Data Management and Visualization Issues in a Fully Digital Echocardiography Laboratory

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Abstract. This paper presents a PACS solution for echocardiography laboratories, denominated as *Himage*, that provides a cost-efficient digital archive, and enables the acquisition, storage, transmission and visualization of DICOM cardiovascular ultrasound sequences. The core of our approach is the implementation of a DICOM private transfer syntax designed to support any video encoder installed on the operating system. This structure provides great flexibility concerning the selection of an encoder that best suits the specifics of a particular imaging modality or working scenario. The major advantage of the proposed system stems from the high compression rate achieved by video encoding the ultrasound sequences at a proven diagnostic quality. This highly efficient encoding process ensures full online availability of the ultrasound studies and, at the same time, enables medical data transmission over low-bandwidth channels that are often encountered in long range telemedicine sessions. We herein propose an imaging solution that embeds a Web framework with a set of DICOM services for image visualization and manipulation, which, so far, have been traditionally restricted to intranet environments.

1 Introduction

In the last decade, the use of digital medical imaging systems has been increasing exponentially in the healthcare institutions, representing at this moment one the most valuable tools supporting the medical decision process and treatment procedures. Until recently, the benefits of digital technology were still confined to the medical imaging machinery and the examples of image data migration to a centralized (shared) archive were reduced.

The medical imaging digitalization and implementation of PACS (Picture Archiving and Communication Systems) systems increases practitioner's satisfaction through improved faster and ubiquitous access to image data. Besides, it reduces the logistic costs associated to the storage and management of image data and also increases the intra and inter institutional data portability. The most important contribution to the exchange of structured medical image between equipment, archive systems and information system was the establishment of DICOM (Digital Imaging and Communications in Medicine) Standard [1], in 1992. Currently, almost all medical imaging equipment manufacturers are including DICOM (version 3) digital output in their products.

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The digital medical imaging imposes new challenges concerning the storage volume, their management and the network infrastructure to support their distribution. In general, we are dealing with huge volumes of data that are hard to keep "online" (in centralized servers) and difficult to access (in real-time) outside the institutional broadband network infra-structure.

Echocardiography is a rather demanding medical imaging modality when regarded as digital source of visual information. The date rate and volume associated with a typical study poses several problems in the design and deployment of telematic enabled PACS structures, aiming at long-range interaction environments. For example, an uncompressed echocardiography study size can typically vary between 100 and 500Mbytes, depending on equipment technical characteristics, operator expertise factors and procedure type [2].

Several institutions are dealing with problems concerning the permanent historic availability of procedure images in network servers, as well their integration with other clinical patient information detained by the HIS (Healthcare Information Systems), in a unique access platform application. On other hand, current clinical practice reveals that patient related data are often generated, manipulated and stored in several institutions where the patient is treated or followed-up. In this heterogeneous and complex scenario, the sharing and the remote access to patient information is of capital importance in today's health care practice.

In these circumstances, compression techniques appear as an enabling tool to accommodate the source data rate to the communications channel and to the storage capacity. The definition of an adequate trade off between compression factor and diagnostic quality is a fundamental constraint in the design of both the digital archive and the telecommunications platform.

In the following sections we will present the architecture of a digital video archive and communication system, which, supporting and extending some DICOM services, is able to preserve the diagnostic image quality, and provides on-line access to whole echocardiographic datasets.

2 Materials and Method

The development scenario is a Cardiology Department PACS infra-structure that was been developed at the Central Hospital of V.N.Gaia, since 1997. This healthcare unit is supported by two digital imaging laboratories: - the Cardiac Catherization Laboratory (*cathlab*) [3] produces about 3000 procedures/year and; - the Cardiovascular Laboratory (*echolab*) with 6000 procedures/year.

The first *echolab* PACS module, installed in 2001, allowed the storage of 14-16 months of US procedures making use of a image compressed format in DICOM JPEG-lossy 85 (10 Mbytes/exam). This volume of information is difficult to handle, namely if one aims at permanent availability and cost-effective transmissions times for remote connections. Also in 2001, a transcontinental project started to develop a telematic platform capable of establishing cooperative telemedicine sessions between the Cardiology Departments of the Central Hospital of Maputo (Mozambique) and the CHVNG, to cardiovascular ultrasounds [4]. This telecardiology project was the catalyst factor for the development of a new PACS software solution (the Himage) to support the local storage, visualization and transmission of coronary US.

2.1 Image Compression

Digital video compression is a technology of the utmost importance when considering storage space and time transmission problems, associated to the huge number of US procedures/year realized in the CHVNG. The preceding Himage approach of using the existent DICOM JPEG lossy format [5], with above expressed study volumes, resulted in an unfeasable solution. As result, our research was initially concentrated in developing a new approach attempting to achieve maximum storage capacity and minimum download times without ever compromising image diagnostic quality.

The methodology to find the "best" compression factor (and other settings) was based on successive evaluations of compression codec/factor versus desired diagnostic image quality for each specific modality and corresponding utilization scenario [6].

Given the spatio-temporal redundancy that characterizes the echocardiographic video signals, there are important gains by choosing a compression methodology that copes with both intra-frame and inter-frame redundancies, like the MPEG family of encoders [7]. The novelty of our compression approach starts by embedding each storage server with highly efficient MPEG4 encoding software. If the JPEG explores exclusively the intra-frame information redundancy, the MPEG4 encoding strategy takes full advantage of object texture, shape coding and inter-frame redundancy ending up with best results.

Since MPEG4 is not a DICOM native coding standard, subsequent image transmission, decoding and reviewing is accomplished through a DICOM *private transfer syntax* mechanisms enabled between storage servers and diagnostic clients terminals equipped with the echocardiography viewing software. In order to achieve full compliance all the other DICOM information elements and structure were kept unchanged.

2.2 DICOM Private Transfer Syntax

As matter of ensuring flexibility, we decided not to insert the MPEG4 directly in the TLV (Tag Length Value) DICOM data structure, i.e. solve the US "specific problem". Instead, as Fig.1 points out, a multimedia container that dynamically supports different encoders was developed. The container has a simple structure, including a field to store the encoder ID code. When it is necessary to decompress the images, the Himage-PACS solicits the respective decoder service to the operating system (like other multimedia application).

This approach represents an optimized high level software solution. If, for instance, in a 5-10 years period a more efficient codec appears, we just need to change one parameter in the "Himage Conversion Engine" (i.e. set the new codec ID) to setup.

Fig. 2 shows a DICOM partial overlap dump, "default transfer syntax" versus "private syntax", of a US 25 frames image sequence with a RGB 576*768 matrix. It is possible to observe two important aspects. First, the DICOM DefaultTransferSyntaxUID identifier (1.2.840.10008.1.2) is replaced by a private PrivateTransferSyntaxUID (1.2.826.0.1.3680043.2.682.1.4). This private UID is based on the root UID 1.2.826.0.1.3680043.2.682 requested by our workgroup. Second, the "PixelData" field size "is reduced" 120 times (33177600/275968).

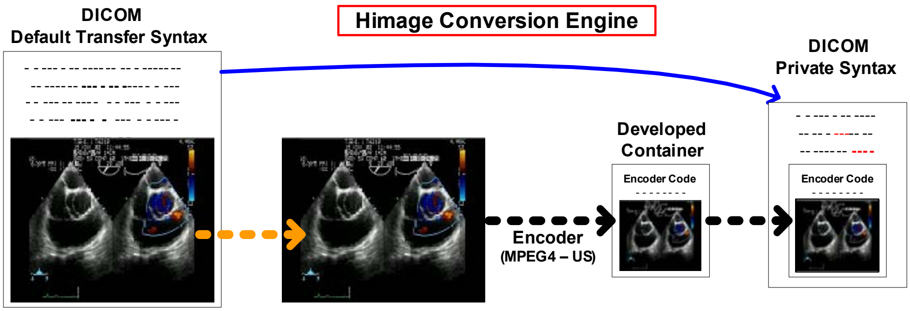

Fig. 1. Conversion of DICOM "default transfer syntax" in "private syntax"

Tag	VR	Contents	length	Comments	
....					
(0002, 0010)	UI	**[1.2.840.10008.1.2]**	# 18,	**DefaultTransferSyntaxUID**	(before)
(0002, 0010)	UI	**[1.2.826.0.1.3680043.2.682.1.4]**	# 22,	**PrivateTransferSyntaxUID**	(after)
....					
....					
(7fe0, 0010)	OW	0000\0000\0000\.......	**# 33177600,**	**PixelData**	(before)
(7fe0, 0010)	OW	4952\4646\355c\0004\...	**# 275968,**	**PixelData**	(after)

Fig. 2. DICOM dump: DICOM "default transfer syntax" vs "private syntax"

2.3 Echolab: Himage PACS Infra-structure

The clinical facility is equipped with 7 echocardiography machines including standard DICOM3.0 output interfaces. Daily outputs to the network reach about 800 images (still and cine-loops). All the acquisition units have a default configuration that ensures an automatic DICOM send service by the end of each medical procedure. Thus ultrasound image data is sent, uncompressed in a DICOM default transfer syntax mode, to an Acquisition Processing Unit (A.P.U) that acts as the primary encoding engine.

The received procedures are analyzed (the alphanumeric data is extracted from DICOM headers) to detect eventual exam/patient ID errors. As is represented in Fig. 3, after a consequent acknowledgement, the exam is then inserted in the database, i.e. the new exam is added to the Himage PACS. The DICOM image data is compressed and embedded in new DICOM private syntax file (Fig. 1). The result is stored in the "Storage Server", to be available to users. The original raw data images are saved and kept online during six months. However, the DICOM private syntax sequences are made available during all the system lifetime (in the "Storage Server"). The developed client application consists on a Web DICOM viewer (Fig. 4) that is available in the "Web Server" (Fig. 3). This software package allows the clinical staff to manipulate and visualize standard DICOM and also our private syntax exams available in the *Himage* system database. Because the Himage client solution is totally developed in web technology, the echolab procedures are accessible, through appropriate security measures, from any Internet point. The communication channel is encrypted with HTTPS following a requested username/password authentication procedure.

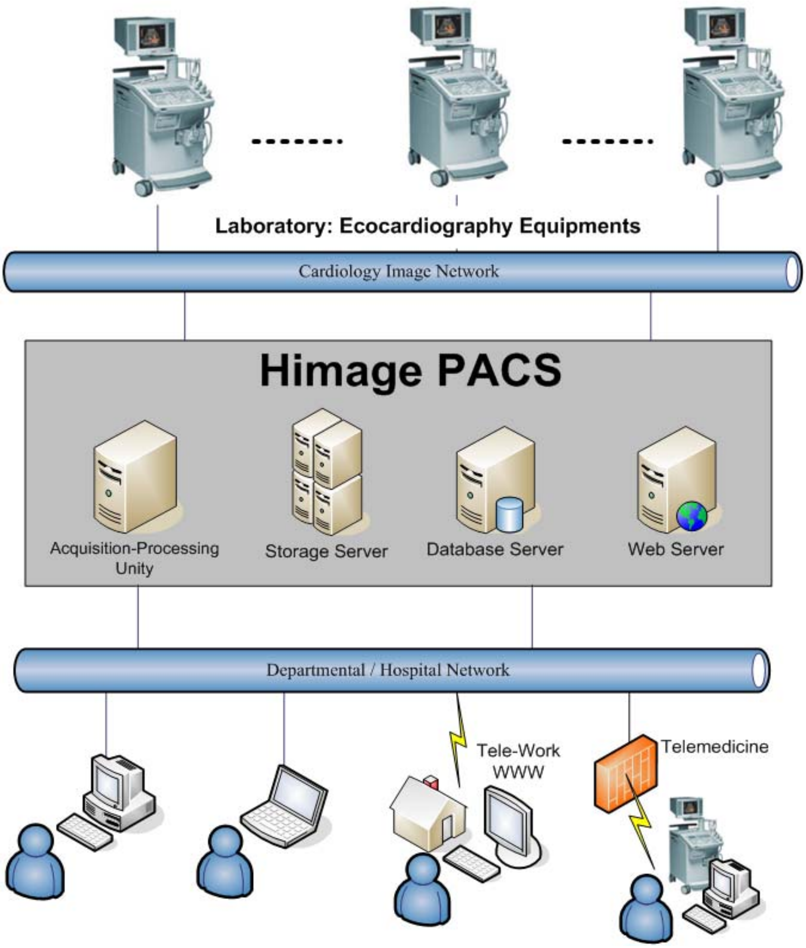

Fig. 3. CHVNG Cardiology Department: Himage PACS Infra-structure

3 Results

With this new Himage system, more than 12000 studies have been performed so far. For example, a typical Doopler color run (RGB) with an optimized time-acquisition (15-30 frames) and a sampling matrix (480*512), rarely exceeds 200-300kB. Typical compression ratios can go from 65 for a single cardiac cycle sequence to 100 in multi- cycle sequences. With these averaged figures, even for a heavy work-load Echolab, it is possible to have all historic procedures online or distribute them with reduced transfer time over the network, which is a very critical issue when dealing with costly or low bandwidth connections. According to the results of user's assessment, the achieved compression ratios do not compromise diagnostic quality, and reduce significantly the waiting time to download and display of images.

In Table 1 it is possible to observe some global statistics.

Table 1. Himage - three years of statistics

Number of Procedures (Exams)	12673
Nº of Images (Still + Cine-loops)	253173
Total of Space Volume	48.934.047.237 Bytes (45,5GB)
Average Procedure Size	3771 KBytes
Average File Size	189 KBytes
Average number of Files/Procedure	20 (majority of cine-loops)

3.1 Image Quality Evaluation

The new DICOM-MPEG4 *private transfer syntax* offers an impressive trade off between image quality and compression factors spanning a wide range of bit-rates. Two studies were carried on assessing the DICOM cardiovascular ultrasound image quality of MPEG4 (768kbps) format when blindly compared with the uncompressed originals. Qualitative and quantitative results have been presented in [8]. An impressive fact coming out from this study was that, in a simultaneous and blind display of the original against the compressed cine-loops, 37% of the trials have selected the compressed sequence as the best image. This suggests that other factors related with viewing conditions are more likely to influence observer performance than the image compression itself.

The quantitative and qualitative assessment of compressed images shows us that quality is kept at high standards without ever impairing its diagnostic value. Using compression factors of the same magnitude in other DICOM coding standards JPEG [9] MPEG1 [10] will lead to a severe decrease on image quality.

3.2 Data Access and Management

Information Technologies (IT) dissemination and availability are imposing new challengers to this sector. The healthcare professionals are demanding new Web-based access platforms for internal (Intranet) consumption but also to support cooperative Internet based scenarios. Consequently, the digital medical images must be easily portable and enable integration with actual multimedia Web environments [8, 11]. The Himage client software answers to theses requirements: - first, all client modules are available in Web environment; - second, the image size volume (mean: 189 Kbytes) has acceptable download times, even to a remote access like, for instance, a telework session using an ADSL Internet connection; - third, easily integration with departmental Healthcare Information System.

As suggested in Fig. 4, the Web client module includes several facilities, besides the customization to handle DICOM 3.0 and our DICOM *private syntax*. Graphically, the main window includes a grid box with the patient's in the Himage database and a simultaneous cine preview of three sequences. The user can "search" procedures by different criterions: patient name; patient ID, procedure ID/type/date and provenience Institutions/equipment. A second graphical application layer provides the communications, DICOM viewer (Fig. 5) and report modules (Fig. 6).

In the Himage DICOM viewer window (Fig. 5) it is possible to visualize the image sequences (still and cine-loops), select image frames (from distinct sequences) that are sent to the report area. Other traditional specific functionalities have been included like, for example, the image manipulation tools (contrast/brightness), the printing capacities and the exportation of images in distinct formats (DICOM3.0, AVI, BMP, Clipboard…).

In the report module (Fig. 6), the user can arrange the images location or delete some frames with a drag-and-drop functionality. At the end, the output images matrix (2x3) is used jointly with the clinician report to generate a RTF file, compatible with any common text editor.

The export module makes possible to record a procedure in a CDROM/DVD-ROM in uncompressed DICOM *default transfer syntax* format and in AVI format.

The Himage client was developed in ASPX .NET and includes components in Visual Basic .NET, JavaScript and a binary object (ActiveX Viewer) that allows the direct integration of the private DICOM files in the Web contents.

3.2.1 Communication Platform

As referenced, the huge volumes of cardiac US medical image data are not easy to transfer in a time and cost-effective way. Healthcare professionals do not adopt telemedicine or telework platforms if they need to wait, for instance, 2-3 hours to receive/download a clinical image study with diagnostic quality.

The reduced image size of DICOM-MPEG4 private syntax US procedures prompts opportunities for new clinical telematic applications, especially in scenarios with low network bandwidth and/or reduced communications budget.

The Himage includes a communication platform that allows the creation of customized study packages, with more than one study, to be sent to predefined remote institutions. With this facility the physician can select images sequences, make annotations, append extra comments and send the examination over the network to the remote unit. In the main Himage interface exhibits a group of buttons ("on/off" and "send") that allows the (de)activation and the selection of sequences that are sent to the communication module. In this last area, the user just needs to choose the target institution and send the data following the email paradigm.

The first telemedicine project has established with Cardiology Department of the Central Hospital of Maputo (Mozambique) [4]. Both clinical partners were equipped with echocardiography machines including standard DICOM output interfaces, videoconference platforms. A network infrastructure was also installed with two server computer in the African partner. The sessions can be conference-based teleconsultations for analysis of real-time clinical cases, or analysis of previously transferred exams files (DICOM *private transfer syntax*). In the last case the remote physician can select echo image sequences, make annotations, append extra comments and send to the Gaia Hospital. This information is stored in one dedicated server and is accessible by the Gaia cardiovascular ultrasound specialists.

Both methods can be used at same time, the physician in Gaia can open and examine a clinic record file previously sent by the remote place, and use videoconferencing equipment for a face to face consultation and comment about diagnosis and therapy. The communication relies on 2x64 Kbps ISDN channels (1 full US exam takes typically 2-5 min using a 64kb channel).

Fig. 4. Himage Web client: database, preview and buttons to second level modules (with virtual names)

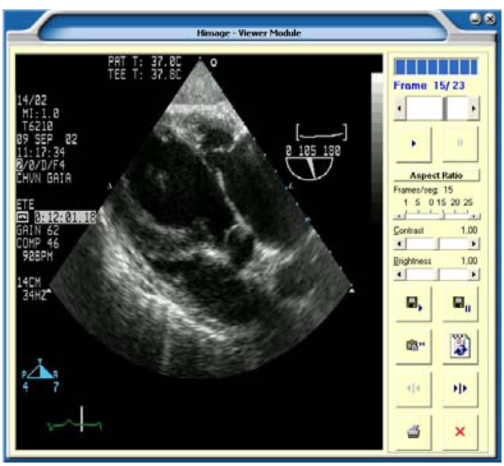

Fig. 5. Himage Visualization Module

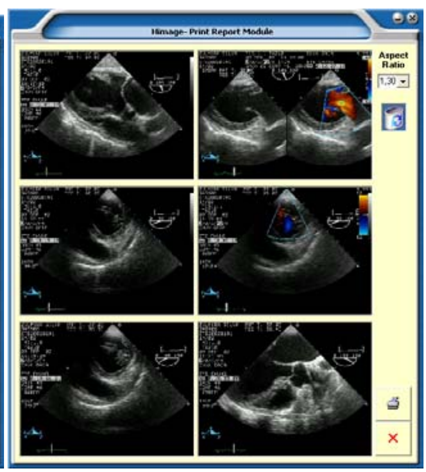

Fig. 6. Himage - Report Module

4 Conclusions

This paper presents and describes a totally home made Web PACS solution that is based on a customized DICOM encoding syntax and compression scheme in a Cardiology medical image scenario. The developed software provides a seamless integration with the traditional DICOM entities, boosts the storage capacity up to the level of several years of online availability while preserving the image quality at high standards. The overall result is a cost-effective system with improved workflow and generalized user satisfaction.

The Himage development was the core element that allows us to implement the first fully digital Echocardiography Laboratory in Portugal. Moreover, the presented Himage-PACS characteristics make it particularly important in telemedicine communication scenarios with low network bandwidth and/or reduced communications budget like, for instance, the Maputo-Gaia project. Thus, as a final overview the following remarks about the Himage-PACS software environment are worth to be pointed out: a) Excellent trade-off between compression ratio and diagnostic quality; b) Availability of all the recorded procedures in Web environment; b) Reduced download times that enables data access outside the institutions wall (telework); d) Huge storage space savings. Very reduced average storage cost per study.

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