A Flexible Medical Image Archiving and Reporting System

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Abstract: *Nowadays diagnostic imaging systems have being used as a daily routine in medical institutions. The evolution of electronics, image technologies and communications has led to quick growing a quantity of medical applications and devices, that process visual information for diagnosing and treatment purposes. For quality management and patient protection reasons these systems are integrated into complex hospital information systems (HIS). Radiological imaging has the highest standardisation level and is widely used with PACS and within Radiology Information Systems (RIS). Unfortunately, other modalities, e.g. ultrasound, microscopy and etc., are suffering from a lack of standards for creating, processing and archiving image material. To fill this gap, many research and commercial organisations have been proposing various local solutions. This paper describes an approach in the application development that supports physicians in selecting appropriate decisions and provides image archiving in a flexible way. The application is positioned first to be used in echocardiography.*

Keywords: Medical imaging, Image Archiving and Reporting, Ultrasound, Echocardiography, Telemedicine, DICOM.

1. INTRODUCTION

Usually, image information taken from various medical scanners is processed and analysed by medical personnel on working stations. A direct connection between a device and a workstation is traditionally the most used type of the communication architecture. This allows to reach maximum of the communication speed, and the diagnosing process can be organised on-line. However, with fast development of clinical networks and optimisation of data flows, this architecture has many drawbacks, such as complexities with the clinical integration, administration and security. A better way to overcome these drawbacks is to store the image material centrally. It allows to improve the data safety, to provide access for other applications and to support necessary functionality in the hospital information system (HIS). A system architecture described by the client-server model (3-tier model) became popular (Fig.1). The system generally consists of scanners, one or more database servers and workstations. Most advanced modern applications that provide to the physicians an access and up-to-date services for the patient information are implemented in radiology departments. As a rule, a picture archiving and communication system (PACS) is used for storing and viewing radiological images and reports. However, image archiving and information management are required for many imaging systems beyond radiology, like ultrasound, microscopes, cameras, etc. The level of standardisation of the image formation and the image acquisition in these systems is much lower than this level in radiological imaging. Pixel intensity, signal to noise ration, colours, geometry and contents depend on an operator and proprietary characteristics of the scanner. Some devices are able to store data in DICOM format, while others use common media formats, like TIFF, JPEG, AVI, etc. Frequently, conditions of the acquisition and some quantitative information are completely ignored or presented as the image content. This incompatibility leads to difficulties in common interpretation of images acquired from different scanners or taken by different operators. It results in suboptimal addressability of medical services, prolongation of the diagnosing procedure, troubles in the contemplation by remote experts.

Utilising radiological PACS only for archiving such material does not solve these problems. Therefore local solutions are required to fill the gap. Such clinical image archiving systems are frequently used not only for storage & retrieval of image material, but as well for supporting medical staff for diagnosing, reporting and implementing clinical protocols as well. A typical system consists of a storage server, diagnosing station, patient tracking and scheduling system, results reporting and network data distribution modules. Frequently, client applications are responsible for most such calculation what can result in some duplication of the functionality. A popular solution is to implement n-tier architecture, where some of the business logic is moved on the server side, located between clients and the database server and called middleware. The system generally consists of patient tracking and scheduling, result reporting and image tracking capabilities.

Echocardiography is beyond ECG the most used clinical method to assess progression of heart disease and results of treatment. Advantages of ultrasound are risk-less investigations, relative cheap equipment, compared with other image-guided diagnostic systems and low cost of exploitation (energy efficient, compact size, minimal service). The investigation provides high quality image material that should be accessed by other medical service providers. The need for a remote diagnose process and telemedicine capabilities has been stated for at least 10 years, but due to cost limitations generated by the investigation itself the implementation of telemedicine echocardiographic facilities is restrained to a small number of metropolitan areas. Especially in European regions with few medical suppliers the addressability of cardiovascular investigations for outpatients is still low.

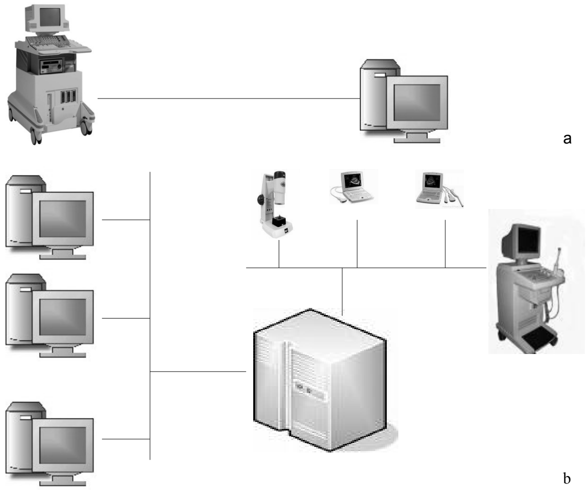

Fig.1 – Topology design, a) direct connection, b) 3-tier.

This work presents a technical architecture of the archiving and reporting system that is able to improve performance and data management as well as to provide a convenient tool for many specialists from various medical areas. The development of the presented system was followed by a deep collection and analysis of medical personnel demands in echosonographic diagnostics. The project was started as a scientific work to support needs of cardiologists in diagnosing heart disfunctions using ultrasound studies [1][2]. Implementation of sophisticated software for automated image processing and time event analysis was not enough to develop an optimal workflow. The system suffered from a lack of data management, and didn't allow the physicians fully concentrate on the diagnosing and the treatment. Therefore, a decision about developing a new flexible ultrasound archiving and reporting system, that can support medical staff in selecting appropriate decision in an optimal way, reduce costs of medical services especially during preventive mass diagnosing and patient investigations, was made. The new system concept was aimed at covering the following needs:

- supporting management of patient and image material;
- providing secure communications and data exchange without utilising additional costs for hardware;
- keeping the independence from imaging system manufacturers;
- providing a common and intuitive user interface and an unificated tools.

Additionally, the conceptual approach, proposed in this work, includes providing a possibility to separate the device specific process of image acquisition from the process of diagnosing and reporting, that can be unified. In such a way, the professional skills of medical staff can be used more effectively, due to the availability of a unificated user interface and a diagnosing workflow, independent from the scanner hardware and data formats.

The planned system became the name Augustus and was positioned for their use on all common computation platforms. Using the system, medical experts are able to view and better understand data from the imaging systems without participating in scanning routines, and generate clinical reports with a high level of automation.

2. ARCHITECTURE

To support effectively needs of medical staff, that are varying and changing permanently, and from another side do not increase costs of further development and support, a polymorphic topology was selected. It is based on the n-tier architecture model, that allows to reach an appropriate flexibility and a scalability level of the system during its integration. Different functional layers can be moved to one or more tiers to provide the necessary price/productivity ration and to correspond with the requirements of the clinical infrastructure. The main supported system topologies are:

- direct connections within a local area network (LAN) as a solution for small practices;
- enterprise network connections (within a hospital);
- interclinical connections.

The clients are connected either locally or via secure channels (e.g. using IPSec protocols). In such a way, remote experts or physicians outside their working places are able to access the system for diagnosing, consultating, controlling and reporting purposes. Communications between clinical networks are organised using DICOM-mails technology [3][4]. Both client and server applications can act as data senders for one or more receivers, i.e. partner workstations, servers or scanners located outside the network of the senders. However, the automation level of servers is much higher than clients have. Data are packed as MIME messages, encrypted using asymmetric cryptographic algorithms and sent as e-mails to the receivers, who are able to decrypt messages using their private (secrete) keys. E-mail servers are usually located in the Data Management Zone (DMZ) and support communications using the SSL-protocol. Various data transfer modes from the manual to fully automatic are available, including following routing schemas:

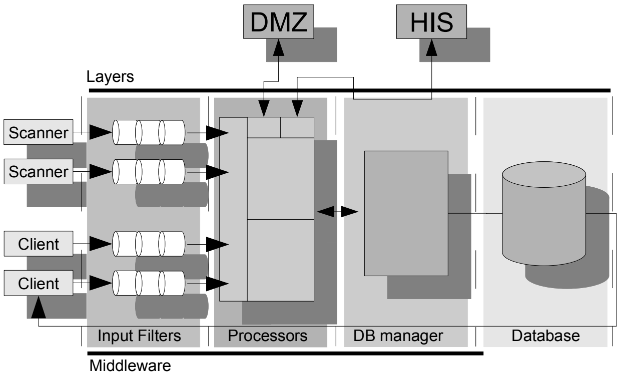

Fig.2 – Layer design.

- doctor-to-hospital,
- hospital-to-doctor,
- hospital-to-hospital,
- doctor-to-doctor.

The DICOM-mail approach provides not only a secure and convenient way for data exchange, but also reduces costs due to the fact, that additional software and hardware are not required. The receivers are able to obtain data using either a special purposed software for receiving DICOM-mails (Augustus or others) or just a convenient mail client with a free cryptographic package like GnuPG.

In the described server architecture (Fig.2), the connections between clients. i.e. scanners and workstations, are organised as graph chains. Each layer can be represented by one or more graph nodes. Usually the connection chains include following layers:

- connection manages
- input filters
- processor
- database manager
- database.

This group of layers, except the database layer, is logically organised into the middle tier (middleware). The connection manager recognises standard and proprietary protocols and is responsible for pulling. The input filters depend on a type of the sender, i.e. each one is able to process the data in proprietary formats from a specific scanner or workstation. The layer is organised as a pipeline of in-place filters, that perform necessary image and signal preprocessing, a content-based analysis and necessary transformations. A typical processing can include modules for image restoration: denoising, debluring [5], distortion corrections, segmentation and data mining. The content of this pipeline is specified by a configuration. The processor collects most business logic to validate, to transform and to transfer data from all input filters. It is also responsible for many output operations. Some of the functionality can be duplicated on the client side for reaching better performance and optimal usability of the system. The database manager is responsible for for creating, filling and controlling the database. Each layer can be configured independently. Such subdivision of the middleware tier was planned solely for the the flexibility and the performance purposes.

The database is responsible for data storing and retrieving with maximal effectiveness. A hybrid data model is supported. The well structured data, i.e. the information about patients, image material, scanning and derived parameters, diagnosing information, is placed in relational tables managed by an SQL server. The data, that can vary or depend on the user demands, is stored using XML data models. It can be structures of the report, diagnosing protocols, configurations and etc. This makes the system very flexible and multi-purpose in it's implementation.

The client application is run on workstations and is aimed at the improving the performance of the medical staff. A deep investigation of the process of image acquisition and diagnosing has shown us, that in many cases it is possible from one side to reduce both the overall time per patient and the personnel load and, from the other side, to improve medical services. It can be realised, for example, due to a separation of the acquisition from off-line processing, diagnosing and reporting. In this case the diagnosing can be performed very effectively off-line by the experts.

The main purposes of the client application are representation of data to the user and providing an automated user friendly interface and the opportunities for processing of medical data. The client application is installed and configured on the every client machine. As our system is using the n-tier architecture the client communicates with database layer through the integrated database manager. Also it uses the direct connections to the server, that gives us a flexible and effective approach for storing and receiving large amounts of data.

Security issues nowadays are have to be taken into consideration when working with medical data. The client application uses custom configured roles, which determine access of each and every user not only to the servers and the database, but also to the functional modules.

The client consists of several modules, which are tightly coupled with each other, providing an all-in-one solution for creating, editing and processing of medical data. The modules can be divided into three groups: the patient scheduling and tracking, visual and quantitative data processing and reporting. The patient scheduling and tracking module allows the user not only to manage new patients and investigations, and working with the current data, but to organise the investigations in projects. The project mechanism optimises the workflow by creation of logical unions of patients, investigations and diagnoses, what improve the search of common cases and the creation of integral reports afterwards. Data processing module provides several tools for measuring, processing and observing the data, obtained from the database or imported by the user from CDs or local disks. As our system is currently aiming the echocardiology field, a special processing module was designed. The main available modules are:

- parameter measurements with the automatically value filling by integrated formulas,
- image and movie player,
- classification module,
- diagnosing,
- calibration module,
- Stress Echo,
- ECG module.

Moreover, scalable architecture of a system gives an opportunity to extend data processing module to accept other kinds of medical data.

The reporting module uses both the data stored in the database and the data derived due to the diagnostic process to generate reports automatically. The user is able to select the information which will be used in the report. The generated reports are validated and can be modified by the user before storing it in HIS. Usage of XML based output format making it easy to extend reports by specifying additional parameters and features. It also allows a simple integration of reports by the 3rd parties.

3. IMPLEMENTATION

The main utilisation of Augustus is image archiving, diagnosing and reporting in echocardiography. Therefore a general setup of the system for cardiologists is as following. An operator imports the data about the patient and the investigation from HIS or types the information manually into the client software, that is installed on the workstation usually located in the same room with the scanner (ultrasound machine). The scanner can obtain necessary patient data though a DICOM Worklist Provider. All acquired images, signals and measured parameters are sent in DICOM format to the server. The operator is able to control the data transfer to the server by observing appearing new thumbnails on the screen of the workstation. He or she can make image classifications based on the modality, the image view, the patient load as well as to describe the content by a few mouse clicks. Then the information can be used for diagnosing (on the same workstation or by a remote expert) or can be set to one or more receivers outside the clinic for consultations. The diagnosing utilises a standardised workflow for all data sources. The work of the diagnosing staff can be controlled by one or more supervisors, who assign the generated report for storing in the HIS.

4. EXTENSIONS

Considering up-to-date trends in medical imaging and demands of modern cardiological hospital departments, Augustus is used as a principle component in implementation of 4D (3D + time) heart modeling and diagnostics system (CAT, Cardiological Analysis Toolkit) [6][7]. A convenient 2D ultrasound machine is used with an optical tracking system to obtain 3D coordinates of the examined organ (e.g. the human heart). The general setup of the system is as follows. First a patient is fixed. Then B-Mode scans are taken and stored into Augustus. Light reflective markers of special geometry are attached to the probe, so the position and orientation of the probe can be calculated by an optical 3D localizer. During the scanning step, all the auxiliary information acquired from the current patient, such as ECG-synchronized ultrasound data, marker coordinates, transformation matrices and patient personal data, is translated to the Augustus archiving system for storage. Organ surfaces are extracted automatically from the US data and are marked during playing the US movie. In such a way a physician is able to see "enhanced" objects and to control correctness of classification. The surfaces are transformed in the 3D space of the optical localizer and visualized as 3D volumetric objects into an extension module connected with Augustus. On demand of a cardiologist this data can be converted and loaded into CAT modules in real-time or in off-line modes for 3D/4D visualization, measurement and diagnosing, optionally using preloaded MRI/CT cardiological data for segmentation, model extraction, statistical shape modeling (SSM) and further analysis.

Due to high flexibility of Augustus and abstracting away from it's application for the mentioned above cardiological purposes only, we are planning it's implementation as a system kernel in some applications of orthopaedic surgery (trauma diagnosing and intro-operative navigation systems [8]), where a similar setup can be used (Fig.3). The further processing can be: measuring the bone geometry, matching with other modalities if necessary, using for surgical guidance and instrument localization. By means of the external parameters reconfiguration and plain adjustment of system modules, it can be used also in a broad-spectrum of medical areas such as digital microscopy (at least for automated image debluring and noise reduction), stomatology, ophthalmology and etc.

5. CONCLUSION

In this work an architecture of an effective image archiving and reporting system was presented. Talking about the effectiveness, it is necessary to mention which metrics were implemented for the estimation of the

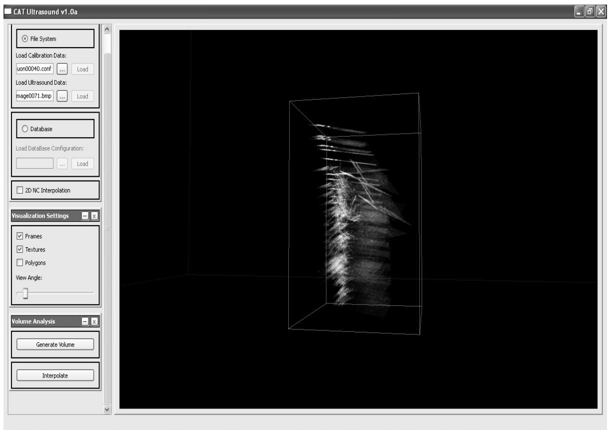

Fig.3 – 3D modeling of bones using B-Mode ultrasound.

system parameters. Decreasing the load of medical staff and reducing duration of the diagnosing from the data acquisition to the report generation without loss of quality, are most important parameters for us. The duration and the quality of the scanning process depend on professional skills of the operator, the patient and the supported clinical protocols. However, due to the possibility to separate the processes of data acquisition and diagnosing by using the system, the involvement of the high-cost medical personnel can be reduced approximately on 20-40%. Utilising the unified diagnosing framework allows to increase effectiveness of the experts in terms of time and quality, due to the standardised approach.

Another criterion of the effectiveness is performance. The system can be configured to fill the requirements for the processing time. The direct connections can be used for on-line processing, while the routing is available for the pulling-requests. Utilising preprocessing in the middleware and automatic value calculations allow to speed-up the clients.

Last but not least is the price. Integration of Augustus system does not require special hardware. Even virtualisation solutions are supported. The architecture has the high modular and configuration levels, that guaranties low extension and support costs. The described approach can be a solution for application used both in small medical practices and large hospitals.

6. REFERENCES

[1] O. Krivonos, T. Poerner, B. Goebel, K.K. Haase, M. Borggrefe, J. Hesser, R. Maenner. Computer Analysis Of Doppler Myocardial Images. *5th Asia Pacific Conference on Medical and Biological Engineering and 11th International Conference on Biomedical Engineering*, 4-7 December 2002.

[2] O. Krivonos, J. Hesser, R. Maenner, T. Poerner, B. Goebel, S. Kralev, K. Haase. Automated ultrasound based classification of myocardial regions. *In 7th Intern. Conf. On Pattern Recognition and Information Processing (PRIP'03)*, 21-23 May, 2003, Minsk, Belarus, V 2, pp. 231-236.A. Author. *Book title*. Editor. Paris, 1990. pp. 234.

[3] G. Weisser et al. Teleradiology applications with

DICOM-e-mail. *European Radiology*, Vol. 17, No. 5. (May 2007), pp. 1331-1340.

[4] P. Mildenberger. Teleradiology with DICOM E-mail. In: *Teleradiology.* Sajeesh Kumar, Elizabeth Krupinski. Springer 2008-09. ISBN: 978-3-540-78870-6 (Print), 978-3-540-78871-3 (Online), p. 71-75.

[5] A. Kryvanos, J. Hesser. Fast Total Variation Image Restoration Methods. *In 8th Intern. Conf. On Pattern Recognition and Information Processing (PRIP'05)*, 18-20 May, 2005, Minsk, Belarus, pp. 140-143.

[6] P. Krasnopevtsev, D. Hlindzich, T. Poerner, A. Kryvanos. A Statistical Approach to Automatic Heart Segmentation and Modelling from Multiple Modalities. *CBMS'08*, 17-19 June 2008 at the University of Jyvaskyla, Finland, pp. 44-46.

[7] D. Hlindzich, A. Kryvanos. A Three-Dimensional Segmentation Approach for Automatic Human Heart Modelling. *AITTH'08*, 1-3 October, 2008, Minsk, Belarus.

[8] D. Hlindzich, O. Krivonos. An Approach to the Estimation of Motion of Anatomical Organs. *In 8th Intern. Conf. On Pattern Recognition and Information Processing (PRIP'07)*, 22-24 May, 2007, Minsk, Belarus, pp. 160-165.