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A MODEL FOR MEDICAL DIAGNOSTIC LABORATORY: MULTIMEDIA DATABASE APPROACH

Abstract. There are two main tendencies in Medical Informatics. One is the development of core theory in the information technology itself and the other one is the use of technologies in applications for health improvement. In recent years the deployment of Health Information System (HIS) applications and Laboratory Information System (LIS) in some big hospitals have enhanced the quality of administrative management and actively supported the diagnosis and treatment tasks of the physician. In this paper we will present an architectural model of the Medical Diagnostic Laboratory (MDL) and show its applications.

Keywords: medical diagnostic laboratory, laboratory information system, radiology information systems, picture archiving and communication system, digital image and communication in medicine, health level

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МОДЕЛЬ МЕДИЦИНСКОЙ ДИАГНОСТИЧЕСКОЙ ЛАБОРАТОРИИ: МУЛЬТИМЕДИЙНЫЙ ПОДХОД К БАЗЕ ДАННЫХ

Аннотация. В медицинской информатике существуют две основные тенденции. Одной из них является разработка теории в области информационных технологий, а другой – использование информационных технологий в приложениях для медицины. В последние годы развертывание медицинских информационных систем и лабораторных информационных систем в больницах повысило качество административного управления и улучшило процессы диагностики заболеваний и лечения пациентов. В статье представлена архитектурная модель медицинской диагностической лаборатории и показаны ее приложения.

Ключевые слова: медицинская диагностическая лаборатория, лабораторная информационная система, радиологические информационные системы, система архивации и передачи изображений, цифровые изображения и их передача в медицине, уровень здравоохранения

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Introduction. Radiology Information Systems (RIS) use digital images (in DICOM, JPEG formats) instead of the traditional method of using films. A doctor can easily interact, process images during the analysis using computer software. DICOM standard continues to evolve to meet the growing and changing the role of imaging in clinical and research environments, as emphasized by the many technical working groups [1]. It will help to reduce the need for using films in diagnosis, save the cost of films and the storage issues. RIS is a core of the HIS with the added requirement of

institution's Picture Archiving and Communication System (PACS) and workflow seen in a radiology department. A distinguishing aspect of RIS vs. PACS is that the former is typically constrained to non-imaging data, whereas PACS is primarily concerned with the storage and manipulating of the imaging data [1]. RIS also help to reduce the number of medical images when patient data are stored in a computer system.

All data related to patient diagnosis are those such as medical images, diagnosis, management reporting, a unified storage, synchronization and security. Therefore, doctors and even patients can view details about the medical history over time easily. This will be a great assistance in the examination and treatment of disease.

The system allows multiple access and fast response. Doctors can access data and images of the patient quickly and accurately every time, anywhere based on computing technology in a network system.

It is extremely important in medicine, more than in any other field, that the accuracy is comparable to experts. Diagnoses that are incorrect, or other diagnoses which are missed, may result in serious consequences for the patients. HIS provides support to medical personnel improving the reliability and quality of treatment [2].

MDL occupies a large part of the structure of diagnostic research, both in the quantity of research and the clinical importance of test results – which are an important source of diagnostic information for modern medical diagnostic processes. According to world statistics, in previous decades the quantity of performed clinical laboratory tests and their diagnostic importance exponentially increased – and it continues to increase [3]. Analogous to RIS for radiology, LIS deal with the requirement of laboratory and pathology departments, providing interfaces to the various instruments used to assess chemistry, hematology, immunology, microbiology, genetic and other histopathologic markers. The use of LIS has now become the standard of MDL activity.

The integration of LIS-RIS-PACS-Teleradiology forms a perfect combination to meet the needs of professional work of physicians. This combination forms a closed system and can replace systems based on traditional medical records, which require significant efforts on consultations during analysis of medical images and video sequences in the case of an emergency or difficult cases. PACS and teleradiology combined model in which the PACS also supports imaging centers for radiology reading is shown in fig. 1.

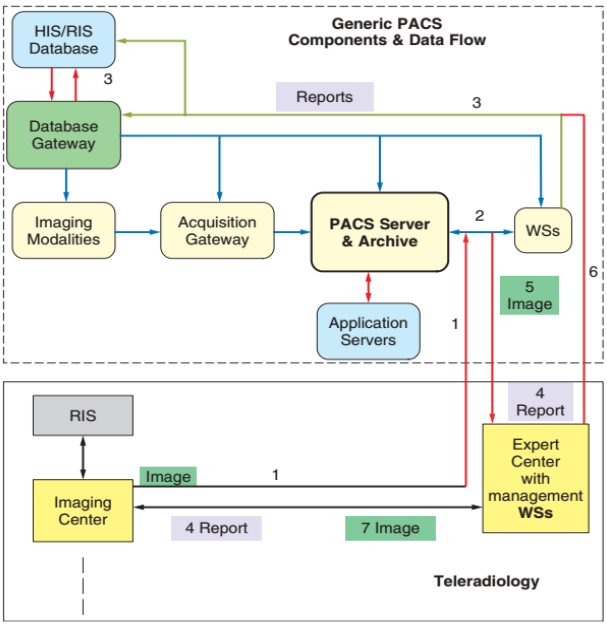

Fig. 1. PACS and teleradiology combined model

Teleradiology can be compiled together with PACS as a healthcare enterprise operation and the workflow of this combined model consists of seven steps:

– Radiologists at PACS WSs read exams from outside imaging centers (step 1).

– After reading by PACS radiologists from its owns WSs (step 2), the reports are sent to the HIS database via the database gateway for its own record (step 3) and to the expert center (step 4, 5) from where the report (step 4) is also sent back to the imaging center.

– PACS can also send its own exams to outside expert center for reading (step 5). The expert center returns the report to the PACS database gateway (step 6).

– The imaging center sends images to the expert center for reading as in the pure teleradiology model (step 7).

Ideally the combined teleradiology and PACS model should be used in a heathcare center with the satellite imaging centers, multiple affiliated hospitals, and with backup radiology coverage between hospitals and imaging centers [4].

RIS and MDL system promises to bring a lot of economic efficiency and social networking in the work of community health, improve the quality of people's health care with approximately 90,000 cases per year can save about 25 % compared with the cost of the film in RIS (Huang 2004). FirstHealth RIS system allows for film budget cuts over 37 %, from approximately $80,000 to $50,000, director of FirstHealth images – Mike McCarthy has told in Computer World.

In this paper, we propose a model for Medical Diagnostic Laboratory together with the ER-diagram of MDL. We also describe issues of development LIS-RIS-PACS-Teleradiology, its integration into Hospital Information System (HIS) and present some results.

Related work

In Vietnam. With the strong development of the information technologies industry in Vietnam in recent years, most of the major hospitals in the country find the need to apply information technologies in a health sector, particularly in data management issues, medical imaging, video and medical needs of patients for the remote consultation. Starting from practical needs, many hospitals have invested to develop software systems and build Hospital Information Systems.

Since 2003, Viet-Duc Hospital has implemented projects for consultant surgical system online. This is part of a big project to build remote sensing centers of Viet-Duc Hospital. With this model, an experienced medical consultant of Viet-Duc Hospital can sit at his hospital to direct or to control a surgical case carring out in other places by means of a camera and a remote monitor.

Foreseeing this need, a number of IT companies in Vietnam concentrate investment in the development of systems related to a medical field, including HIS and RIS systems. General research and development of RIS systems are still slow and not being invested properly although this is a core system and it is extremely important.

Transmission infrastructure in Vietnam is the next generation network NGN (Next Generation Network) with IP high-quality backbone network by the Posts and Telecommunications Corporation. It provides fiber optic transmission as technological security VPN (Virtual Private Network) which is a very good support for telemedicine applications. In addition, with the development of research and education network in Vietnam (VinaREN), high-speed connection organizations, research centers and universities in Vietnam have opened up opportunities for the new applications requiring more bandwidth, and there is a large amount of data which need to be exchanged and computed. Combined with the TEIN2 network (currently being upgraded to TEIN3 network), VinaREN can connect to the countries with great potential in science and technology such as France, Hong Kong and Taiwan, etc. This is the foundation network infrastructure to develop the high quality RIS and teleradiology systems.

In the world. In recent years, the term MDL, RIS and Telemedicine has appeared in more developed countries such as the United States, Canada, Switzerland, Japan. Telemedicine is the application of information technologies which conveniently, quickly and effectively bring health service, health education to remote users. These systems have gradually proved necessity and appropriate life needs of a growing society.

First PACS Project titled "Installation Site for Digital Imaging Network and Picture Archiving and Communication System" was implemented in U.S. in 1983 with the investment of U.S. Army and managed by The MITRE Corporation in 1986. According to estimates predicted in 2001, the United States has a cost to the healthcare system to nearly $2 billion, not including the cost of equipment and other software applications.

In Asia, the First International Symposium on PACS and PHD (Personal Health Data), was held in Japan (7/1982) by the Japan Association of Medical Imaging Technology. Japan considers development of PACS as a national project. The national resources are distributed to many manufacturers and hospitals, universities.

In Europe, EuroPACS (Picture Archiving and Communication Systems in Europe) conferences are held every year since 1983. National Health Service (NHS) in the UK is one of the leading organizations in the research and development of PACS in Europe and also had a lot of success. According to the latest analysis from Frost and Sullivan indicates PACS market in Europe reached 535 million euros (679 million dollars) in 2009 and the figure is estimated to reach 1,065 million euros (1,353 million dollars) in 2016.

Due to the differences in operating conditions and environment, PACS are different in North America, Europe, and Asia. At first, the research and development of PACS in the U.S. set huge support from the government agencies and manufacturers. In European countries, the PACS developed through the support of local organizations and multinationals. The European research teams collaborate with major manufacturers, because most of the components of the PACS systems were developed in the U.S. and Japan [5]. RIS systems are also very popular in European countries and America. RIS are widely deployed in most hospitals, and also there are many components of RIS which have been developed as an open source and are available for users to learn and use. This is a favorable condition for us to learn and develop appropriate RIS, LIS and MDL systems in Vietnam.

Needs of local hospital. According Viet-Duc hospital, every year over 1,000 cases transferred to hospital died. In many cases, if the initial emergency handling is good and in time then the patient can live. Meanwhile, local hospitals are lack of equipment and qualified physicians are limited, which are not regularly updated. So how the physicians in central hospitals and in medical universities can support as well as consult for remote medical stations. Surgical teleconsultation system is an ideal solution.

Currently, almost all the general hospitals in Vietnam were equipped with diagnostic imaging equipment with new technologies such as Computed Tomography (CT), Magnetic Resonance (MR), Computed Radiography (CR), UltraSound (US). All devices are supported by the digital data standards (DICOM, JPEG, video). However, many hospitals still work with professional film images. They still spend a part of their budget for the purchase and storage of plastic film images.

The devices operate on an independent base and they are still not connected and have no exchange between departments with different expertise. Because of that it takes so much time and efforts to collect information about patient, to perform a general diagnostic or consultations. This causes a significant reduction in speed, flexibility, accuracy and convenience in handling cases of emergency or urgent surgery. This is an essential requirement in order to improve the quality of health care for people.

The process of receiving and processing patient data in traditional medical records are still complex and time-consuming in the examination and treatment. The issue of cost of film, film storage and replication is always a burden for hospitals. To retrieve patient records on traditional medical record, film records and learn the medical history of the patient is also a difficult issue for physicians. Therefore, solutions on integrating the LIS-RIS-PACS Teleradiology will be a good remedy to help address all the above issues.

LIS-RIS-PACS Architecture at general hospital

PACS Architecture. According to the general architecture, PACS system is divided into three main classes: Class Image Devices (modalities), Class PACS server systems and Class Workstation Applications (fig. 2).

The conventional imaging devices are digital X-ray (CR) cameras, Computed Tomography (CT), UltraSound (US) and Magnetic Resonance (MR) scanners. These devices are be able to provide medical images or video sequences.

PACS Server is a core component of the system responsible for three main functions:

– Collecting data from medical imaging devices immediately after patient admission photography pictures port (PACS GATEWAY).

– Organize storage and management of medical data and other relevant information of the patient.

– Provides, coordinates the application support the examination and treatment: information function to filter, display support functions, image processing and analysis, functional diagnosis support, functional support consultation.

The client application is a machine worked by physician and other medical staff. It will typically have high requirements on the display device (size, resolution, brightness, etc.) and it will help health officers to exploit the functionality offered by the system.

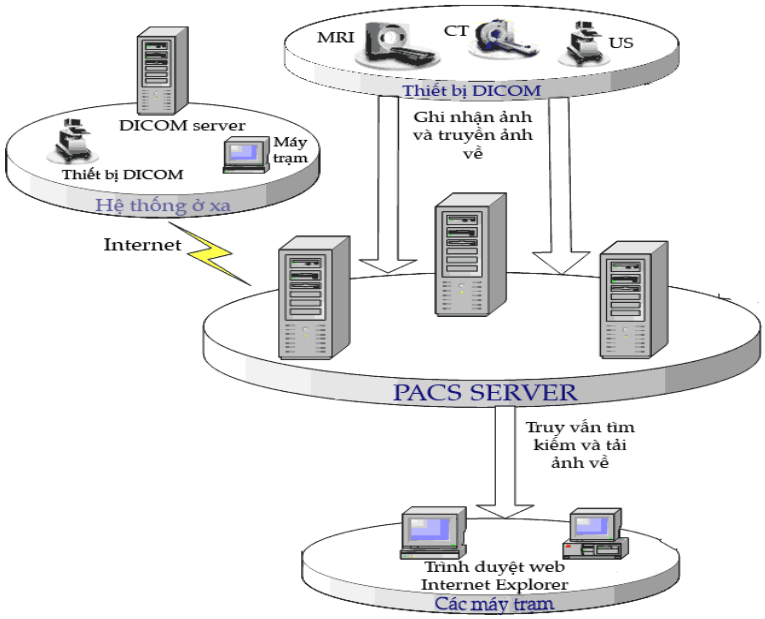

Fig. 2. Architectural model of PACS system

HIS-RIS-PACS Architecture. PACS is a system platform in the application system for the medical field. Typically, the PACS system will provide image data/video systems for medical rest. All three systems HIS, RIS and PACS need to be closely connected with each other, truly meet the requirements of the hospital and fully exploit the power that the number of medical devices can bring.

Therefore, PACS should be built as open system interfaces connected to the development of data standards in the field of medical standards like DICOM and HL7. This is useful when hospitals in developing countries synchronize three systems HIS-RIS-PACS together (fig. 3). Some hospitals develop first RIS-PACS or HIS, then continue development of remaining systems. This requires that the system must be able to communicate with each other easily, flexibly through common data standards.

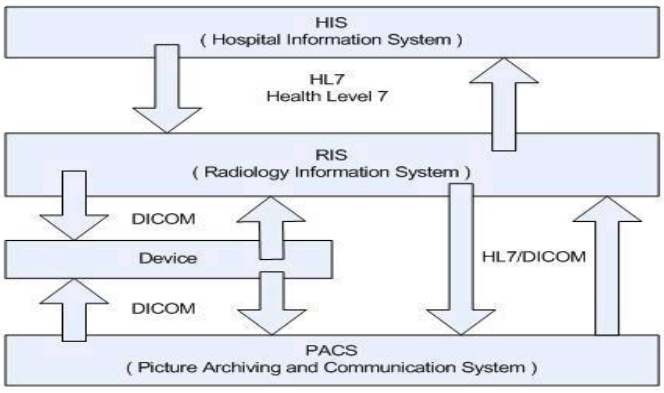

Fig. 3. The links model between HIS-RIS-PACS

Data Standards used for communication and representation. Three data standard most commonly used in the system as DICOM and HL7.

– Health Level 7 (HL7): The computer can only exchange data with each patient when they have a common communication protocol (communication environment and common language). It was developed in 1987 and HL7 has become a common protocol to be applied globally to share patient data.

– DICOM (The Digital Image and Communication in Medicine) is a standard that defines the format and rules of exchange of medical images and related information. Medical imaging is received from a device with different digital images such as CT (Computed Tomography), MR (Magnetic Resonance), US (UltraSound), NM (Nuclear Medicine). It creates a common language for communication and allows exchange of images and related information between medical devices and information systems in healthcare networks.

– LOINC (Logical Observation Identifiers Name, and Codes) is a codification for clinical laboratory values and common observation.

Flowchart of the workflow for deployment of the HIS-RIS-PACS system. PACS system was designed in conjunction with RIS to meet the work requirements of the medical staff from the stage of welcome patients, receiving and storing medical data (images, video) to the stage of support the display, processing, analysis and diagnosis of the health status of patients.

The RIS-PACS system is guaranteed to bring the convenient, fast processing for both medical staff and patients, along with historical information of patient. The biggest advantage when deploying the RIS system is the rapid speed of the response, convenience and the ability to assess the medical history of the patient. With this system, right after the hospital receive a patient, a physician immediately can review a medical history of the patient. Since then, the medical doctor gives the order to the Diagnostic Imaging Department. After photographing finished, the patient does not have to wait for receiving film and confirmation by doctors at the Department of Diagnostic Imaging. Patients do not need to bring the film back to the clinic or emergency department (fig. 4). At the clinic or emergency department, physicians can easily view, process and analyze images immediately after patients were taken. In particular, at this moment the doctors between the concerning departments can organize and conduct the diagnosis through remote consultation program. Soon there will be conclusion for the patient. This contributes to simplification of procedures for patients and shorten the process time and handle the medical emergencies.

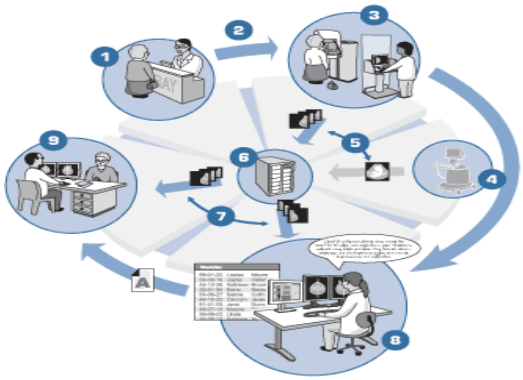

Fig. 4. Flowchart of workflow to deploying HIS-RIS-PACS systems

Medical diagnosis laboratory model. To provide a basis for the development of LIS which really meet the requirements of health care workers, a domain analysis for Electronic Health Records (EHR) has been undertaken in close cooperation of computer scientists with several domain experts [6].

Firstly, based on field studies in some hospitals, a generic hospital laboratory structure is derived and the relevant entities for MDL are identified. Secondly, hospital specific laboratory workflow problems are discussed. Sources of the information for construction of information model are document circulation and experts of laboratory. As well as in any other organization, passage of

documents through MDL is accompanied by the certain procedures of the coordination, the statement and signing of documents and the control over their origin [7].

A macro model of MDL functioning follows a certain sequence of events. First, during input, research orders and biomaterial samples are registered and brought into correspondence with each other. Next, analyses (a set of laboratory tests) are carried out automatically or manually. Then, the obtained results of these tests are passed to a requester. The following peculiarities can be outlined at this stage:

– Test results (and their dynamics) are of great diagnostic importance.

– There is significant document circulation between clinical departments and laboratories.

– There are a great number of tests to perform.

– There is an availability of efficient automatic analyzers, information from which can be transferred.

– There is a necessity to improve the reliability and quality of laboratory research.

– There is a great deal of routine work completed by laboratory employees.

– The necessity of laboratory operational statistics preparation and availability of scientific statistics.

All of these factors work together to propel the necessity to solve the problems of transferring and storing data, as well as the need to act responsibly to ensure the reliability and quality of publicly available laboratory research results. Therefore, the best solution to these problems is the use of modern IT technologies and facilities in laboratory activities.

Relations between Hospital Information System, Laboratory Information System and Radiology Information System are shown in fig. 5.

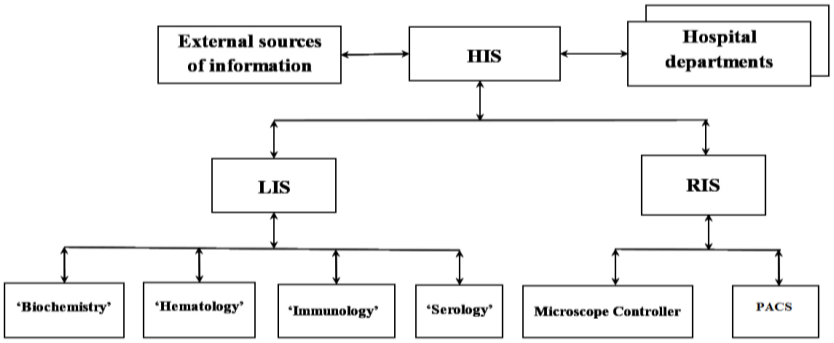

Fig. 5. Relations between Hospital Information System, Laboratory Information Systems and Radiology Information System

The ER-diagram of MDL. The database of MDL contains relevant information concerning entities and relationships in which the MDL is interested. A complete description of an entity or relationship may not be recorded in the MDL database. It is impossible (and, perhaps, unnecessary) to record every potentially available piece of information about entities and relationships [8]. From now on, we shall consider only the entities and relationships (and the information concerning them), which are to enter into the design of a database.

Entity Relationship Diagrams illustrate the logical structure of databases. An entity is an object or concept about which you want to store information. Relationships illustrate how two entities share information in the database structure.

On the basis of domain analysis, the high-level (not detailed) ER-diagram of MDL is presented in fig. 6. This diagram incorporates some of the important semantic information about the MDL. Its components are rectangles that represent entities and diamonds represent relationships.

An explanation of the model in fig. 6 is given as follows. Analysis (entity **ANALYSIS**) is a set of the laboratory tests (entity **TEST**). For example, biochemical blood analysis includes whole protein, albumin, glucose, etc.

Reference range of the test depends on the method of testing, patient's gender and age.

Result values of some tests can be verbal. Verbal values are collected in the entity **TERM**.

In some cases, entities can be self-linked. For example, tests can include other tests (relationship **component**).

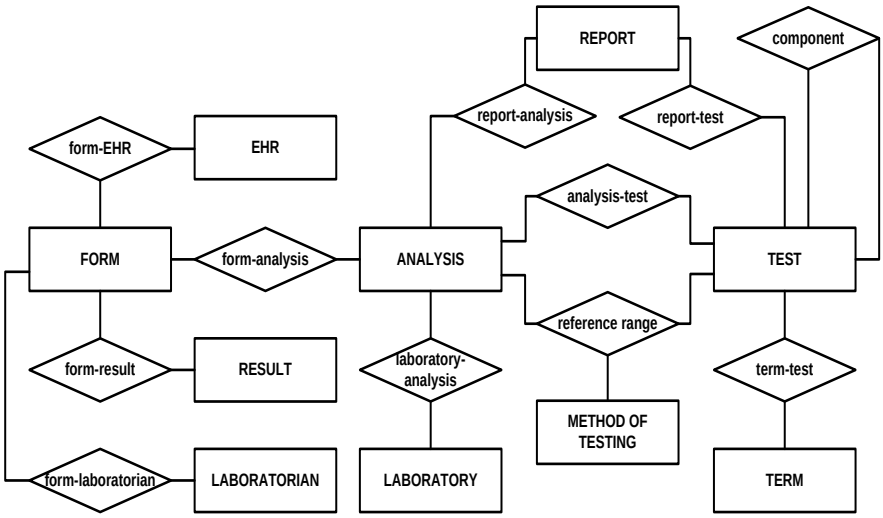

Fig. 6. The ER-diagram of Medical Diagnostic Laboratory

The entity **FORM** collects all information on analysis (patient ID, doctor, date of sampling, etc.). All patients' analyses are contained in the entity **FORM**, which is linked to the entity **EHR** by relationship **form-EHR**. The entity **RESULT** is intended to store the results of laboratory tests. The list of laboratory employees is represented as the entity **LABORATORIAN**.

Representation of **TEST** as a separate entity lays in the basis of our approach [9]. According to this approach, the database scheme does not depend on quantity and structure of laboratory subdivisions and tests in MDL.

Implementation and results

Deployment at the common health hospitals. From the orientation of the system above, we want to introduce some typical functions of the system that we have developed and that are being implemented effectively in a number of hospitals.

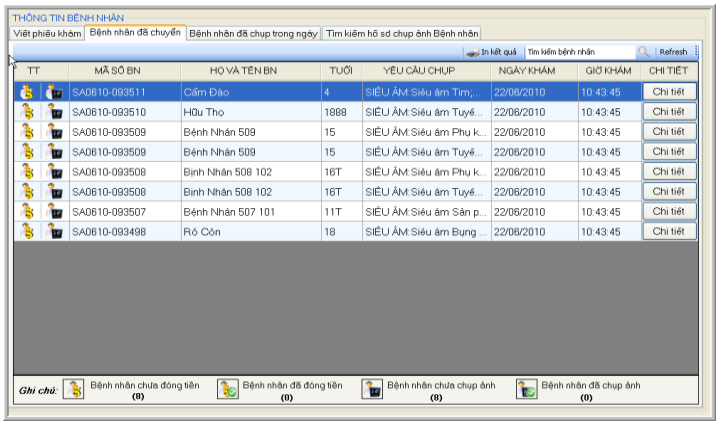

Fig. 7. Program manager for examination and treatment at the Diagnosis Department

Program manager for examination and treatment at the Department of Diagnostic Imaging is shown in fig. 7. It connects information flows between: patient reception area, Examination Department, Emergency Department, Finance and Accounting Department, Diagnostic Imaging Department [10].

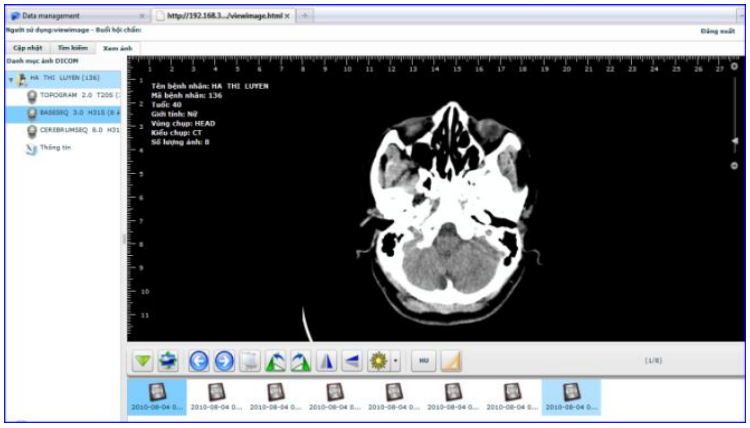

Fig. 8. Specialized software for medical image filtering and visualization

The software extracts patient information, search, view detailed photos/video of patient diagnosis (fig. 8). Moreover, the software also supports operations change the image size, image change direction, increase or decrease the contrast, changing the light/dark, HU factor analysis, measuring the size of the damaged region, recording results and conclusions.

The user interface of the software for management and tracking data, management of patient data related to diagnostic imaging, user management, management of information services for imaging diagnostics is depicted on the fig. 9.

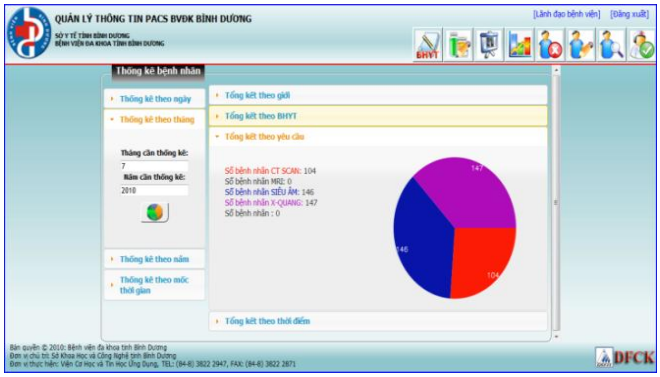

Fig. 9. The UI of the software for management and tracking patients' data

The software supports activities at the Department of Diagnostic Ultrasound images (fig. 10). It allows the storage, management, display the ultrasound images and video.

Fig. 10. The software for ultrasound consultations

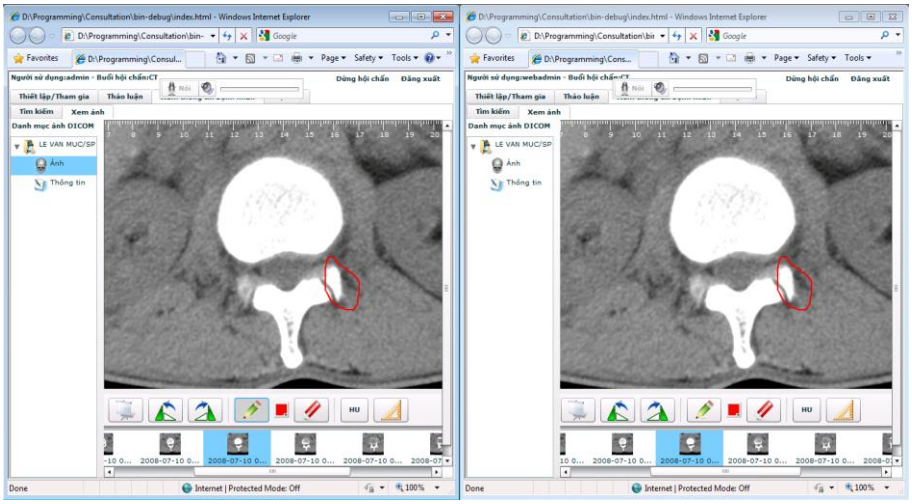

Fig. 11. The software for remote consultation program based on medical imaging

The software for organization and management of remote medical consultation based on medical images is presented in fig. 11. It allows to perform synchronization and coordination of activities during consultation. The end users of the consultation infrastructure can communicate with each other by means of chat window, voice communication and screen sharing (image synchronization with the tools to create focal points, objects localize etc.).

MDL and tuberculosis prevention. In tropical countries the most serious illness besides cancer is tuberculosis. Implementing Medical Diagnostics Laboratory on the Data Center will support all the hospitals which have not been implemented for their local PACS there. We have suggested the HCM City Public Health Association to survey all the hospitals which participated to the Tuberculosis Prevention Program then implemented Cloud PACS Server at the Data Center to receive all the images of Patients in remote hospitals (fig. 12) [11].

At present, there is an emphasis on sharing clinical and research data. Beyond the obvious reasons of facilitating patient care outside of single institution model, it is believed that new knowledge about diseases and their treatment will only come about through team science and pooling of data, computational resources, and domain expertise [12]. Imaging with its emergent role in all areas of healthcare, has been a particular so as to establish normalized datasets for research and validation studies [13].

PACS Server and PACS Gateway have been implemented at Pham Ngoc Thach Hospital to carry out the Tuberculosis Prevention Program of HCM City Public Health Association.

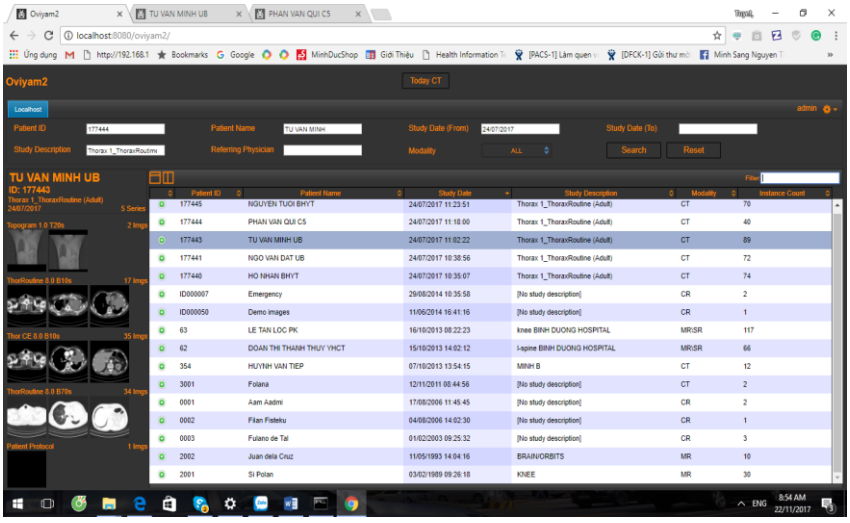

Fig. 12. The Medical doctor and the person in the TPP Program have an access to the database

The chest radiology is often the first examination to suggest pulmonary pathology. More advanced imaging techniques such as CT, MR, and ultrasound are typically used to better characterize respiratory pathology because they provide cross-sectional perspective and eliminate the superimposition of structures that is characteristic of projection imaging [14]. CT is the most commonly used advanced imaging technique to further characterize pulmonary parenchymal, pulmonary vascular, and pleural pathology, owing to its high spatial resolution and the high native contrast of aerated lung relative to soft tissue (fig. 13 and fig. 14).

Fig. 13. An example of a lungs CT archived in the database of PPT Program

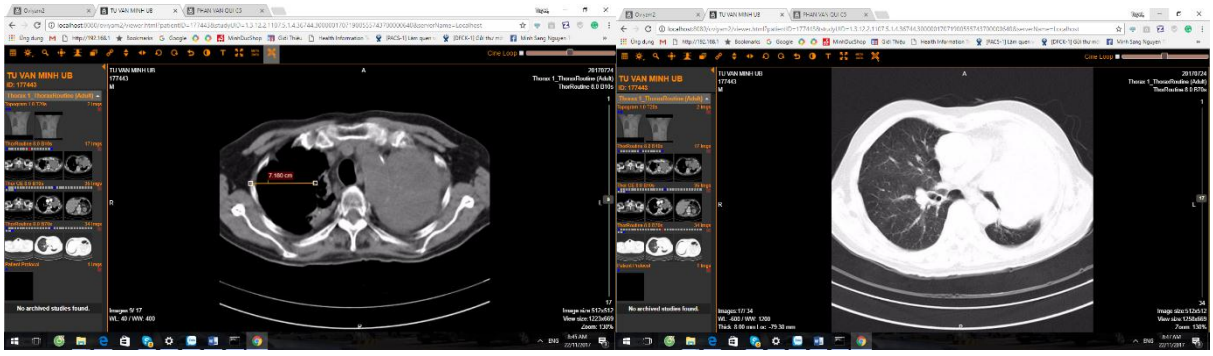

Fig. 14. Axial CT images in a patient with mild asthma show

Conclusion. Medical Imaging informatics is the rapidly evolving field combining biomedical informatics and image processing, developing and adapting core method in informatics to improve the usage and application of imaging in healthcare; and to derive new knowledge from image study. LIS-RIS-PACS-Teleradiology system improve the use of imaging throughout the medical care process. Along with the strong development of science and technology, particularly the application of information technology in practice, it can be said that better development is needed. The application of this system in hospitals will contribute greatly to improvement of the quality of healthcare in the community.

User applications of information technologies into a health sector are key directions which the Government and the Ministry of Health are very interested in. Accordingly, we continue strong investment in research and development, further improving LIS-RIS-PACS-Teleradiology system.

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