3D Coding of Volumetric Medical Data Sets

László Tóth

Department of Networked Systems and Services, Multimedia Networks and Services Laboratory
Budapest University of Technology and Economics, Hungary
tothl@hit.bme.hu

Abstract— **Advancements in digital radiology have led to a significant increase of the sample bit-depth and resolution of data sets, causing accordingly grow in size. Both efficient storage and efficient transmission of large medical data sets request efficient compression techniques. In this paper, we investigate the state-of-the-art volumetric medical data compression techniques. We present our web-based interactive test system for storing and visualising 3D medical images, and testing and comparing several compression methods.**

Keywords— **DICOM,JPEG2000,3D Image Coding**

I. INTRODUCTION

The DICOM (Digital Imaging and Communications in Medicine) standard generally is used for the exchange of images and related information. Nowadays, all medical imaging devices (also known as Modality), such as CT, MRI, supports the DICOM standard [1].

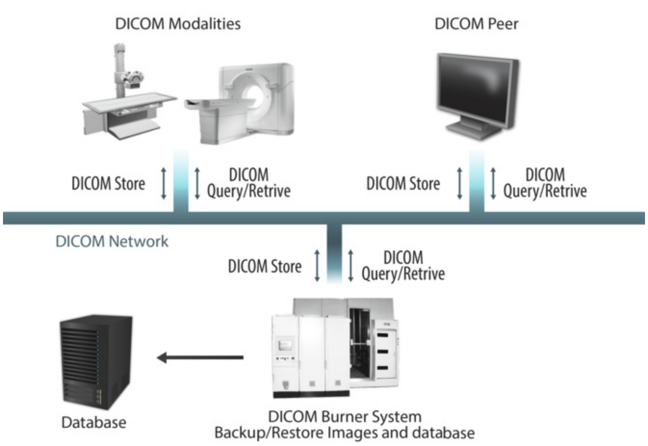

Fig. 1: DICOM Network

The scope of medical imaging is wide, from a digital image of a bone X-ray (a single frame), to a set of tomographic slices through all of the body. Projection X-ray images and reconstructed tomographic slices are grayscale, but typically require encoding with a resolution beyond 8 bits.

Digital medical imaging devices generate large amounts of volumetric data sets. Advancements in digital radiology have led to a significant increase of the sample bit-depth and resolution of data sets, causing accordingly grow in size.

DICOM provided a set of standards that allow for interoperability and compatibility in a multi-vendor eco-system. DICOM technology provides interface between imaging devices and a network, and it makes the communication robust and transparent(Figure 1).

In this paper we investigate the state-of-the-art compression techniques of 3D medical data.

II. THE JPEG 2000 TECHNOLOGY IN MEDICAL DATA COMPRESSION

The JPEG 2000 standard defines a new image-coding scheme using wavelet-analysis based compression techniques [3]. The present version 3.0 adopted existing image compression standards from the JPEG working group. Because promising results of wavelet-based compression methods DICOM adopted JPEG 2000 Part 1, so the standard is able to offer efficient compression, storage and transmission of two-dimensional medical images. Additionally, JPEG 2000 with embedded block coder by optimized truncation (EBCOT) technology delivers excellent quality and bit-rate scalability [4].

In spite of this even the JPEG 2000 Part 1 2D methodology is still considered state-of-the-art image compression technology. In practice, often simple schemes are employed in lossless of medical data. For instance, only incorporating run-length coding is defined in DICOM.

While in everyday use it is tolerable transient inconvenience of having to download a new software (or a new codec) version to view a picture or video, such untrustworthy operation is absolutely unacceptable in the practice of medicine.

DICOM'S one main disadvantage is, that it allows a very limited set of compression methods that can be used both on the network and on offline interchange media[7].

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III. Implementation and Test System

Aiming to investigate JPEG2000 compression techniques, we have implemented a test system based on JPEG2000 technologies. In common applications these technologies is not widely used.

The JPEG 2000 codec even in FFMPEG is still experimental [1]. (The j2k codec, both encoder and decoder are not lossless nor bitexact with reference jpeg2000 implementations, which explains why they are experimental). For further investigation we had to build an own test system to work with j2k techniques in medical imaging.

We implemented an OpenJPEG based test system for export medical data from DICOM and compression.

All major functionalities, like 2D preview from slices, volume rendered 3D preview, compression method selection, parameter setting, statistics form result are easily accessible from a simple menu.

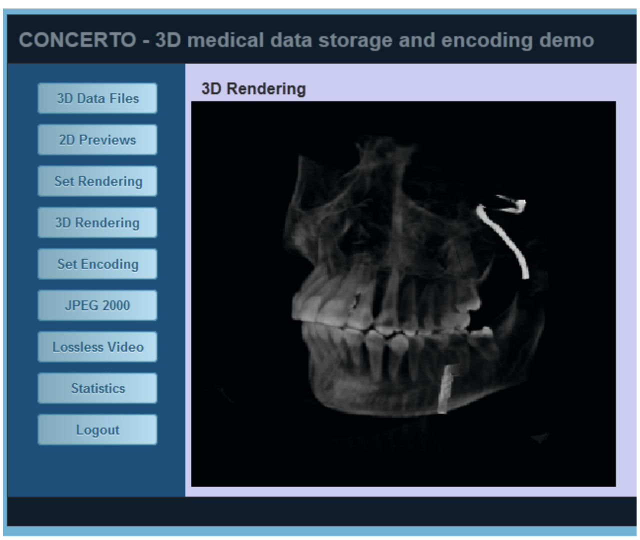

Fig. 2: Web interface of the test system

Many scanning devices, such as CT and MR, result in slices through an object, each 2D slice is presented as a grey scale image. Each pixel in the image corresponds to some characteristic at that point in space, for example X-ray absorbtion in CT scans or protein density in MR.

The 3D medical data storage and encoding test-system, has a web-based user interface, and a database interface for 3D medial data files, where input (original 3D medical data) files can be selected, 2D preview montage can be generated, parameters for directory-based and JPEG2000 encoding can be set, volume rendered image can be generated, statistics about the test results can be viewed. The interface has a simple menu-system, from where each important service avaiable (fig 2).

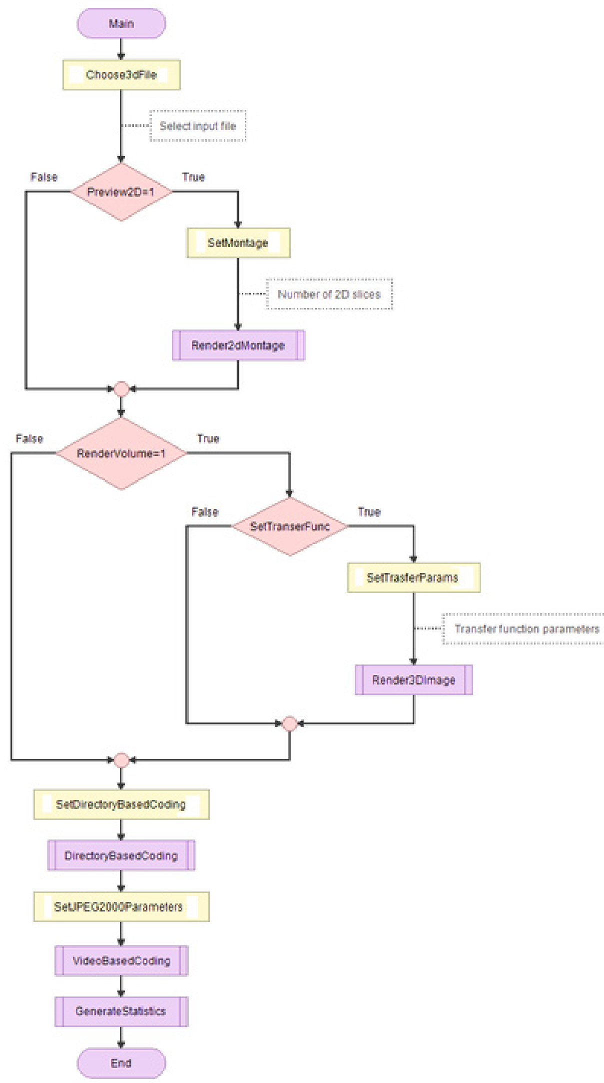

Fig. 3: Flowchar of testing

The 3D medical data storage and encoding test system has the following functionalities: viewer for 2D Medical data (1 slice), montage-viewer for set of 2D medical data, free point of view volume renderer for 3D medical data, transfer function changeability for volume renderer, efficient 3D medical data storage with JPEG2000 and H264 video coding, 3D RAW data encoder and decoder.

[1] 2015.02.10

A. Test Story-line

The 3D medical data sets are stored in the database of our test server. One 3D data set consists of slices through an object, where each 2D slice is normally presented as a grey scale image. We can view the 2D images one-by-one, or get a montage of the 2D slices (as a preview), in 9, 16, or 64 pictures in array.

In order to view the original 3D data, we apply a texture-based volume rendering technique, where we perform the sampling and compositing steps by rendering a set of slices inside the volume.

Using our volume rendering engine, we can render a free point of view 3D image from the original data set. We use an optical model to map data values to optical properties (like color and opacity). Optical parameters calculated by applying transfer functions to the data. For example, with changing the transfer function, we can render the tooth with more intensity than the surrounding bones.

For the efficient storage of 3D medical data, we applied and compared several compress methods. The used compression methods are: lzma, gzip, bz2, lzma with e parameter, and lossless jpeg2000. Our test system generates statistics from the efficiency of compression.According our test results, the jpeg2000 techniques are quite efficient for encoding medical data sets.

Because of the correlation between neighbouring slices, we can interpret the sequence of 2D slices as frames of a video stream (Fig. 20). In our test system, we generate a video from each 3D data sets, using lossless video encoding (H264 with ultrafast and veryslow presets, and ffv1).

In the test, at first, user selects the original 3D data to be processed. An optional montage of 2D slices is available, where the user sets the number of slices to be viewed. A free point-of-view volume rendered 3D image is also applicable, with some optional settings for the rendering (like parameters of the alpha blending). After choosing the applied directory-base methods (lzma, gz2 etc), and setting the parameters for JPEG-2000 and H264-based encoding, the medical data file is encoded in several different ways, and statistics are generated about the different compression methods.

B. Test Results

According to our test results, the H264 with ultrafast preset is much faster and near that efficient like the best directory-based methods. The H264 with very slow preset is more efficient compared to the directory-based methods and the j2k. Our environment also comprises a web-based GUI, so the rendering and compression steps can be controlled from the far client as well.

We investigated the JPEG-2000 file size at lossless compression compared to other lossless format (Figure 4).

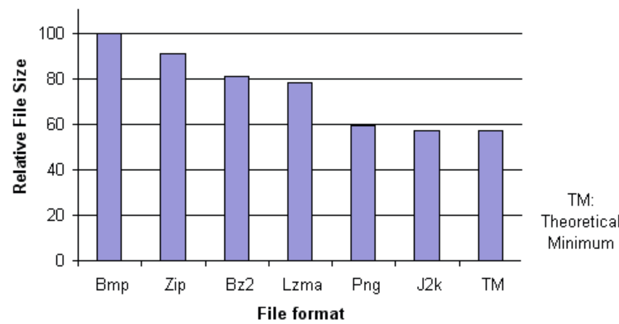

Fig. 4: File sizes at lossless compression

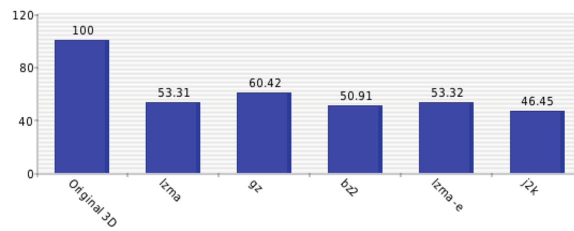

Fig. 5: Applied lossless file compressions - file sizes in percentage

According our test results, the lossless JPEG-2000 compression is more efficient then the other common compression methods (zip, lzma, bzip2...). We have calculated the Shannon-entropy of the test files (defined by $H = \sum x_i p(x_i)$ and the average code word length to find out the theoretical minimum of the lossless encoded files. The theoretically minimal file size is more than 99.99% of the j2k encoded file, so the JPEG-2000 lossless encoding could be considered quasi-optimal and practically applicable (against the Huffman-coding).

In addition to the efficient lossless compression, the JPEG-2000 techniques provide near-lossless and highly scalable lossy compression

We investigated the lossy JPEG-2000 compression file sizes at different Peak Signal to Noise Ratio (Figure 6).

At 80dB PSNR (and above) the file size is about equal to the lossless compressed file (theoretically inf PSNR). So if the medical application requires at least 80dB PSNR, the lossless compression is more relevant.

Under 40dB PSNR the degradation of quality makes the compressed file useless. Between 40 and 80 dB, the file size sharply increasing (almost linearly).

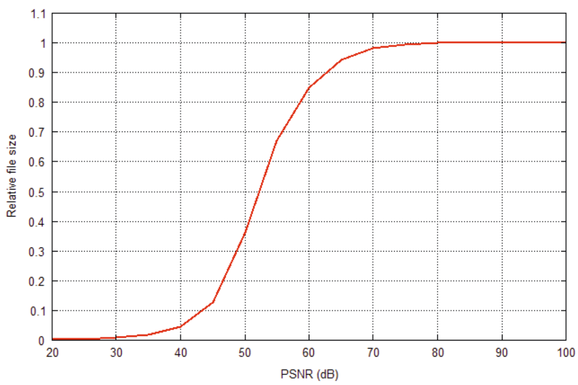

Fig. 6: Relative file size - PSNR function

We have investigated the required compression time at different PSNRs. According our measurements (fig 7), the compression time is nearly independent of the PSNR (constant).

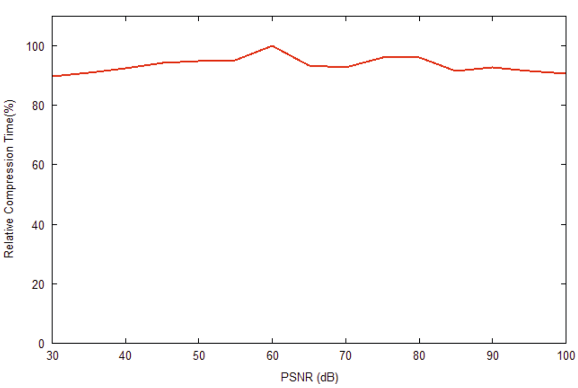

Fig. 7: Compression time - PSNR function

There are local extreme points and increasing and decreasing intervals on the function, but the test was performed not with a dedicated machine, so fluctuations may have been caused by other background processes. It could be said that with lossy compression the compression time is irreducible.

Investigating the decompression time, we obtained a near-linear, slightly increasing tendency. Reducing the image quality, the decreasing the decompression time is significantly lower than decreasing of file size.

IV. Conclusion

We implemented a test system to investigate state-of-the-art coding technologies in DICOM stored medical data compression. The lossless coding is more effective than the other,

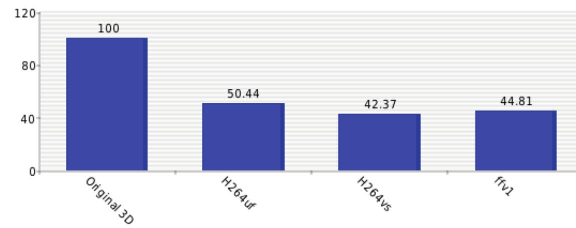

Fig. 8: Applying video coding for 3D data sets file sizes in percentage

common-used methods (like variable length coding). If an application needs at least 80 dB PSNR, the lossy coding is not appropriate. Between 40 and 80 dB, the file size sharply increasing (almost linearly). The JPEG-2000 technology is quite efficient for 3d medical data compressing.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Author: László Tóth
Institute: Budapest University of Technology and Economics
Street: Műegyetem rkp. 3.
City: Budapest
Country: Hungary
Email: tothl@hit.bme.hu