arce G.R (2000) Fast algorithms for weighted myriad computation by fixed-point search IEEE Trans. Signal Processing 48:159–171
7. Pietka E, Kawa J, Spinczyk D, Konopka M.N (2005) Computer-aided diagnosis workstation for detection and volumetric measurement demyelination plaques in multiple sclerosis. Radiological Society of North America, Inc., Oak Brook (IL) (2005) 855

Predicting Clinical Image Delivery Time by Monitoring PACS Queue Behavior*

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ABSTRACT

The expectation of rapid image retrieval from PACS users contributes to increased information technology (IT) infrastructure investments to increase performance as well as continuing demands upon PACS administrators to respond to "slow" system performance. The ability to provide predicted delivery times to a PACS user may curb user expectations for "fastest" response especially during peak hours. This in turn could result in a PACS infrastructure tailored to more realistic performance demands. A PACS with a stand-alone architecture under peak load typically holds study requests in a queue until the DICOM C-Move command can take place. We investigate the contents of a stand-alone architecture PACS RetrieveSend queue and identified parameters and behaviors that enable a more accurate prediction of delivery time. A prediction algorithm for studies delayed in a stand-alone PACS queue can be extendible to other potential bottlenecks such as long-term storage archives. Implications of a queue monitor in other PACS architectures are also discussed.

Keywords: PACS system performance, image retrieval delivery time, response time, benchmark

1. INTRODUCTION

PACS designers minimize the delivery time of images to users at their workstations through a number of technologies including high-speed networks, fast servers and pre-fetching algorithms. Researchers aid these designers by developing monitoring tools to identify bottlenecks (e.g., Nagy et al[1]) between a PACS and workstations on a local network. Careful selection of hardware and use of monitoring tools prevent most problems with slow delivery during initial deployment. But PACS usage inevitably grows over time resulting in slower delivery times each ensuing year.

Most solutions to slow delivery times have focused on increasing the ability to "supply" images such as faster hardware for storage, servers, networks and workstations. However, a cost-effective PACS implementation will unlikely be able to accommodate "spikes" of maximum usage during peak hours. As a consequence, there will be limited periods of peak use where delivery times are slower than normal. Not knowing the expected delivery time may lead to unreasonable expectations. Sustaining reasonable image delivery times during peak usage necessitates managing the "demand" for images or investing in expensive hardware upgrades for a few short bursts of peak usage.

One technique for managing demand is to inform users about the expected delivery time of an image request. Computer usability guidelines recommend progress indicators to mitigate user expectations when tasks take more than a few seconds such as in downloading files or a system with slow response resulting from busy servers [2 3]. A queue monitor is a tool that informs users of predicted delivery time when a backlog of requests is developing. Users could then choose to take a short break or temporarily switch to other tasks rather than waiting. While some current PACS can provide the administrator with the status of a series (e.g., pending, sending) or users an image counter (e.g., sending image 3 of 59), none to our knowledge can predict delivery time.

The paper begins with a description of our laboratory test bed that allowed us to identify the PACS parameters to be used in a queue monitor prediction algorithm. Section 3 summarizes the simulation data that illustrates the interaction among the parameters important to predicting delivery time. The results and implications to PACS designers and system implementers are discussed in Section 4.

2. MATERIALS AND METHODS

Our goal was to identify the PACS parameters that play a part in predicting the delivery time of a study under conditions of queuing such as during peak usage in a clinical setting. These parameters would be used to develop a delivery time prediction algorithm by monitoring a PACS queue. We simulated a clinical environment in which the requests to retrieve clinical images from our laboratory's PACS Simulator resulted in requests being queued rather than sent immediately. The queuing behavior could then be examined under various conditions. The prediction algorithm would be derived from the performance data for this PACS particularly with respect to the PACS queue. The study assumption was that saturating a PACS with delivery requests would result in an observable backlog of requests in the queue. A slow PACS can be saturated with much fewer requests for studies than a faster PACS. However, a faster PACS could eventually be saturated with more study requests and larger studies (e.g., hundreds of slices). Demonstrating a queue backlog with a slow PACS should therefore be generalizable to a fast PACS.

A laboratory test bed that modeled a clinical setting allowed us to analyze PACS parameters without disrupting an actual clinical operation. Actual clinical images were requested at 5 to 10 minute intervals to represent the typical workflow of a radiologist. Sometimes, multiple studies were requested at about the same time to reflect the condition when prior studies had to be retrieved for comparative purposes. Section 2.1 describes the laboratory test bed and the workstations used. Section 2.2 summarizes the clinical data used in the study. Section 2.3 identifies the parameters to be used in the prediction algorithm.

2.1 Workstation Test bed Description

A clinical setting was simulated in our IPI Laboratory. A PACS and five workstations running DICOM client software were placed on two different network segments. Three of the workstations were placed on the same 100 Mbps network segment as the PACS representing the conditions found in a reading room. Two other workstations were placed on a different 10 Mbps network segment representing workstations for clinicians or radiologists in a different part of the building.

The PACS Simulator in the IPI Laboratory was used for the PACS in the study. The software runs on an Ultra 2 Sun machine using SunOS 2.8. The database was Oracle 8i. The PACS Simulator is DICOM-compliant using the standard patient – study – series data model. There are four internal queues to which study requests are sent. Papers by Law et al [4] and Zhou et al [5] provide a more complete description of the PACS Simulator.

A PACS running on slower hardware was chosen so that fewer workstations could generate enough requests to saturate the PACS and cause some study requests to be delayed. In addition, placing two workstations on a slower network segment was expected to force more requests to be queued. The configuration of the five Windows-based computers that acted as reading workstations is shown in Table 1.

Workstation	DICOM Client	OS	CPU	Network	Database
Client1	Conquest 1.4.7	XPP	P4 2.8 Ghz	Same as PACS (100 Mbps)	Built-in DbaseIII
Client2	Conquest 1.4.7	XPP	P3 0.7 Ghz	Same as PACS (100 Mbps)	Built-in DbaseIII
Client3	Cedera I-View 5	W2K	P4 1.3 Ghz	Same as PACS (100 Mbps)	Vendor-provided
Client4	Conquest 1.4.7	W2K	P4 2.8 Ghz	10 Mbps subnet via firewall	Built-in DbaseIII
Client5	Conquest 1.4.7	W2K	P2 0.4 Ghz	10 Mbps subnet via firewall	Built-in DbaseIII

Table 1 Workstation Specifications in Queue Monitor Testbed

2.2 Data Acquisition

The data collection objective was to saturate the PACS server with DICOM send requests (i.e., C-Move) so that some study requests would be queued. The sequence of requests and time between requests should be representative of a clinical setting. This precludes selecting a large number of exams via a wildcard search and requesting all the resultant studies to be sent all at once. Such an approach would

greatly distort the results particularly with the queue algorithm of our PACS Simulator. Studies transferred under a single query are all sent to the same queue within the PACS Simulator even though four queues are available. A backlog in a single queue is created because processing is done sequentially. Thus it was necessary to manually query and retrieve every study by name from a workstation.

The data collection procedure was to request a study from each of the five workstations until all of the anonymized data had been transferred from the PACS server to a workstation. The testing sequence began by initiating a query from the first workstation (e.g., Client1) to the PACS for locating a specific study. Once the results of the search are returned from PACS, a transfer was requested from the PACS to this workstation. The second workstation then queried a different exam based on study number. Once again the transfer was requested immediately after the query result was returned by the PACS. The same procedure was done for workstations 3, 4, and 5. The researcher would then return to workstation 1 and query another exam. The transfer was initiated and the process repeated on workstation 2. Sometimes additional exams were requested on a client to simulate the retrieving of prior studies for comparison. Table 2 tabulates the breakdown of 131 studies that were requested over a 40 minute period. Nearly 2 gigabytes of data were transferred and almost 4500 individual DICOM images were sent. There were studies from modalities of computed radiography (CR), computed tomography (CT), magnetic resonance image (MRI), a single ultrasound (US) study and a CR study containing two highly compressed files.

Workstation	Total MB	Total Images	Studies	Modality				
				CR	CT	MR	US	CR*
Client1	372	920	25	3	13	7	1	1
Client2	355	918	25	3	13	7	1	0
Client3	455	892	29	7	14	6	1	1
Client4	390	931	25	5	11	8	1	1
Client5	444	803	26	7	11	6	1	2
Total	2012	4464	131	25	62	34	5	5

*compressed

Table 2 Distribution of Studies by Workstation Destination

After all of the requested studies were processed on the five workstations, the queue transaction log of the PACS Simulator was accessed using a SQL client and an ODBC connection. The data preserved in the queue log included DICOM requestor and recipient, assigned queue, time of retrieval request, start time of retrieval, finish time of retrieval, and specific study identifier.

2.3 Algorithm Description

The prediction algorithm takes into consideration site-specific conditions. These include network segment, client computer capability, DICOM application software, load on the PACS, and specific file parameters of a clinical study. All of these factors affect the transfer rate of images to a workstation. Network segment affects speed of transfer depending upon bandwidth. In addition, the file may pass through any combination of firewall, switch or hub. Computer capability determines the speed at which our DICOM client software could receive and store images locally. The DICOM headers had to be analyzed and the meta-data stored as a record on a local database. Application software affects transfer speed by choice of database and processing algorithms. Load on the PACS reflects the capability of the PACS hardware and software to send multiple studies at the same time. There may be limitations on throughput due to network card, buffer or thread implementation, server memory and processing power. Clinical study specifics include modality, number of images or slices and compression. CR studies have a few large images which means transfer rates are dominated by number of bytes to be transferred. In contrast, MR images are small (256 X 256) but ten's if not hundred's of images which means a greater percentage of time is spent on header processing and DICOM file transmission overhead.

3. DATA

A log from the PACS Server was generated from the simulation requesting 131 studies from five workstations over a 40 minute interval beginning at 46,000 seconds (12:47 pm) to 48,500 (1:28 pm) seconds. The analysis of this log is presented in this section.

A 400 second interval from the total 2,500 second simulation is shown in Figure 1 graphically illustrating the sequence of studies transferred for the five clients. The horizontal axis is in seconds for that day (e.g., interval starts at 1:07:30 pm). The time to transfer a study consists of a delay in the start of transmission (i.e., sitting in queue) and the actual send (transmitting) time. The chronology of the first 13 studies in this figure is explained, beginning from the bottom. Clients 1 and 2 already have a study transfer in progress at time 47250 which is why no delay time is evident. Client1 then makes three additional requests within a 16 second period beginning at time 47251. The next request by Client1 takes place at 47501 seconds. Client2 makes a single request at 47283 seconds. Six minutes later Client2 requests a set of six studies. The 14th to 26th study represents the studies requested by Client3, Client4, and Client5.

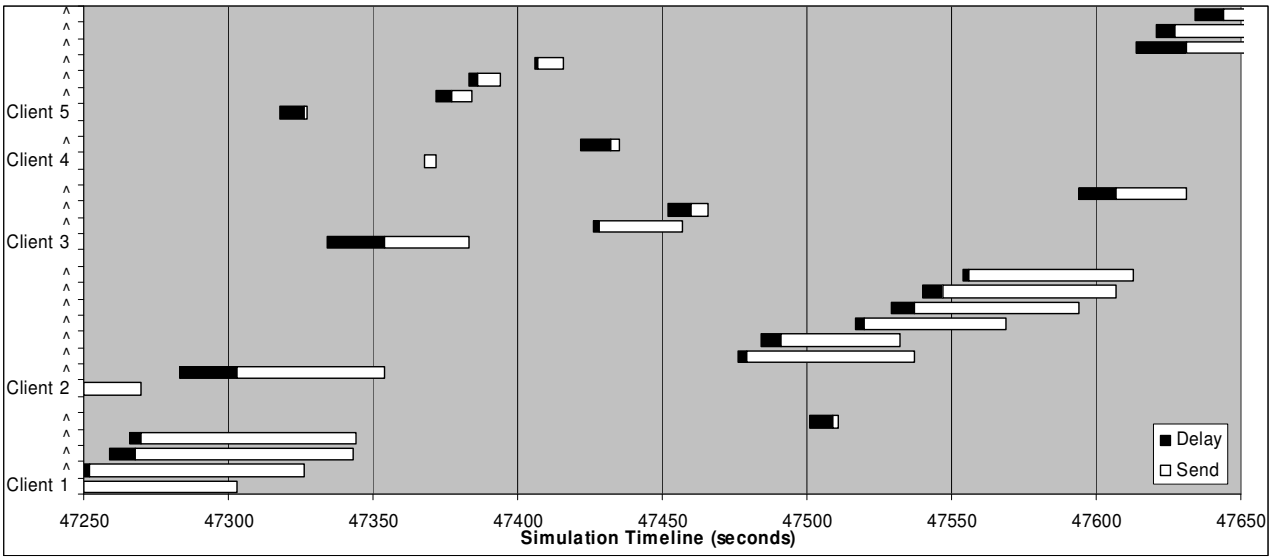

Figure 1 **Sequence of Study Transfers over 400 seconds**

The remainder of Section 3 consists of descriptive statistics from this simulation. Performance characteristics of each workstation are contained in Section 3.1. Section 3.2 describes the impact of modality upon workstation performance. The reader should note that 13 of the 26 delays in the interval shown in Figure 1 resulted from a queue backlog which is discussed in section 3.3.

3.1 Workstation Performance

The differences in transfer rates to each workstation reflect a number of parameters important for a delivery time prediction algorithm. These include the computer components of the workstation, network segment, and application software. Table 3 provides average performance for each client showing relative differences between the workstations without regard to modality (see section 3.2). The standard deviation is shown in brackets for each value.

Workstation	Average Time for Study (sec)	Average Transfer (MB/s)	Average Start Delay (sec)	Average Start Delay w/o Backlog (sec)
Client1	53.6 [22.5]	0.34 [0.15]	7.0 [3.5]	7.0 [3.4]
Client2	48.1 [12.6]	0.38 [0.17]	7.1 [5.9]	5.2 [2.9]
Client3	23.5 [12.3]	2.01 [2.26]	7.8 [6.7]	5.4 [3.4]
Client4	10.2 [5.7]	4.21 [1.94]	6.5 [5.5]	5.3 [3.4]
Client5	17.0 [8.2]	1.72 [1.16]	6.2 [3.8]	5.9 [3.3]
All	29.8 [21.5]	1.77 [2.01]	6.9 [5.2]	5.7 [3.3]

Table 3 Transfer rates by workstation destination (standard deviation in brackets)

The average time for processing a study in the first column ranges from 10.2 seconds on Client4 to 53.6 seconds on Client1. This is the time from when the PACS received a request to the time that PACS records in the log that the study has been sent. The average transfer rate is measured in megabytes per second as shown in the second column, where the total size in megabytes of the study is divided by the time from when the PACS begins transmitting the images to the workstation until the study is completed. Clients 1 & 2 have very slow transfer rates because of their location on a 10 Mbps (1.25 MBps) network segment. The third set of measures is the average start delay in seconds as shown in column 3. Start delay ("delay") is the time from the PACS receiving a request to the time the transmission of images has begun. Our PACS Simulator uses four queues. There were 22 studies that became backlogged in a queue during the 40 minute simulation. Many of these 22 studies had lengthy delay times simply because of waiting for the previous study to finish. The average delay in seconds excluding these 22 studies is found in column 4.

3.2 Workstation and the Impact of Modality

Modality determines the file characteristics of a study especially image size (MBytes) and number of images. A CR study has large images (e.g., 8 MBytes) but only a few images. A MR study has small images but many slices (e.g., 50 to 60 in this study). Since our workstations functioned as local DICOM servers, the images were both transferred to the hard disk of the workstation and catalogued. This meant the headers on each DICOM image had to be processed so that storage could take place locally. Hence, more workstation resources are spent processing an MR study than transferring the image. This is why the transfer rates for CR are typically higher than CT and MR. This is shown in the average transfer rate column of Table 4. Standard deviation is shown in parentheses. The anomalous result of Client1 for CR reflects a relatively rare situation where all three CR studies in the simulation for Client1 were retrieved simultaneously. Section 3.4 explains how simultaneous transfers decreased throughput by nearly one-half.

	Transfer Rate (Mbytes/sec)		
Workstation	CR	CT	MR
Client1	0.3 [0.03]	0.4 [0.1]	0.3 [0.2]
Client2	0.6 [0.2]	0.4 [0.1]	0.2 [0.1]
Client3	5.1 [2.5]	1.4 [0.8]	0.3 [0.1]
Client4	6.4 [1.2]	5.0 [0.6]	2.2 [1.0]
Client5	3.3 [0.6]	1.7 [0.4]	1.7 [0.4]
Average	3.8 [2.6]	1.7 [1.7]	0.8 [1.0]

Table 4 Transfer rates by modality and destination (standard deviation in brackets)

3.3 Backlog in Queues

A queue backlog occurs when there are more requested studies than queues to process the requests. Figure 2 shows the concept of a queue backlog taken from the study data from time 47250 to 47500. Client1 workstation requested a study at 47247. This request is assigned to Queue 2 finishing at 47326. The next

study request assigned to Queue 2 comes from Client5 workstation. The request occurs at 47318 but cannot start sending until 47327 because each queue processes requests sequentially. Similarly, Client2 workstation requests a study at 47283 which is placed in queue 3 and finishes at 47354. The study requested by Client3 workstation at 47334 must wait in queue 3 until 47354 to begin sending. This figure also shows that our PACS Simulator distributes studies evenly across the queues. For example, three requests from Client1 workstation made within 20 seconds of each other (47247 to 47267) are sent to queues 1, 2, and 4.

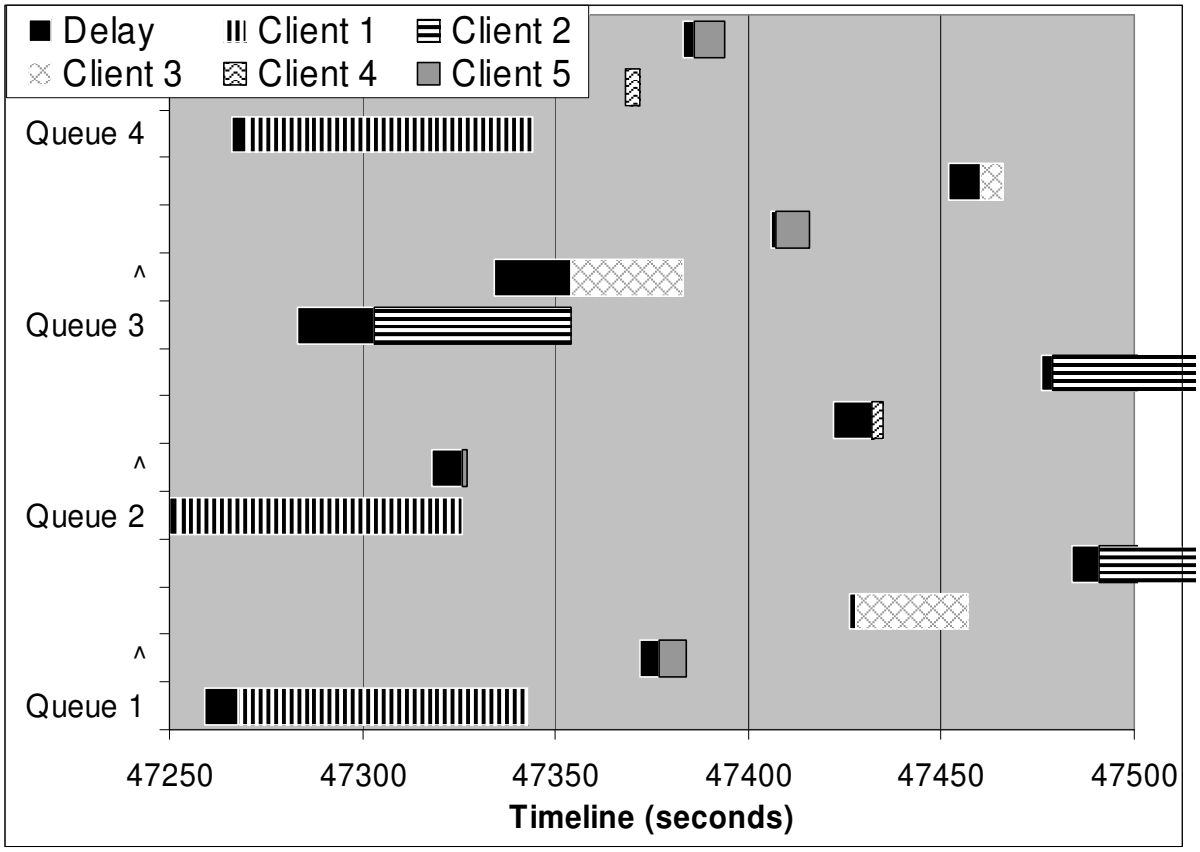

Figure 2 Delays Caused by Overlapped Studies in a Queue

Exclusion of delays caused by the 22 incidents (29% of requested studies) of queue overlap reduces the average delay time (averaged for all the studies) from 6.9 to 5.7 seconds (e.g., last row in last two columns on Table 3). All delay times over 12 seconds (10 incidents) were attributed to queue overlap. The standard deviation (average for all the studies) drops from 5.2 to 3.3 seconds.

4. RESULTS

The queue backlog condition that was simulated in this research allows several types of findings to be discussed. Several critical assumptions and parameters of importance for at least our laboratory configuration are discussed in Section 4.1. The framework of a prediction algorithm is described in Section 4.2. Section 4.3 discusses the implications of these findings on clinical systems. We discuss future research plans based on our findings in Section 4.4.

4.1 Important Parameters

Our simulation results reflect an important data collection assumption – that each study request had to be queried individually. A unique study number had to be manually typed in to query and then retrieve the study. This protocol was adopted after observing that a query command retrieving multiple studies (e.g., all studies of patient xyz or studies containing string 1234) placed all of the selected studies in the same queue of our PACS Simulator. This places multiple study requests in a single queue forcing a queue backlog to develop. The transmission rate to workstations would then be limited by the sequential processing of the queued requests regardless of the state of the three remaining queues. It should be noted that our PACS can process requests made from multiple workstations at the same time, just not multiple studies requested at the same time from the same workstation.

Some might argue that this protocol assumption was somewhat artificial. After all, a radiologist might wish to retrieve all studies for a particular patient before starting to read an examination. Or a PACS might be configured with the policy to pre-fetch all studies for a patient. Our point is that the implementation approach chosen by our PACS developers for requesting multiple studies at the same time will increase the duration of transfer. All of the studies made in a single request ended up in the same queue. A more effective implementation is to assign each study requested to its own queue or thread.

The bottleneck in our laboratory configuration was a slow 10 Mbps network segment where Client1 and Client2 resided. The transfer rate is slow to these two workstations which lengthened the time a study resides in the PACS while being processed. Since our protocol required studies to be requested individually, more than one study could be transferred at one time to a workstation. For these two workstations, other studies were being processed simultaneously 88% and 76% of the time respectively. In contrast, the other three workstations on the fast network (e.g., 100 Mbps) received the studies quite quickly which reduced the incidents of a study being transferred at the same time to between 19% and 28% of the time.

The key parameters encountered in this simulation that can be used in predicting delivery time consist of two types. The first type of parameters are related to physical attributes such as network configuration, image type (e.g., modality), and workstation hardware. Choice of network segment has a large impact for two reasons. First, the studies may need to pass through additional network devices such as firewall or switch. Second, network contention further slows transfer rates when studies are being transmitted simultaneously. Client1 and Client2 on a network segment passing through both a firewall and 10 Mbps switch were markedly slower than Client3, Client4, and Client5 sitting on the same segment as PACS. Transfer rates were also markedly different by modality type (Table 4) for all of the workstations. The configuration of workstation hardware is a parameter when the DICOM client must process the header and store the files locally. For example, Client4 (2.8 GHz CPU) transfers studies several times faster than Client5 (0.7 GHz CPU).

The second parameter type affects the delay in starting transmission of a study. The presence of a queue backlog is one such parameter when one or more studies are waiting for the queue to finish transmitting a study. The transfer rate between the PACS and the workstation can be used to determine how long the study in the queue will take to complete. We found by examining each study request (total of 131) that delay times greater than 12 seconds were always caused by a queue backlog. Another parameter is the number of simultaneous studies being transmitted since each study being processed consumes CPU resources. The number of DICOM query requests will also consume CPU resources slowing the processing of a study request. The varying consumption of CPU resources is the likely source of the 3.3 second standard deviation in average delay time (for all studies) of 5.7 seconds (i.e., 2.4 to 9.0 seconds for one standard deviation) as shown in bottom row of last column in Table 3.

4.2 Prediction Algorithm

The prediction algorithm for a typical study request in which the PACS is not overloaded is quite simple. The algorithm using standard programming style for variable names is:

> *predictFinishTime* = *predictSendStart* (= delay time) + sending time based on transfer rate of the workstation on its network segment given the particular study specifics (*transferRateClient*) given the load on a PACS sent to a particular workstation configuration.

For example, Client5 requests a CR study consisting of two 8 MByte images. A value of 5.7 ± 3.3 seconds will be used for the delay. Table 4 in Section 3.2 indicates a transfer rate of 3.3 Mbytes/sec under average conditions. In the case of Client5 during this simulation, about 20% of the studies were done simultaneously with others. For the condition of a lightly loaded PACS Simulator, the predicted finish time is 5.7 + (16/3.3) ~ 10 seconds. However, what happens if the PACS is busy and the request from Client1 arrived before the request from Client5. The request is for a 200 slice MR (about 27 Mbytes) which means a download at 0.3 Mbytes/sec. So after 90 seconds (27/0.3), the backlogged request can begin. The predicted delivery time would then be 95 seconds.

4.3 Implications for a Clinical System

A properly designed clinical system means minimal periods of peak usage conditions. So a queue monitor will not be used frequently. However, there are numerous possibilities in which unplanned heavy usage could make use of a queue monitor valuable. For example, digital mammography generates very large files that take many seconds to transfer to or from a PACS. A queue backlog could be generated during this transfer period as one of the queues is dedicated to this large study. Usage often peaks during start of a shift or after lunch. So a contingency plan is necessary – buy more hardware, fine-tune the existing system and notify users of peak usage. A queue monitor helps to understand the behavior of the system such as our experience of workstation performance degraded not only by the network configuration but the load on the PACS.

PACS architectures described by Huang[6] are increasingly client-server or web-based rather than standalone. While the transport mechanisms and protocol of the image files being transferred may change with a client-server or web-based architecture, the underlying basis of queue monitoring does not change. There must be a queuing mechanism implanted in any PACS server to accommodate a backlog of requests. Status indicators on PACS clients that already provide feedback in the form of a showing that 1, 2 … of N images have been received is a first step. Adding predicted delivery time is the next step. A client-server PACS architecture may actually facilitate the use of a queue monitor. The connection between client and server could be used to measure actual transfer rates and provide predictions to the users. The PACS in a client-server architecture has more information about the state of clients. These vendors can more easily incorporate software code into the client that gives users insight on study transfer times and the performance of the PACS.

Testing a stand-alone PACS with peak load conditions as done is this research will be difficult in a clinical environment. The speed of current PACS hardware makes it difficult to overload the PACS with requests so that a backlog in the queues is created under ordinary conditions. Access to many workstations would be required with near-simultaneous requests for studies being made. One approach during acceptance

testing to simulate a peak load would be to transfer very large studies with 1000's of images from as many clients as practical. The lengthy transfer time of a very large study fills one queue slot so that other requests are sent to other queues. Fewer workstations and the personnel to operate them would be needed to create a peak load.

When selecting a vendor, questions should be asked about the means in which connections are established between the client or web application and the PACS server. Our PACS placed all the requests for multiple studies (e.g., using wildcard search) in the same queue for transmission since only a single DICOM connection was established. We have concerns that increasing interest among clinicians for web access means most of the requests are coming from browsers rather than reading workstations. This means a PACS architecture should be examined to determine how web and client connections are established with the PACS. For example, a typical implementation with web clients (e.g., DataServer[7]) allows a maximum of 10 simultaneous connections with further requests queued or even rejected if the queue is full.

The implementation of a queue monitor requires that the PACS software store sufficient information to assess the state of the queues. This information does not need to be in one table of the database. However, the information about these queues must be queried in real-time (read-only) from a queue monitor application. Unfortunately, a prediction algorithm in the form of an SQL query would have to be developed for every PACS since there are vast differences in implementation and database structure. A read-only query minimizes the load on the PACS server. Ideally PACS developers would write all of the critical queue information in a single table in a standard format. By doing so, a read-only table copy would only be necessary rather than the computation-intensive joins needed in an SQL query.

Our research focused on queue backlogs for PACS and the transmission time of images. Yet the longest delays are probably not in the transfer of image files. Once files have begun to be transferred from PACS the prediction of delivery time is straightforward. A greater benefit comes from monitoring the queues of long-term storage devices. For example, a radiologist may wish to retrieve a "prior" study several years old that has been automatically migrated to a tape silo. Pre-fetching is of course possible but storage

policy will inevitably limit a pre-fetch to more recent studies. There is a delay of tens of seconds (e.g., robot selects tape then streams tape to desired location) before the images can be transferred. If there are many requests to the tape silo, then the delay grows quickly as more requests are queued. Having this delivery time information, the radiologist can exercise other options besides waiting. For example, prediction of a long delay can be sent to the PACS. The PACS can in turn update the Radiology Information System (RIS) which could suggest to the radiologist that this patient be skipped for the moment.

4.4 Future Research

Our future research will be directed towards building a web application so that the prediction algorithms can be accessible from anywhere in the clinical setting. Other PACS queue implementations and PACS architectures will also be studied so that a generalized prediction algorithm can be written based upon different implementation approaches. A queue monitor architecture can then be proposed to a standards body. Other potential queue bottlenecks such as long-term storage or tape archives will also be incorporated into the algorithm.

While the queue monitor manages user expectations by predicting delivery times, the prediction algorithm can also serve in a load balancing capacity as a back-end tool in the PACS infrastructure. Pre-fetching of studies likely to be needed that day can be retrieved in advance during slow periods especially off slower media such as tape. The prediction algorithm could also be used in distributed storage networks (e.g., data storage grid [8]) to predict which storage resource is likely to provide the quickest delivery times. When images are distributed across a wide area network (WAN) delivery time depends upon all the parameters considered in a local PACS architecture plus the actual speed of the connection to the remote site.

Since this study was conducted on a PACS that utilizes older hardware, future testing on faster PACS hardware will require a reading workstation simulator. The simulator must provide for multiple DICOM clients residing on different network segments that request studies individually over a time interval consistent with radiologist reading habits. While some load on the PACS can be created with larger studies (100's of slices instead of 10's), simulating peak load conditions will require the use of multiple DICOM

clients. The workstation simulator will also be useful in establishing benchmarks for a particular PACS. We expect each PACS to have vastly different performance behavior under peak load conditions because of the means in which simultaneous studies are processed.

Our prediction algorithm considered average transfer rates. In reality, there will be a large number of workstations whose configuration will be known including hardware components, software and network location. A self-learning algorithm seems ideally suited for a queue monitor application. There are many known variables about each workstation and the type of study being sent. Each of these sets could be associated with measurable PACS parameters such as processor and memory utilization as well as queue status (e.g., presence of queue backlog). The transfer rates could be periodically updated using all of the previous studies as a training set.

5. CONCLUSIONS

A queue backlog condition that results from too many requests for clinical studies from a PACS has implications beyond slow delivery of clinical images. We demonstrated the feasibility of a PACS Queue Monitor algorithm so that performance of our stand-alone PACS could be monitored under peak loads. Monitoring the queue of our PACS allowed us to predict delivery time potentially offering a means to "manage" user expectations. We found that fast performance from a PACS requires more than just fast networks and fast workstation hardware. The queuing implementation and the connection established between a PACS and a workstation is also a factor. Our prediction algorithm can predict approximate delivery times but further understanding of PACS behavior under peak load conditions is necessary to refine the algorithm. In particular, monitoring the queues of relatively slow storage devices such as tape is necessary to accurately predict delivery time.

REFERENCES

1 Paul G. Nagy, Mark Daly, Max Warnock et al., *PACSPulse: A Web-based DICOM Network Traffic Monitor and Analysis Tool*, Radiographics **23** (3), 795 (2003).
2 J. Nielsen, *Usability Engineering*. (Morgan Kaufmann, San Francisco, 1994).
3 Dennis F. Galletta, Raymond Henry, Scott McCoy et al., *Web Site Delays: How Tolerant are Users?* Journal of the Association for Information Systems **5** (1), 1 (2004).
4 M.Y.Y. Law and Z Zhou, *New direction in PACS education and training*, Computerized Medical Imaging and Graphics **27**, 147 (2003).
5 Z. Zhou, H.K. Huang, B.J. Liu et al., *A RIS/PACS simulator with web-based image distribution and display system for education*, SPIE Medical Imaging **5**, 372 (2004).
6 H.K. Huang, *PACS and Imaging Informatics: Basic Principles and Applications*, 2 ed. (Wiley-Liss, 2004).
7 A A T Bui, G S Weinger, S J Barretta et al., *DataServer: An XML gateway for medical research applications*, in *Techniques in Bioinformatics and Medical Informatics* (2002), Vol. 980, pp. 236.
8 Brent J. Liu, M.Z. Zhou, and J. Documet, *Utilizing data grid architecture for the backup and recovery of clinical image data*, Journal of Computerized Medical Imaging and Graphics **29** (2-3), 95 (2005).

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WIRELESS REMOTE CONTROL OF CLINICAL IMAGE WORKFLOW: UTILIZING A PDA FOR OFFSITE DISTRIBUTION AND DISASTER RECOVERY*

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Abstract

This paper describes a PACS (Picture Archiving and Communications System) tool based on web technology that remotely manages medical images between a PACS archive and remote destinations. Being successfully implemented in a clinical environment and also demonstrated for the last 3 years at various conferences including RSNA (Radiological Society of North America), this tool allows a very practical and simple manner to manage PACS including offsite image distribution and disaster recovery. The application is robust and flexible and can be used on a standard PC workstation or a Tablet PC but more importantly, it can be used by a Personal Digital Assistant (PDA). With the PDA, the web application becomes a powerful wireless and mobile image management tool. The quick and easy-to-use features allow users to perform DICOM (Digital Imaging and Communications in Medicine) query and retrieves with a single interface without having to worry about the underlying configuration of DICOM nodes. In addition, this frees up dedicated PACS workstations to perform their specialized roles within the PACS workflow.

This tool has been used at Saint John's Health Center (SJHC), Santa Monica, CA for close to 2 years. The average number of queries per month is 2,021 with 816 C-Move Retrieves. Clinical staff can utilize the PDA to manage image workflow and PACS exam distribution conveniently for offsite consultations by referring physicians and radiologists, and for disaster recovery. This solution also improves radiologists' effectiveness and efficiency in health care delivery both within the radiology department and offsite clinical coverage.

Keywords: PACS, Wireless 802.11b/g, PDA, Disaster Recovery, Image Workflow

1. PURPOSE

This paper presents a web-based PACS (Picture Archiving and Communications System) management tool that can be used from a PDA (Personal Digital Assistant) [1], which, in conjunction with a wireless network provides a mobile tool for distributing medical exams. First, we describe the basic ingredients of this tool including design considerations, clinical workflow needs, and the PDA server. The disaster recovery design utilizing this tool based on a particular disaster recovery scenario is presented. Finally, we provide some statistics acquired during the last 2 years at the Saint Johns Health Center (SJHC), Santa Monica, CA. Because the tool is a web-based application, it can also be used from any PC (Personal Computer) or Tablet PC as long as these devices have access to the PDA server and a web-based browser. In this paper, "destination" is defined as a DICOM (Digital Imaging and Communications in Medicine) node that has been already registered at the PDA server and the PACS Archive to which the clinical examinations will eventually be sent. The "Local PACS" means the

PACS at the local site; thus, the local PACS archive means the archive at the local PACS, local a workstation (WS) means the WS connected to the local PACS networks, etc.

Although the basic design of the PDA tool is quite simple, its utilization spreads into a significant range of needs within the clinical environment. For this reason we broadly classify its applications into the following two major categories:

- **Image Distribution from local PACS archive:** This is the most common application which sends examinations from the local PACS archive to specific destinations which could be any DICOM nodes such as Display Workstations or CD burning devices connected to the same PACS networks.

- **Disaster Recovery:** In this application, the local PDA queries and retrieves images from the back up archive located at a remote facility to be sent to the local PACS during a disaster. For example, in an ASP (Application Service Provider) model [6, 7, 8] using a FT (Fault Tolerant) Backup Archive, the PDA requests examinations from the remote back up archive to be sent to a local PACS WS. The characteristics of this application are that the PDA device, the PDA server, the back up archive, and the final destination could be in different locations. Section 2.3 describes the design of Disaster Recovery application in more details.

The advantages of this application in a PACS environment are its simplicity to access different DICOM nodes using the same user interface in the PDA. First, the web server manages the necessary configuration, specifically, in terms of DICOM Entity Title

information. The end-user can focus on the Study Management workflow. The other advantage is the granularity of privileges, which provides to the users access to only a set of pre-authorized servers and destinations. This provides flexibility, security and simplicity all at the same time.

In the following, Section 2 describes the clinical needs and the architecture design for the applications. Section 3 provides some statistics from the clinical data collected from SJHC.

2. METHODS

This section describes the clinical need assessment, the design of the PDA server and image query/retrieve operation, and its use for disaster recovery.

2.1 Clinical Needs Assessment

The practices for delivering healthcare have changed over the years, and one of the factors that contributes the most is technology. However, technology by itself cannot solve a particular need in the clinical environment. Thus, it is very important to find areas in common where there exists clinical requirements to be improved and, at the same time where current technology is capable of offering a feasible solution. In our case, the PDA server provides some technical features that fulfill the PACS clinical expectations, making it an excellent tool to address the clinical workflow needs. Table 1 summarizes the technical features of a PDA device which satisfy certain PACS clinical needs.

Table 1 - List of both the Clinical Requirements and the Key Technical Features that result in the decision process of designing a Wireless PDA Server Tool.

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

HTTPS: Secured Hyper Text Transfer Protocol

WEP: Wired Equivalent Privacy

SSL: Secured Socket Layer

UMTS: Universal Mobile Telecommunications System

EDGE: Enhanced Data for Global Evolution

IEEE: Institute of Electrical and Electronic Engineers

2.2 PDA Server and Graphical User Interface (GUI) Development

A PDA server is the key component of this application. It serves as a gateway between the users and the DICOM nodes. The PDA server is a web server combined with a DICOM query/retrieve tool that allows easy and fast translations of web requests to DICOM commands. The PDA server was implemented in a Red Hat 8.0 server (Pentium 4 CPU 2.8 and 512 MB of RAM) with apache2 as the web server and perl programming language for server side coding. Whenever a user uses the web client to navigate through the PDA application the input is passed to the PDA server which will properly convert to DICOM format and communicate to the designated DICOM node. Because the DICOM standard does not enforce a single manner of implementation, we have developed the PDA server to successfully interact with different PAC Systems. The current version of the application has been successfully tested against the following DICOM-complaint off-the-shelf vendor nodes: Datcard PacsCube [2], Siemens PACS [3], IPI PACS Controller [4], Stentor web [5] application and Cedara I-View 5.0 [6]. Figure 1 shows the system diagram at Saint John's Health Center, Santa Monica, CA for the PDA application.

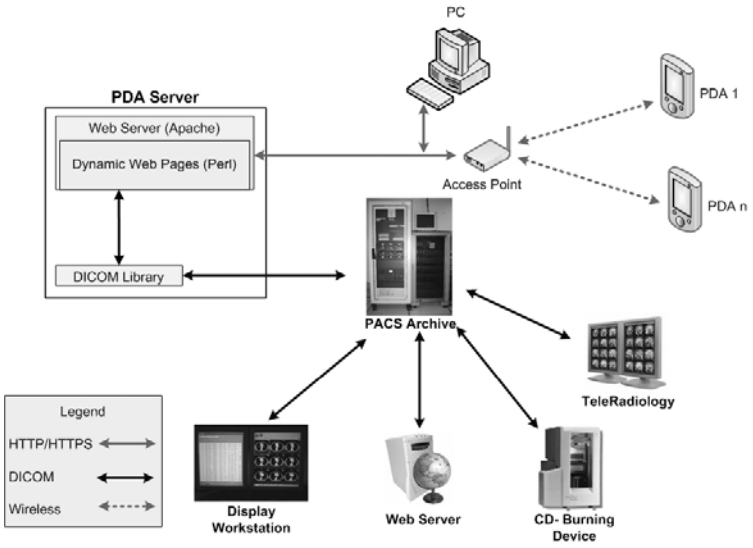


Figure 1 – The Diagram shows the use of the PDA server tool for remote management of the PACS at the Saint John's Health Center, Santa Monica, CA

Because the DICOM query/retrieve application requires an easy access from a PDA, one of the key requirements was to keep the GUI as simple as possible. For this reason, this application provides the only needed steps to distribute an examination to the destined node.

The screenshots from Figure 2 to 5 show the following four steps described in the figure captions. Figure 6 shows a user activating the PDA in a clinical environment for retrieving images to the CD-Burning device for copying.

Step 1 (Figure 2): To perform a query by the user.

Step 2 (Figure 3): PDA shows the queried results.

Step 3 (Figure 4): User selects studies from query results for retrieval

Step 4 (Figure 5)**:** PDA shows the retrieved results

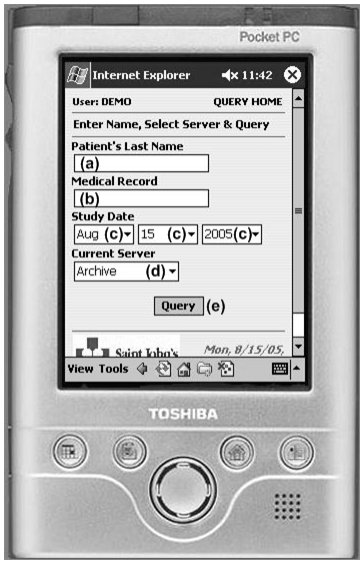


Figure 2 – Step 1: To query the Server the user can enter the patient's last name in field (a) or enter the Medical Record in field (b). A logical AND is performed when both inputs are presented. If both are blank, then the Study Date (c) can be used for the query. The user then uses the current server (d), to select the input server where the query will be performed on. Finally the user clicks the "Query" button (e) to activate the query request. (In this example, a Toshiba PDA was used, any other brand names with similar capability can be used as well).

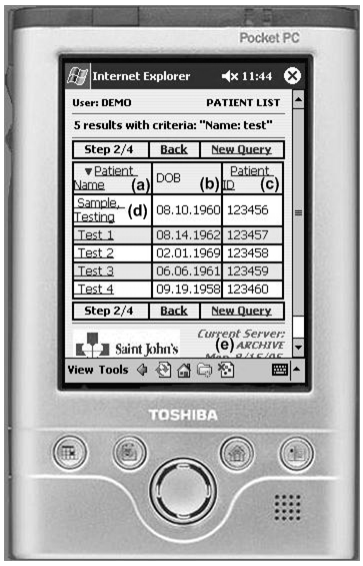


Figure 3 – Step 2: This screen shows the list of patients that matched the input search criteria from the previous step. The user can sort the result by using either "Patient Name" (a) or "Patient ID" (c). The date of birth (b) is also shown as a reference but is not sortable. To obtain the list of studies for a particular patient the user can tab the patient name of any of the results. In this example, the patient "Testing, Sample" (d) is selected. The field (e) shows the current server from where the query was obtained.

Figure 4 – Step 3: This screen shows the list of studies available for the selected patient. (a) displays the patient's name and ID as reference to the user. The checkbox (b) allows the user to select all studies, or each study at the appropriate checkboxes. The user can also sort by Study Description, Study Date-Time, or Accession Number; all those columns are shown in (c). The user then selects where to send the selected examinations to by checking the "Destination" list (d). Finally, clicking the "Send Exams" button (e) completes the retrieval process.

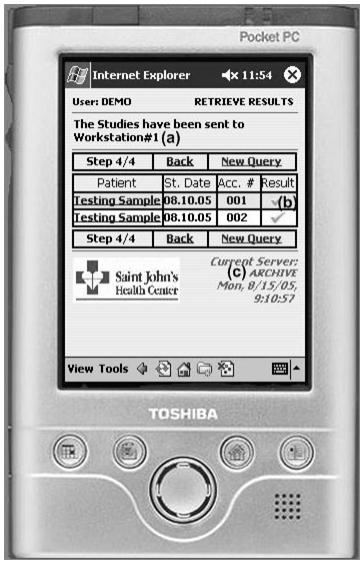


Figure 5 – Step 4: This screen shows the results after the Retrieve has been completed. (a) shows the destination, in this example, Workstation#1. The check marks at (b) depict that all selected studies from the previous step were successfully sent, the information shown includes "Patient", "Study Date", "Accession number". The server from where the studies were retrieved is shown in (c); in the example the server was chosen in step1 and stayed the same for all other steps. The user can always go back to the previous page to resubmit the query or can go back to the first page.

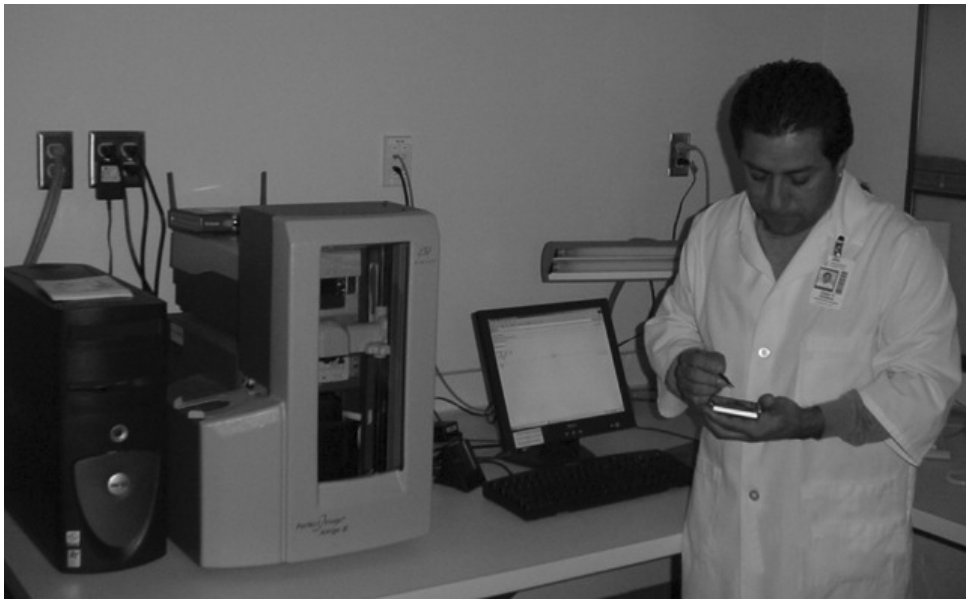


Figure 6 - Picture showing a clinical user utilizing the PDA Application. In this case an examination is being sent from the PACS Archive to the CD Burning Device (PacsCube)

2.3 Disaster Recovery Design

In a disaster event, the need for PACS data may not necessarily be at the local PACS 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 7 shows one implementation where three separate sites are connected. The primary site is a community hospital, the secondary site is a nearby academic hospital, and the third site is where the backup clinical images are achieved, IPI (Imaging Processing and Informatics Laboratory). Because the PACS at each site could be different, the types of network connections could vary between sites. Also, it is important for each of the three sites to have an internal wireless network (for wireless PDA application) as well as an internal high-speed LAN (Local Area Network) for its own PACS operation.

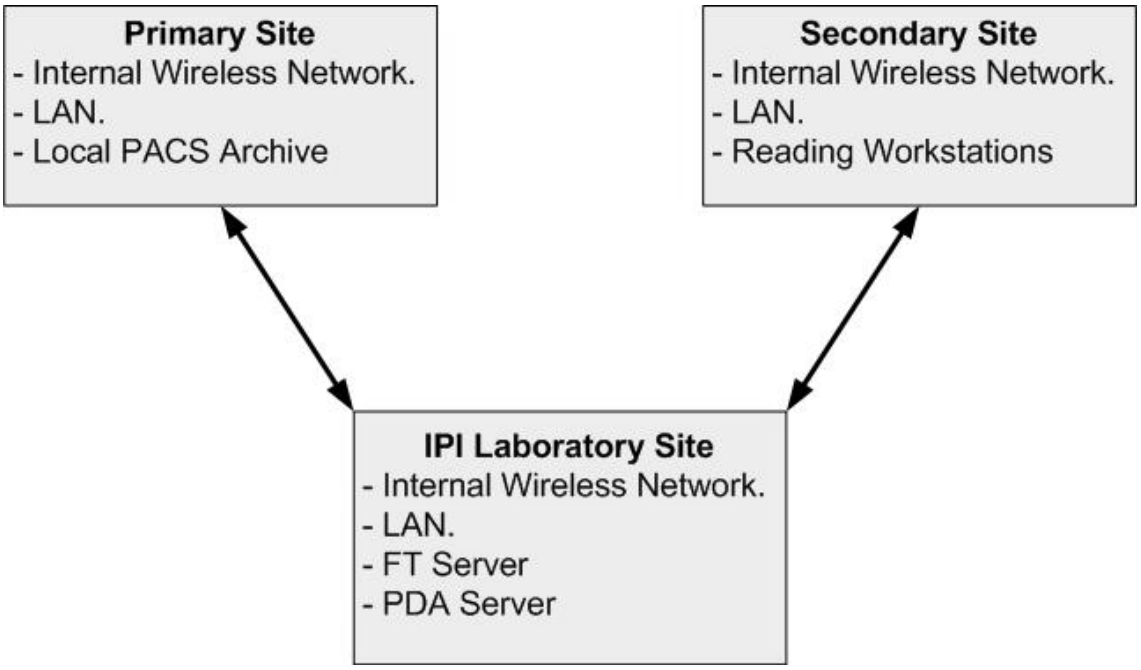


Figure 7 - This diagram shows the Disaster Recovery Scenario requirements and connectivity for multiple sites. The primary site is a community hospital, the secondary site is a nearby academic hospital, and the third site is where the backup clinical images are store at IPI Laboratory.

Once all the key building blocks are implemented, the Disaster Management Tool can be designed and evaluated by creating Disaster Scenario Drills. This is an important 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) Primary site encounters a disaster event that cripples the site.
2) The clinical PACS archive is destroyed.
3) Patients are transferred to nearby secondary site.
4) Historical PACS exams from the primary site are needed at this secondary site.

5) Physician and/or Radiology needs to view PACS exam immediately at secondary site.
6) A second copy of the PACS exams of the primary site have been stored offsite in the ASP backup archive, IPI Laboratory.

Having all the building blocks available allow us to create a real-life scenario for this architecture which we call the “Mobile Transit Scenario” where the user of the PDA application is in transit in a Metropolitan Area but is still capable of performing the remote sending of exams to the chosen destination (in this scenario to Secondary Site). The workflow for this scenario is as follows:

1) During normal operation, a copy of the PACS exam is stored offsite at the ASP backup archive. [6, 7, 8]
2) Utilizing a PDA in a mobile wireless network, the user, while in transit to the secondary site, queries for particular PACS exams from the ASP backup archive, IPI Laboratory.
3) Once exam is located, a Retrieve is made for the ASP backup archive to forward the exam for viewing when the user eventually arrives at the Secondary site.

This scenario is challenging to implement since it utilizes wireless mobile technologies integrated with the multi-sites.

3. RESULTS

3.1. Clinical Statistics gathered at Saint John's Health Center (SJHC)

Saint John's Health Center has successfully implemented the PDA Server tool to Query and Retrieve their clinical PACS archive with the flexibility of being mobile and portable for almost two years. From the PDA, studies can be transferred without interrupting the normal workflow functions of SJHC's PACS workstation or other different DICOM nodes. Table 2 demonstrates that the average number of queries per month is 2,021 with 816 C-Move Retrieves. In this context, the retrieve is defined as a single study with varied number of images.

Table 2 - Number of Monthly Queries and Retrieves from the statistics obtained at Saint John's Health Center.

	Query	Retrieve	Total
Feb '04 *	408	179	587
Mar '04	1991	1038	3029
Apr '04	2113	1489	3602
May '04	1995	1146	3141
Jun '04	2841	1666	4507
Jul '04	1957	933	2890
Aug '04	2024	904	2928
Sep '04	1552	687	2239
Oct '04	1449	642	2091
Nov '04	1316	510	1826
Dec '04	1213	501	1714
Jan '05	1919	848	2767
Feb '05	1468	679	2147
Mar '05	2605	837	3442
Apr '05	2905	595	3500

	Query	Retrieve	Total
May '05	4158	977	5135
Jun '05	2482	600	3082
Jul '05 †	1978	449	2427
Total	**36374**	**14680**	**51054**
Average	**2021**	**816**	**2836**

* Only 7 days of data was collected.

† Only 26 days of data was collected.

Table 3 displays the number of Retrieves (remote distribution) grouped by destination. Only the most representative DICOM destinations are included in the tabulation. The four most frequent used destinations are the CD Distribution, Fileroom WS, ER/Out Patients, and Teleradiology which are describe here. The CD Distribution has an average number of retrieves of 123 per month. This node is used to give patients their Radiology examinations burned digitally on a CD. With 176 number of retrieves per month, the Fileroom workstation ranks as the third highest average. This workstation's main function is to reprint hardcopies requests. According to the workflow analysis this behavior was expected because some of the users of the PDA Tool are indeed Film Clerks, File Clerks or Imaging Managers, who are typically at the center of study workflow management and in charge of these tasks. The Emergency Room/Outpatient DICOM node has the second largest number of retrieves. Utilizing this tool allows the staff to send the previous examinations of patients in the ER without physically being in the location. The highest average is 231 exams per month, and those examinations are sent to Teleradiology servers for offsite reading and diagnosis. This node has only 5 months of activity, because it has been added to the PDA application recently, but it is

this destination that performs the greatest number of retrieves on average. This demonstrates the usefulness of the PDA Server in the teleradiology application.

Table 3 – Most common DICOM destinations selected at Saint John's Health Center when utilizing the PDA Application. The table includes the total number of retrieves to each destination, the number of months the destination has been utilized and the average number of retrieves proportional to the month's activity.

Destination	Total	Average/month	# months
Offsite Distribution (Stentor)	77	7.7	10
Review Workstation 1	135	9.6	14
Radiation Oncology Reading Station	207	14.8	14
Review Workstation 2	187	20.8	9
Outpatient Tower Imaging Center	330	30.0	11
In Patients	733	45.8	16
CT/MR Neuro	913	50.7	18
CT/MR Body	1640	91.1	18
PACSCUBE (CD Distribution)	2225	123.6	18
Fileroom Workstation	3174	176.3	18
ER/Out Patients	3477	193.2	18
Teleradiology	1158	231.6	5

4. CONCLUSIONS

The PDA Server as the Study Management Tool has been shown to be a low cost, fast turn around time, and flexible solution for the distribution of PACS examinations in clinical environments. This tool allows for distribution of studies to multiple DICOM nodes at the fingertips of the user. Based on our workflow analysis results, this tool

avoids having a user to Query/Retrieve the same study at every DICOM node where the study is needed. This complements the fact that these users tend to be mobile and at the center of the workflow management.

At SJHC, this tool has significantly modified the way how studies are sent to a variety of DICOM destinations. It has become the first choice for querying information about a PACS examination by users who are in charge of the image management workflow. It has been shown in previous sections that this tool fits very well for remote distribution of exams both for local or offsite delivery and for disaster recovery scenarios.

For PACS workstations, either in a Standalone or Client-Server architecture, the main function should be reserved for physicians to perform diagnosis and/or review of PACS studies instead of performing study management tasks. Based on the workflow analysis, this tool has freed these resources of performing such tasks as query/retrieve as much as possible and allows the users to perform multiple PACS study distribution to various DICOM nodes all at their fingertips through PC or mobile technology. Also, for some DICOM devices that do not feature DICOM query/retrieve, this tool is even more effective.

In addition, because the tool is web-based, it can be utilized wherever there is a PC or mobile technology device supporting a web-based browser, thus, making it useful throughout the hospital enterprise. With all these features and capabilities, this tool fulfills some of the clinical workflow needs in a low cost, powerful, yet easy-to-use package.

REFERENCES

[1]. The USU Medical PDA Initiative: The PDA as an Educational Tool, L. Moore. B.R. Richardson, R.W. Williams, Proc AMIA Symp 2002:528-532.

[2]. Datcard PACScube. http://www.datcard.com

[3]. Siemens PACS. http://www.medical.siemens.com

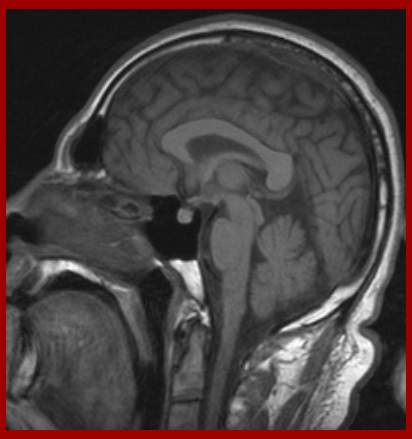
[4]. Stentor Web Server. http://www.stentor.com/

[5]. Cedara I View. http://www.cedara.com/

[6]. B. J. Liu, H.K. Huang, F. Cao, M.Z. Zhou, J. Zhang, G. Mogel, A Complete Continuous-Availability (CA) PACS Archive Server Solution, RadioGraphics, July 2004. Vol 24: pp 1203-1209

[7]. H.K. Huang, F. Cao, B. J. Liu, J. Zhang, Z. Zhou, A.Tsai, G. Mogel, SPIE Medical Imaging, Fault-Tolerant PACS Server Design, Vol 4323-14, Feb. 2001. pp 83-92.

[8]. B. J. Liu, H. K. Huang, F. Cao, L. Documet, J. Muldoon, Clinical Experiences With an ASP Model Backup Archive for PACS Image, Radiology, Vol. 225 (P), p 313, 2002.



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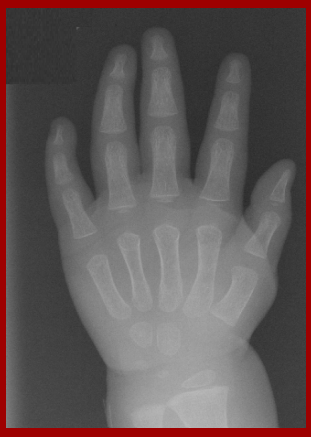

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Tuesday Nov. 29, 2005	**12:15pm – 12:25pm**	Theater 7B	Cost Comparison of Patient Tracking Technologies for an Outpatient Radiology Center	Nelson King, PhD
Tuesday Nov. 29, 2005	**12:25 – 12:35pm**	Theater 7B	A Workflow Study from Results Obtained by a Patient Tracking and Biometric Verification System in a Clinical Environment	Bing Guo, MD
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Nov. 27, 2005 Dec. 2, 2005	**On - Going**	InfoRAD Lakeside Center CODE:9903PDA-i	PDA Mobile Application for Distribution of Medical Images and Patient / Staff Tracking / Verification	Jorge Documet, BS
Nov. 27, 2005 Dec. 2, 2005	**On - Going**	InfoRAD Lakeside Center CODE:9129 DS-i	A CAD System for Diagnosis of Normal Pressure Hydrocephalus Based on Brain MR Images	Arkadiusz Gertych, Ph.D
Nov. 27, 2005 Dec. 2, 2005	**On - Going**	InfoRAD Lakeside Center CODE: 9711 NT-i	Patient Tracking and Facial Biometrics Integrated in a Clinical Environment for HIPAA Security Compliance	Bing Guo, MD
Nov. 27, 2005 Dec. 2, 2005	**On - Going**	Educational Lakeside Center CODE: LPH14-01	Cost Comparison of Patient Tracking Technologies for an Outpatient Radiology Center	Nelson King, Ph.D
Nov. 27, 2005 Dec. 2, 2005	**On - Going**	InfoRAD Lakeside Center CODE:9304 EMR-i	A Treatment-oriented Open Architecture ePR-based Radiotherapy Information System	Maria Law, D.Sc
Nov. 27, 2005 Dec. 2, 2005	**On - Going**	InfoRAD Lakeside Center CODE: 9137 DS-i	Computer-aided Diagnosis Workstation for Detection and Volumetric Measurement of Demyelination Plaques in Multiple Sclerosis	Ewa Pietka, D.Sc.
Nov. 27, 2005 Dec. 2, 2005	**On - Going**	Educational Lakeside Center CODE: 2557CE- e	Data Mining for Average Images in a Large-scale Digital Hand Atlas	Aifeng Zhang, MS
Nov. 27, 2005 Dec. 2, 2005	**On - Going**	Scientific Poster Lakeside Pavillion Code : LPL08-02	Carpal Bone Segmentation and Features Analysis in Bone Age Assessment of Children	Aifeng Zhang, MS
Nov. 27, 2005 Dec. 2, 2005	**On - Going**	InfoRAD Lakeside Center CODE:9607 PACS-i	Novel Architecture of HIPPA Compliant Automatic Monitoring System for RIS-integrated PACS Operation	Jianguo Zhang, Ph.D
Nov. 27, 2005 Dec. 2, 2005	**On - Going**	Educational Lakeside Center CODE: 2563CE-e	Integration of Lossless Digital Signature Embedding (LDSE) and Patient Tracking and Biometric Verification (PTV) Logs with a HIPAA Compliant Auditing System	Zheng Zhou, Ph.D.

CODE: LPL10-05
SESSION: Physics (Cellular Imaging, MR Imaging)

DATE: Wednesday, November 30 2005
START TIME: 12:55 PM
END TIME: 01:05 PM
LOCATION: Theater 5B

Use of Fat Saturated Spoiled Gradient Echo Recalled Sequences in Magnetic Resonance Imaging of Spine

***Tao Chan, MBCHB**, Hong Kong ● Kwok Chun, Cheng, BS ● Chiu Man Lee, MBBS ● Ka Fai Ma, MBBS ● Man Chiu AuYeung, MBB*

PURPOSE
To evaluate and validate the use of fat saturated spoiled gradient echo recalled sequences for contrast enhanced magnetic resonance imaging of spine.

METHOD AND MATERIALS
Ten consecutive patients referred for contrast enhanced magnetic resonance imaging (MRI) of spine were included in this prospective study. Different regions of spine including cervical (2), thoracic (6), and lumbar (5) have been studied. All the examinations were performed on a 1.5T imager. Post Gadolinium T1 weighted images were obtained using spoiled gradient echo recalled (SPGR) and spin echo (SE) sequences, both with fat saturation. Tissue contrast and contrast to noise ratios were calculated from region of interest measurements. The sequences were also compared against each other by three radiologists, with regard to their clarity in depiction of anatomic details and pathology.

RESULTS
Average contrast ratios between cord/CSF and marrow/CSF were significantly higher in the SPGR FS images compared with the SE images ($p<0.05$). Average contrast to noise ratios between cord/CSF, marrow/CSF, and cord/marrow in the SPGR images are higher than those in the SE images($p<0.001$). In subjective evaluations by consensus amongst three radiologists, the SPGR images are considered superior in 6 cases (60 %), similar in 4 cases (40 %), and none as inferior comparing against their SE counterparts in depiction of anatomic details. Concerning visualization of pathology in the 8 patients with identifiable lesions, the SPGR are considered superior in 4 cases (50%), similar in 3 cases (37.5%), and inferior in 1 case (12.5%). The SPGR protocol (including sagittal and axial sections) took an average of 3 min 45 sec to perform, which is far less than the mean time of 7 min 16 sec needed for the SE images.

CONCLUSION
Despite the much shorter time needed for image acquisition, post-gadolinium SPGR images fare better than the corresponding SE images, in terms of both objectives.

CODE: LPH14-02
SESSION: Radiology Informatics (Practice Management)

DATE: Tuesday, November 29 2005
TIME: 12:25 PM - 12:35 PM
LOCATION: Theater 7B

A Workflow Study from Results Obtained by a Patient Tracking and Biometric Verification System in a Clinical Environment

***Bing Guo, MD,** Marina Del Rey ● Jorge Documet, BS ● Brent Liu, PhD ● Han Huang, DSc ● Edward Grant, MD, Los Angeles ● Rasu Shrestha, MD*

PURPOSE
Patient workflow involves complex processes which require interdisciplinary teamwork among registration clerks, technologists, and physicians. In an effort to improve and optimize workflow processes, a workflow study was conducted focused on areas where mis-identification and extensive waiting times occur for the patient undergoing a radiological examination. To capture this data, we implemented a novel location tracking and verification system using Wi-Fi and Facial Biometrics Technology at an outpatient imaging facility, Healthcare Consultation Center 2 (HCC2) of USC.

METHOD AND MATERIALS
The patient workflow study was first collected via an observation period at HCC2. Each modality type workflow was observed (e.g., CT, MR, CR, US) including any interaction with the integrated HIS/RIS/PACS/VR (voice recognition) system at HCC2. From this study, baseline measurements were collected such as productivity, which was measured as the rate of patient throughput from normalized timing studies of a given typical workweek. The overall length of time for service was calculated from the time when the patient was registered in the RIS to the time that the image is available on the PACS. Once the baseline workflow study was complete, a location tracking and verification system was implemented. Data from the same parameters mentioned above were collected and compared and any interesting observations were documented.
RESULTS
Based on the comparison of the baseline workflow measurements and the measurements collected once the location tracking and verification system was implemented, numerous benefits were achieved: 1) The workflow processes of patients at HCC2 were streamlined and optimized reducing overall patient procedure time; 2) Unnecessary patient waiting times were reduced; 3) Improvement in overall productivity based on patient throughput; and 4) Mis-identification of patients undergoing a radiological procedure was virtually eliminated.
CONCLUSION
The workflow study shows that by implementing a location tracking and verification system for patients and clinical staff, an outpatient imaging facility can reap the benefits of improving workflow efficiency, productivity, and accuracy.

CODE: LPH14-01

SESSION: Radiology Informatics (Practice Management)

DATE: Tuesday, November 29 2005
TIME: 12:15 PM - 12:25 PM
LOCATION: Theater 7B

Cost Comparison of Patient Tracking Technologies for an Outpatient Radiology Center

***Nelson King, PhD**, Beirut Lebanon ● Bing Guo, MD ● Jorge Documet, BS ● Brent Liu, PhD ● Han Huang, DSc*

PURPOSE
Tracking of patients in a clinical setting is more than finding patient location in a busy facility. Patient location can be linked to workflow which enables verification of patient identity, controlling access to restricted areas, and improved efficiency by quantifying time spent at each location. Two-dimensional (2D) tracking of patients in real-time is a necessity when patient location is to be integrated with the clinical workflow. Most approaches require each patient tag to be within range of multiple sensor devices. However, radiology sites require shielding for modalities including CR/DR, CT, MR, and PET which blocks the propagation of signals from the tag to a sensor increasing the number of sensors required. A cost comparison of three technological choices for a 2D tracking system in a 13,000 square foot outpatient radiology center is described.

METHOD AND MATERIALS
Numerous location tracking products applicable to a clinical setting have reached the market. Passive RFID has received the most publicity (e.g., Walmart) but impractical for 2D patient tracking due to limited signal strength of the tag. Other technologies are active RFID, many variants of active wireless and infrared. Cost estimates for three technological approaches were made for a patient location module integrated with a clinical workflow system based on active RFID, passive RFID, and wireless 802.11 b/g using radio fingerprinting.
RESULTS
Our clinical site might require four to six sensor devices for tracking patient location without shielding but 20 or more with shielded rooms. A wireless 802.11 b/g product based on signal strength measurements was the clear choice based on costs. A wireless access point is an inexpensive sensor device compared to proprietary devices of other tracking technologies. The study also found that the annual cost of re-usable active tags worn by patients was less expensive than disposable tags. While 100 times more than an active tag, this center would require 25,000 disposable tags annually but only 50 re-usable tags.
CONCLUSION
Cost drivers in a patient tracking system are choice of location technology, type of tag, and placement of sensors in a shielded facility.

CODE: LPL08-02
SESSION: Pediatric (General)

DATE: Wednesday, November 30 2005
START TIME: 12:25 PM
END TIME: 12:35 PM
LOCATION: Theater 3B

Carpal Bone Segmentation and Features Analysis in Bone Age Assessment of Children

***Aifeng Zhang, MS**, Marina Del Rey ● Arkadiusz Gertych, PhD ● Brent Liu, PhD ● Han Huang, DSc ● Sylwia Kurkowska-Pospiech, PhD, Poland*

PURPOSE
A computer-aided diagnosis (CAD) method has been developed based on features extracted from epiphyseal regions of interest (ROI), which provides accurate bone age assessment of children 12 to18 of age. For children below 12 of age, the features of carpal bone ROI are required to achieve similar degree of accuracy. Past work on carpal bones segmentation has been done using dynamic thresholding. However, due to various stages of carpal bones development and the limitation of the segmentation algorithm itself, feature analysis of carpal bones has not been successful implemented. The goals of this study are: 1) To implement active contour model (snakes) to segment the carpal bones and extract pertinent features, 2) To refine the feature space using the data mining technique, 3) To combine the features from both epiphyseal and carpal ROIs for bone age assessment.
METHOD AND MATERIALS
The preprocessing of the hand image was preformed to automatically locate carpal bone ROI. Before an active contour model was applied to segment out carpal bones, prior knowledge about the centers of the bones was needed. The Gibbs random field procedure to locate the center of each carpal bone was developed. The number, size and separation features of all carpal bones were extracted. A feature selection procedure determined the most important features while eliminated the redundant ones. This reduced feature space was used to assess the bone age. The separation of carpal bones was useful for bone age assessment of children 0-9 of age and the amount of bone overlapping for children 9-12.
RESULTS
The new method was tested initially on 30 cases and is being applied to over 500 cases in our collection. Size and shape features of each carpal bone were extracted from each image successfully and applied to bone age assessment.
CONCLUSION
This research describes an image segmentation method on carpal ROI by active contour model with adaptive parameters. Preliminary results show that the accuracy of bone age assessment of children 0-12 of age is improved with the inclusion of carpal ROI, especially when the epiphyseal ROI analysis originally had failed.

INFORAD EXHIBITS

CODE: 9128 DS-i

DATE: Monday, November 28 2005
INFORAD TIMES: Sun. - Thurs. 8:00 AM - 5:00 PM & Fri. 8:00 AM - 12:45 PM
LOCATION: infoRAD Theater

Computer Aided Diagnosis of Acute Intracranial Hemorrhage on CT

***Tao Chan, MBCHB**, Hong Kong ● Han Huang, DSc, Marina Del Rey*

LEARNING OBJECTIVES
1. To learn the various image processing techniques useful in the CAD system related to acute intracranial hemorrhage on CT. 2. To understand the concept of knowledge based approach in image analysis of intracranial hemorrhage. 3. To appreciate the application of CAD in emergency conditions.

ABSTRACT
Diagnosis of acute intracranial hemorrhage on CT images is usually straightforward. But it can become difficult if the amount of blood is small, particularly for non-radiologists who need to scrutinize CT images in the acute management of

head injury or neurological symptoms. We have developed a computer aided diagnosis (CAD) system that can identify even minute amount of intraaxial or extraaxial hemorrhage, as small as 3mm across on conventional axial sections of CT brain. Candidate high density intracranial contents are extracted and mapped to a standard coordinate system. Their morphological and positional features are evaluated by fuzzy classifiers, based on anatomical and pathological knowledge. Our system achieves an accuracy of 92% in the initial 64 test cases, which include cases of clinically proven but inconspicuous intracranial hemorrhage. We are in the process of extending the study to a 300 case sample for statistical evaluation.

CODE: 9903 PDA-i

PDA Mobile Application for Distribution of Medical Images and Patient / Staff Tracking / Verification

Jorge Documet, BS *,Marina Del Rey ● Brent Liu, PhD ● Bing Guo, MD ● Nelson King, PhD, Beirut Lebanon ● Luis Documet, Santa Monica*

LEARNING OBJECTIVES
1. Demonstrate the capability to manage and distribute PACS image data from a PDA with a wireless network connection. 2. Integrate a patient/staff tracking/verification capability to the application. 3. Demonstrate a hands-on experience of patient/staff tracking/verification.

ABSTRACT
Last year an application to perform wireless remote control of PACS image distribution utilizing a Personal Digital Assistant (PDA) was presented. It was shown that this application is a powerful tool to distribute PACS exam data to diagnostic/review workstations, a PACS web server, a teleradiology system and a CD burning device. The ease-of-use of the application simplifies PACS exams distribution by allowing the user to perform remote control distribution from the PDA, making it a very attractive option especially when dealing with many DICOM nodes added to a clinical environment with PACS. In addition, a new management feature that allows the hospital personnel to obtain precise information about patient/staff location and verification/identification through biometrics has been integrated to the PDA application. This new feature will help to reduce unnecessary patient mis-identification and waiting time during a Radiology procedure.

CODE: 9129 DS-i

A CAD System for Diagnosis of Normal Pressure Hydrocephalus Based on Brain MR Images

Arkadiusz Gertych, PhD*, Marina Del Rey ● Brent Liu, PhD ● Chi-Shing Zee, MD, Los Angeles ●Tao Chan, MBCHB Hong Kong*

LEARNING OBJECTIVES
1. To identify the imaging features of NPH relevant to CAD. 2. Learn about image processing analysis of intracranial volume structures. 3. Study collected control group cases and pathological cases of NPH.

ABSTRACT
Normal pressure hydrocephalus (NPH) is an uncommon but potentially treatable cause of dementia. A CAD tool for automatically measuring compartments based on processing of MR images and making volumetric measurements of cerebral spinal fluid containing spaces (CSFCS) is developed. T1/2-weighted 5mm axial MR sections are acquired by a 1.5T Scanner and used as tool input. A 3D reconstruction of the ventricular system is followed by hybrid non-interactive image segmentation procedure including random fields and active contours techniques. Standardized parameters reflecting hydrocephalus and ratios between CSFCS in 17 diagnosed NPH cases are evaluated for comparison to a reference dataset of 75 normal adults. Appropriate cases are available for display. The whole process for one series of MR images takes approximately 5 min. to complete on a P4 2 GHz PC. CSFCS and relative ventricular volume ratios are confirmed to be useful parameters in CAD assessment of NPH.

CODE: 9711 NT-i

DATE: Thursday, December 01 2005
INFORAD TIMES: Sun. - Thurs. 8:00 AM - 5:00 PM
Fri. 8:00 AM - 12:45 PM
LOCATION: InfoRAD Theater

Patient Tracking and Facial Biometrics Integrated in a Clinical Environment for HIPAA Security Compliance

Bing Guo, MD, *Marina Del Rey ● Jorge Documet, BS ● Brent Liu, PhD ● Han Huang, DSc ● Nelson King, PhD, Beirut Lebanon ● Edward Grant, MD, Los Angeles*

LEARNING OBJECTIVES
1) Learn about real-time, high accuracy tracking systems, 2) Learn about ID Verification through Facial Biometrics, 3) Implementation pitfalls and challenges to the system integration, and 4) How to create a security zone in a clinical environment utilizing the proposed system integration to manage and locate patients and staff.

ABSTRACT
The purpose of this exhibit is to demonstrate a novel system for a clinical environment using wireless and facial biometric technology to monitor and automatically identify staff and patients in order to streamline the patient workflow, protect against erroneous examinations and create a security zone to prevent and audit unauthorized access to patient healthcare data under the HIPAA mandate. The USC Department of Radiology, Healthcare Consultation Center 2 (HCC2), which just implemented a fully digital environment with integrated HIS/RIS/PACS/VR (Voice Recognition) was a good initial first clinical test environment. The system is an integration of two components: a wireless real-time tag locating system to locate patients and staff and a Biometrics system to verify the patient and staff. Based on the workflow and user needs, a database with Graphical User Interface (GUI) was developed which allows users to extract real-time location information and identity verification

CODE: 9304 EMR-i

A Treatment-oriented Open Architecture ePR-based Radiotherapy Information System

Maria Law, DSc*, Hong Kong ●Lawrence Chan, PhD ● Fuk Hay ● Tang, PhD ●Han Huang, DSc, Marina Del Rey*

LEARNING OBJECTIVES
1. The use of DICOM-RT standard for integration of radiotherapy patient image and treatment information 2. The incorporation of intelligence into the information system for monitoring progress of treatment in oncology patients

ABSTRACT
This exhibit demonstrates an open architecture DICOM-RT based radiotherapy information system. The prototype consists of a DICOM-RT Archive Server used for storage of DICOM-RT based radiotherapy information such as images, treatment plans and records and a web client/server for information distribution. The system is designed according to ePR (electronic patient record) architecture in that each patient's information is grouped under the patient's identification number. Intelligence such as comparison of a patient's pre- and post-treatment images using computer-assisted detection method can be integrated into the system. This will enable the determination of the response of the tumor towards the radiation treatment or the associated chemotherapy. Nasopharyngeal carcinoma and brain tumors patients under radiation treatment are used for demonstration.

CODE: 9137 DS-i

Computer-aided Diagnosis Workstation for Detection and Volumetric Measurement of Demyelination Plaques in Multiple Sclerosis

Ewa Pietka, D.Sc., *Gliwice ● Jacek Kawa, MS ● Dominik Spinczyk, MS ● Marek Konopka, MD*

LEARNING OBJECTIVES
(1) Study the design of the computer aided diagnosis system, (2) review the MS cases included in the data base, (3) review the image analysis methodology able to detect and measure the demyelination plaques, (4) review the image analysis methodology able remove the skull and perform the 3D rendering which implements the OpenGL technology.

ABSTRACT
Multiple sclerosis (MS) is a chronic disabling disease of the central nervous system. The total estimated MS population in the United States is approximately 300,000. MR imaging is a common examination tool used to track and predict the progression of MS once the presence of the disease has been detected. The plaque segmentation is performed by implementing the kernel functions in the c-means clustering technique. The type of functions depends on the MR acquisition technique implemented at the examination procedure. Once the spots are detected, a 3D rendering technique is implemented to view the demyelination areas. It includes also an active contour procedure which removes the skull. A set of 100 studies has been successfully tested. A graphical user interface shows the volumes of each plaque and sums up the total. If a false positive occurs in the image, the user is able to remove it.

CODE: 9607 PACS-i

Novel Architecture of HIPAA Compliant Automatic Monitoring System for RIS-integrated PACS Operation

***Jianguo Zhang, PhD**, Shanghai ● Xiaomeng Chen ● Jianyong Sun, PhD ● Yuanyuan Yang, MS ● Jin Jin ● Han Huang, DSc*

LEARNING OBJECTIVES
1. Novel architecture of AMS monitoring RIS-integrated PACS with DICOM defined auditing trail mechanism; 2. Monitor and control security status of the entire PACS operation in real time from any where; 3. Track patient and image data flow and RIS work flow automatically; 4. Identify and respond any failure in any PACS process.

ABSTRACT
RIS-integrated PACS (PACS) is a large system consisting of many components. Chances of any of these components fail at a given period of time are high. Also, the HIPAA requires security services being implemented in healthcare information systems, and DIOCM defines a mechanism to collect the Auditing Trail Messages generated by applications to facilitate detection of improper creation, access, modification and deletion of Protected Health Information. For this reason, we present a HIPAA compliant automatic monitoring system (AMS) with a novel architecture to monitor PACS operation. The AMS consists of two parts: monitoring agents and a Monitor Server. Monitoring agents connect to all services in each PACS component. The Monitor Server tracks the status of individual component, and verifies image/reports being used in accordance with the healthcare provider's security requirements. The PACS manager can monitor the PACS operation from anywhere with AMS.

EDUCATIONAL EXHIBITS

CODE: 2379CE-e

An Illustrative Application of CAD in Neuroradiology: Intelligent Automated Detection System of Intracranial Hemorrhage

***Tao Chan, MBCHB,** Hong Kong ● Han Huang, DSC, Marina Del Rey*

LEARNING OBJECTIVES
1. To recognize that CAD is valuable for diagnosis of acute intracranial hemorrhage. 2. To illustrate how various CT artefacts can hamper diagnosis of intracranial hemorrhage. 3. To learn some basic principles and techniques of CAD.

ABSTRACT
Application of computer aided diagnosis (CAD) in neuroradiology has not been well established. Here we introduce a CAD system that detects acute intracranial hemorrhage on CT. This everyday task remains elusive to inexperienced clinicians and computer alike. CT numbers of intracranial hematomas significantly overlap those of brain parenchyma. Artefacts like partial volume averaging and beam hardening further complicate the problem by obscuring or simulating small blood clots. Basic concepts and techniques that enable CAD for handling such difficulties, including artificial intelligence and use of a priori knowledge, will be discussed. Results on the initial 64 test cases were promising (sensitivity 96%, specificity 90%). It only missed one out of the six cases of hemorrhage that were rated as difficult by experienced radiologists. A large database containing various acute intracranial hemorrhage cases is being collected to test the robustness of the system.

CODE: 2557CE-e

Data Mining for Average Images in a Large-scale Digital Hand Atlas

Aifeng Zhang, MS, *Marina Del Rey ● Arkadiusz Gertych, PhD ● Brent Liu, PhD ● Han Huang, DSc ● Sylwia Kurkowska-Pospiech, PhD, Poland*

LEARNING OBJECTIVES
1) Learn data mining methodology and its applications, 2) Study feature selection procedure in a large-scale CAD medical application, 3) Study the average feature vector matching method, 4) Understand the significance of objectively selected average images in a digital hand atlas.

ABSTRACT
A digital hand atlas contains hand radiographs of 1,152 normally developed children. For each image, 11 bony features were extracted from each of 6 regions of interest. A data mining procedure was developed to objectively select the average image which is the best representative of skeletal maturity for each age group. A feature selection procedure was performed to reduce the feature dimension from the initial 66-dimension feature space and determine the weight vector which indicates the discriminative power of the feature. To find the average image objectively, the data of an image representation in the features domain was mined. This was done by an average feature vector (AFV) matching based on the weight vector. The closest match in terms of Euclidean distance to the AFV among all the images in a specific age group was chosen as the average image. The average images, functioning as teaching files, are available for radiologists to evaluate in clinical practice.

CODE: 2563CE-e

Integration of Lossless Digital Signature Embedding (LDSE) and Patient Tracking and Biometric Verification (PTV) Logs with a HIPAA Compliant Auditing System

Zheng Zhou, Ph.D*., Marina Del Rey ● Brent Liu, PhD ● Han Huang, DSc ● Bing Guo, MD ● Jorge Documet, BS ● Nelson King PhD, Beirut Lebanon*

LEARNING OBJECTIVES
1. Learn HIPAA Security Rules, 2. Learn how to generate HIPAA audit trails of image data access on demand through the HCAS, 3. Gain knowledge on image integrity protection through LDSE methods, 4. Gain knowledge how to track and verify patients in clinical environment through patient tracking methods.

ABSTRACT
HIPAA Security Rules require healthcare providers to protect the privacy and integrity of health data and demonstrate examples of mechanisms that can be used to accomplish this task. Also required is the ability to provide on demand audit trails of data access for a specific patient. In 2004 RSNA, a HIPAA Compliant Auditing system (HCAS) for facilitating the generation of HIPAA compliant audit trails on image data access in PACS was presented. This year, two new components are integrated with HCAS: LDSE for image integrity assurance, and PTV for clinical systems security access and identification verification. PTV creates a security zone to locate patients in clinical environment and verify a user with facial biometrics during access to a clinical system. Log data from LDSE and PTV is captured and added to the HCAS. The integration of the LDSE and PTV with HCAS can provide additional information for image data access audit trails and assure image integrity and data access privacy.