Medical Image Processing and Radiology Information System

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ABSTRACT

The development of comprehensive picture archive and communication systems (PACS) has mainly been limited to proprietary developments by vendors, though a number of freely available software projects have addressed specific image management tasks. The Medical Image Processing and Radiology Information System project aims to provide an open source, common foundation upon which not only can a basic PACS be readily implemented, but to also support the evolution of new PACS functionality through the development of novel imaging applications and services. The project consists of four main software modules: 1) image order entry, which enables the ordering and tracking of structured image requisitions in single frame and multiframes i.e. DICOM, BITMAP, JPEG and JPEG2000; 2) an agent-based image server framework that coordinates distributed image services including routing, image processing, and querying beyond the present digital image and communications in medicine (DICOM) capabilities; 3) an image viewer, supporting standard display and image manipulation tools i.e. DICOM, INTERFILE, BITMAP, JPEG and JPEG2000 presentation states, and structured reporting i.e. Effective Renal Plasma Flow (ERPF), Glomerular Filtration Rate (GFR) and Renogram; and 4) reporting and result dissemination, supplying web-based widgets for creating integrated reports. All components are implemented using Borland Delphi 6.0, PHP and MySQL to encourage cross-platform deployment. To demonstrate the usage of this project, a preliminary application supporting primary care/specialist communication was developed and is described herein. Ultimately, the goal of the project is to promote the wide-scale development and usage of PACS and imaging applications within academic and research communities.

Keywords: DICOM, JPEG, JPEG2000, PACS, RIS.

1 INTRODUCTION

The increasing presence of medical imaging within clinical care is evident: as an objective source of documentation and as a means to improve communication, imaging serves as a tenet of evidence-based medical practice [1]. Moreover, images contain important biomarkers, providing in vivo snapshots of anatomical and physiological processes. Thus, imaging also plays an emergent role in research, expanding the understanding of normal and disease states. With the growing estimates from tera- to peta-bytes of imaging data acquired annually, which will need to be compressed before sending or collecting data because of the limited of the band width and also limited capacity of the data saving space [2]. Therefore, compression technology in PACS is more important part than any part in store or transmission and the effective management of imaging data is now a paramount necessity. Unlike standard medical data, however, images pose additional, distinctive management challenges. These problems are only amplified in consideration of the rapid developments in medical imaging ranging from core technical investigations into new imaging modalities, to novel applications of existing imaging all of which are capable of marshaling an evolution in healthcare; but such changes must be integrated into the clinical environment and research in order to be practical. Facilitating this objective requires an infrastructure that can support both the common requirements of today imaging applications, while further serving as a springboard for future explorations.

The Medical Image Processing and Radiology Information System project leverages earlier work by the authors in teleradiology and medical imaging information systems to provide an open source architecture for a picture archiving and communication system (PACS), creating a foundation for integrated imaging applications. Three considerations permeate the design of the project: 1) cross-platform development and deployment, leveraging both Borland Delphi 6.0 and web-based technologies; 2) standards compliance, focusing on archiving, compression and presentation about digital image and communications in medicine (DICOM) protocols; and 3) extensibility, allowing additional types of functionality (e.g., distributed image processing, non-DICOM querying) and standards (e.g., web services) to be incorporated in a unified manner by abstracting image-handling processes.

The project framework loosely considers the mul-
tiple aspects of image management in terms of workflow, starting from the point of ordering an image, to its interpretation and use in documentation, through to the final distribution of results. Collectively, the software under this project aim to provide a common, comprehensive suite of tools that can be adapted by developers to readily implement PACS-based functionality.

The remainder of this paper is organized as follows Section 2, the methodology and algorithm are outlined briefly provides background on related work in the area of PACS and imaging informatics, focusing on image acquisition, image compression, image processing and image management issues. Whats more provides an overview of the project architecture, followed by the design issues and implementation details of each major module making up the system. The experimental results and discussion using this project to support rapid communication between primary care physicians and specialists is described in Section 3. Finally, we conclude on the project issues, and future directions for this project in Section 4.

2. METHODOLOGY

2.1 Image Capture [3][4]

This research has done with collecting the imaging data by selecting the data from video signals which have sent to the monitor console by using video capture card (model: Life View Chip BT 8.7) processing through AVICAP Windows Class. These function as the interface between Application and Device Driver to control the image receiver to collect the image signal in single or multiple windows bitmap file (.BMP) type.

2.1.1 DICOM

DICOM is a standard, which has been developed by ACR/NEMA. The ACR is the American College of Radiology and NEMA is the National Electrical Manufacturers Association. This standard allows different manufacturers equipment to communicate. For example, all CT images are stored in the same format irrespective of manufacturer and the header information pertaining to the CT images going to also be in the same format irrespective of whose device generated the image. The early standard is focus on viewing data between each other dissimilar companies based on point-to-point connection. Therefore, DICOM standard with rapid development of computer network and PACS is used present through the concept controlling information in network standards as shown in figure 2. Furthermore, DICOM standard has strong adaptability, it is necessary to adopt DICOM standard in several professional fields. Standard number has form of "PS 3.X-YYYY". Here, X is a part number and YYYY is publication year. For example, DICOM Part 2 is "Conformance" and document number "PS 3.2-2003". DICOM standard rules are divided into 16 parts [5].

2.1.2 DICOM Information Object Definition

DICOM specifies that image information represents an Information Object which is defined in Information Object Definition (IOD) as shown in figure 3 [5], and commanding word is relating to Service Class which is defined in DICOM Message Service Element (DIMSE).

IOD specify information for medical image where is corresponding to patient’s name, examination type, date and it looks like a format dealing with standardized medical information. With these items, if there are real values on each item, it is called Information Object instance.

2.1.3 Data Element

DICOM communicates each attribute as shown in Figure 4 One data element communicates one attribute, and several data element should be necessary for IOD instance whole. That is, several data element must be combined as shown in Figure 4 to make
any person IOD instance. One data element’s details structure of them is a form in Figure 4 lower columns. Figure 5 shows the example of any tag which has Tag (0010, 0010) that is consisted of two integers representing Patient’s Name. VR (Value Representation) specifies the characteristics of information that has form of PN. If value field is a name (date), it can be represented as PN (DA). Value field used often like patient’s name may understand even if do not clarify PN. It is known that this is implicit VR. Because patient’s name corresponds to implicit VR, it is same effective on the results for transmission. Otherwise, we are called explicit VR in the case of whether we should inform the information characteristics.

Sometimes VR may be omitted. The value length is the number that displays how much length of data in value field and value field corresponds to data actually. Here, PN means the patient name and DA means date.

Figure 6 shows the steps of DICOM-format image archive as follows 5. Firstly, data analysis and classification analyze whether raw (input) data is compressed or other archive. Later, the data separate text data such patients curing history and binary code data such image data from medical instrumentation. Secondly, text data addition which is data important to the original image don’t have curing history or data. Thirdly, decoding text data from the first step to the stimulation (model) of DICOM format by sending the tag number into encoding module from (respective number) first to end which image data on the last place. Finally, decoding into DICOM format taking the tag number from the third step to compare with standard dictionary program, and then get the value (number) for encoding to absolutely data element.

2.2 Image Compression

A medical image, that unlike an image that is used usually, requires very high quality. For example, a chest image that is acquired in Compression Ratio (CR) amounts one image size to 7 - 8 MB. Like this, when an image acquiring from various equipments is deciphered by interpretation doctor or stores for conservation to long term storage device etc., it should be compressed in extent that do not influence on next interpretation. Therefore, compression technology in PACS is more important part than any part in store or transmission.

In DICOM standard, the compression technology specify in lossy or lossless methods such as JPEG, run-length encoding, or JPEG-LS. Currently, JPEG2000 in [5] is added in new standard of DICOM image compression. Thus, compress the original imaging data based on the JPEG and JPEG2000 image compressing standard.

2.2.1 JPEG

The JPEG standard for image compression is comprised of a toolkit that has three distinct components: baseline lossy, extended lossy, and lossless. Baseline lossy JPEG, which the most widely implemented of the three, utilizes the discrete cosine transform (DCT) to decompose an image into sets of spatial frequency coefficients.

Figure 7 shows the main procedure for all DCT-base encoding and decoding processes. The DCT is done on an 8 × 8 pixel block-adaptive basis. Baseline lossy JPEG supports 8 bits-per-pixel source imagery, offers a simple quantization scheme that enables users of the algorithm to trade off the degree of file size reduction, i.e., compression ratio, with image quality, and utilizes sequential Huffman entropy coding. Extended lossy JPEG is also based on the 8 × 8 pixel block adaptive DCT.

2.2.2 JPEG2000 [2][6][7][8][9]

JPEG2000 characteristic can embody lossy and lossless compression at the same time in one encoded bit stream, and is shown quality of more excellently eminent image than existent JPEG in high compressibility. In addition, JPEG2000 in a sense of ROI (region of interest) coding is possible, and can be applied to technique of watermarking, labeling etc. for security of image. Also, it has various bit depth to 1 bit through 16 bits in compression and supports compression of motion image.

Figure 8, shows a block diagram for JPEG2000 algorithm. The strength of JPEG2000 is that it is capable of tiling unlike JPEG (Figure 9). Since JPEG processes 8x8 subimage tiling and DCT (discrete cosine
3. ROI BOUNDARY DETECTION BASED ON GEOMETRIC ACTIVE CONTOUR MODEL [10]

A region of interest (ROI) is a portion of an image that you want to filter or perform some other operation on. You define an ROI by creating a binary mask, which is a binary image that is the same size as the image you want to process with pixels that define the ROI set to 1 and all other pixels set to 0. Which can define more than one ROI in an image. The regions can be geographic in nature, such as polygons that encompass contiguous pixels, or they can be defined by a range of intensities. In the latter case, the pixels are not necessarily contiguous. Thence, ROI boundary detection based on geometric active contour model for sets ROI semi-automatically on region of expected disease which is used in this research. Active contour model consist internal force and external force from edge detection based on variance image and Canny edge detection. Finally, comparison time and efficiency of ROI processing between variance image and Canny edge detection.

4. FUNCTIONAL REQUIREMENTS

Free DICOM viewers such as ezDICOM [1112] which runs on Windows computers. Available as a standalone Windows program or as an ActiveX component (allowing plug-and-play use with Delphi, VisualBasic, C#, Visual C, Internet Explorer and other ActiveX aware programs). It is able to display most types of DICOM image (many other viewers are limited to showing uncompressed grayscale DICOM images) and can automatically detect and open Analyze, DICOM, Genesis, Interfile, Magnetom, Somatom and NEMA images. ezDICOM is part of the Source forge community. This programs have weaknesses in providing facilities for image processing and image analysis. The one of main purpose of this research is to facilitate physicians to display, processes and analyzes the images easily.

Essential functional requirements in parts of DICOM viewer, image processing and image analysis are listed in the below. These requirements are obtained from physician and technical stas in the radiology department of hospital in Thailand.

⊙ Display various standard formats of digital image data both single frame and multiframe: such as DICOM, INTERFILE, BITMAP, JPEG and JPEG2000.
⊙ Zoom in/out: zooming full image or partial image in and out for better image analysis.
⊙ Contrast/Color map: adjusting the contrast of a dim image by reassigning pixel brightness levels. Linearly adjusting the contrast range (by assigning the darkest pixel value to black, the brightest value to white, and each of the others to linearly interpolated shades of gray) makes the better use of the display and enhances the visibility of features in the image. Color mapping is applied to image according to the
difference of the image pixel value.

⊙ Quantitative Analysis: the quantitative analysis is to obtain average, maximum, minimum, dispersion and standard deviation of the pixel values in a ROI that can be set up in various forms such as rectangle, ellipse, line and polygon. More than one ROI can be set in a single image. Thence, Semi-auto ROI setting that sets ROI semi-automatically on region of expected disease.

⊙ Computer-aided diagnosis program: such as calculation of Glomerular Filtration Rate (GFR), Effective Renal Plasma Flow (ERPF), and plot of the Time Activity Curve or Renogram.

5. OVERVIEW OF MEDICAL IMAGE PROCESSING AND RADIOLOGY INFORMATION SYSTEM

In addition, a Radiology Information System (RIS) can be defined as a system that provides medical image services over long distance. The RIS service is one of the newest medical services that provides transmission of medical image and information for diagnosis, consultation, medical treatment and health education by using a communication network such as local area network, wireless network and internet. Thus, demands on an effective RIS have been ever increasing. With the advent of computer and communication technologies, construction of an effective RIS system becomes possible. Medical image databases play an integral role in a digitized clinical environment starting from storing of electronic patient records, scanned medical images generated by Modalities like X-Ray and MR to reporting and billing. The operations in the clinical environment such as image storage and retrieval, viewing, and post processing can be served by a reusable database component using which different modalities can develop their own clinical applications [12].

Component of the Medical Image Processing and Radiology Information System project can be used by the various modalities for reusable storage as shown below in figure 10.

The medical database storage component can be considered to be made up of two parts: 1) Data Access Layer 2) The underlying storage media. The medical database storage component exposes its functionality through the data access layer as shown in the figure 11. The data access layer of the medical database repository implements a published set of data access interfaces to store, retrieve, modify and query the data present in the underlying repository. These interfaces are concerned with access and transfer of medical data. The data access layer abstracts the underlying storage media, which in our case happens to be a commercially available RDBMS from the client.

The architecture of the reusable medical database component gives a provision where in the lowest layer, which accesses the storage media, can be a plug-in component in itself. This gives a provision for various modalities to plug in their specific storage accessing mechanism based on the commercial off the shelf database they opt as shown in figure 12. In addition to the performance tuning done at the RDBMS level, it is also important that the data access layer is designed for good performance. One of the key high performance use cases of any medical database is the fast rendering of a medical image. Medical images contain pixel data and it is very important to ensure that this pixel data is stored for extremely easy and fast access. In our database component, the pixel data is stored in a separate file on the file system whilst the Meta information is stored in the database. This gives a dual benefit:

1) Fast query of the Meta information as the data is stored in the database.
2) Fast access to pixel data given that the pixel data is stored on the file system and file IO performance can be maximized when the CPU is busy processing the meta information.

Medical images comprise of pixel data. This pixel data can be stored by modalities on different hardware configurations. The architecture of medical database storage component gives a provision where
in the modality could choose to plug-in its own pixel handling plug-in. As with off the shelf databases, the component is provided with a default implementation of the pixel plug-in which can readily deployed on a Windows based operating system in any modality. The component also has the provision of working with customized schemas in a modality. As noted earlier, certain modality might already have an existing schema on which certain specific applications (like for e.g. reporting) might be using. In such situations, in order to make our component work with modality private schema, Database Views are used. The modality owners can then provide the mapping from views to private tables. Having a provision for the modality to develop their own accessor plug-in component that understands the underlying schema for storing data provides this flexibility.

Medical images stored in the DICOM format would contain redundant information. For example, let us say 10 CT Images are acquired out of a CT scan. Each of these 10 images in the DICOM format will contain the same information with respect to the patient details such as patient name, patient Id, birth date, and study date, study time, series modality information. It is good to avoid this redundancy and for this the data must be normalized and stored in the repository. On normalization, the patient information, which is identical in all the DICOM files, is stored as a single entity in the Patient table in the database. Similarly, the study and series information, which are identical in all the DICOM files are stored as just two entities in the respective Study and Series tables.

6. RESULTS AND DISCUSSION

The Medical Image Processing and Radiology Information System project by using Borland Delphi 6.0, PHP and MySQL for image archive, image compression, image processing, image analysis and image transmission. To control the image capturing through the image capturing device, the program can connect to the hardware and bring video signals from the radiological modality. Then collect the imaging data from the video signal. The collection was sent to the single frame, 15 image/sec rated multiframe and fixed multiframe which could fix time range and frame rate radiological modality in Windows Bitmap file format (.BMP) without changing of image shape. The facilities in a part of image archiving as shown in Figure 13. For converting data to the DICOM data construction, the program can convert the data to the DICOM data construction after both various image collecting process and also automatic image collecting by converting without changing the image point data or not changing any the image data in the process.

The image compression, the program can compress from collect the imaging data in single frame file format and multiframe file format before compress to JPEG and JPEG2000 by having the same compressing ratio as shown in figure 14 and 15. The significant advantage of JPEG2000 over normal JPEG is that the error from JPEG2000 compression is smaller than the error from JPEG. Moreover, comparison of an image quality, a general evaluation tool, RMSE (Root Mean Square Error), has been adopted. The RMSE can be written by following.

\[
RMSE = \left[ \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} (f(x, y) - g(x, y))^2 \right]^{\frac{1}{2}}
\]  

(1)

Table 1 and figure 16 shows the comparison results based on compression ratios with JPEG and JPEG2000. Which show that compressing image in JPEG2000 has less error than normal JPEG compression. Both compression processes will increase the number of errors when the compressing ratio has increased.
Table 1: The RMSE Comparison JPEG and JPEG2000.

<table>
<thead>
<tr>
<th>Compression Ratio</th>
<th>JPEG</th>
<th>JPEG2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>15:1</td>
<td>2.29</td>
<td>4.77</td>
</tr>
<tr>
<td>35:1</td>
<td>1.60</td>
<td>3.08</td>
</tr>
<tr>
<td>65:1</td>
<td>2.71</td>
<td>3.75</td>
</tr>
<tr>
<td>Single Frame</td>
<td>4.82</td>
<td>21.14</td>
</tr>
<tr>
<td>Multiframe</td>
<td>6.19</td>
<td>4.82</td>
</tr>
</tbody>
</table>

Fig.14: JPEG and JPEG2000 single frame image (compression ratio 23:1).

Fig.15: JPEG and JPEG2000 multiframe image (compression ratio 68:1).

Fig.16: RMSE comparison curve.

Fig.17: DICOM viewer.

As shown in Figure 14, 15, 16 and Table 1, the overall performance based on JPEG2000 shows better result than JPEG. The system have developed a prototype in parts of DICOM viewer, image processing and image analysis. Figure 17 shows the GUI of DICOM viewer a part of this system. As depicted in figure 17, frequently used function are provided in the form of ICONs. Also, at image loading time, the program analyzes the DICOM 3.0 header and displays the header information with the corresponding image. In addition, the viewer has an image processing and image analysis tool bar that can be docked [12].

Functions provided with prototype can be summarized as follows: (1) DICOM viewer which can display various standard formats of digital image data both single frame and multiframe such as DICOM, INTERFILE, BITMAP, JPEG and JPEG2000. As depicted in figure 17. (2) Image processing which has also the capabilities to zoom in/out and contrast/color map. (3) Image analysis which determine the pixel values in a ROI that can be set up in various forms such as rectangle, ellipse, line and polygon. Thence, Semi-auto ROI setting that sets ROI semi-automatically on region of expected disease. Additionnally, more than one ROI can be set in a single image. As depicted in figure 18. (4) Nuclear medicine diagnosis which are more functions on nuclear medicine for renal study such as calculation of Glomerular Filtration Rate (GFR), Effective Renal Plasma Flow (ERPF), and plot of the Time Activity Curve or Renogram. As depicted in figure 19, 20 and 21.

These requirements are obtained from physicians and technical staffs in the radiology department of hospital in Thailand. As depicted in figure 16.

Moreover, time of ROI processing and efficiency between variance image and Canny edge detection are compared. The results shown that edge detection based on variance image have less time of ROI processing than edge detection based on Canny edge detection but have nearly efficiency of ROI processing both variance image and Canny edge detection. This research was tested with the DICOM 3.0 standard image compared the APEX - XPERT Program. The result showed that no significant difference can be found (= 0.05).

Figure 16 (a) depicts the architecture of this project. The DICOM server is connected to local/remote image acquisition system. Upon acquiring an image, the server stores the image in the DICOM v 3.0 format by using the DICOM encoding module. The stored image can be displayed by using the DICOM decoding module. The server also includes modules for image compression and DICOM viewer.
**Fig. 18:** Time Activity Curve or Renogram.

**Fig. 19:** The facilities for definition of personal value.

**Fig. 20:** Calculation of Effective Renal Plasma Flow (ERPF).

**Fig. 21:** Calculation of Glomerular Filtration Rate (GFR).

**Fig. 22:** Basic structure and sequence of interactions between clients and server in the system.
Clients (a personal computer, a notebook or a PDA equipped with a Web browser) can download and install the DICOM viewer from the DICOM server via WWW. From then on, clients can be selected and opened single frame and multiframes, each of which can exhibit information in .dcm file format and digital image processing based on local contrast enhancement, adaptive interpolators techniques, colour transformation and cine loop. Also, for a situation in that a client wants to discuss with other client, the server provide facilities for making Webboard.

Finally, The results of functional testing of the constructed project shows that a client can connect to the DICOM server through WWW, authentication by using a login processing is performed. The client can examine the list of image stored in DICOM server, select the desired image and download the selected image. When a client issues a command, then the command is transferred to DICOM server through the Web server.

After, DICOM server finished the requested job, the result image is sent to the client through the Web server. In the event of image display and image processing is performed by DICOM viewer which the client can download the DICOM viewer in the form of plug-in from the server.

7. CONCLUSION

The Medical Image Processing and Radiology Information System project is designed and developed a prototype running on personal computer under the Windows OS. The prototype provides various function for image archive, image compression, image processing, image analysis and image transmission. Furthermore, the system has been developed and provided medical image services over long distance which showed the usefulness of our approach. Past works in imaging and open source projects have remained fragmented, only offering niche solutions. Thus, developers are often left with the task of reinventing or integrating dissimilar software components; ultimately, it is hoped that this project, as an umbrella framework for all these efforts, can serve as starting point to foster new developments in PACS and the use of imaging in support of evidence-based medical practice, research, and education.

References

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