THE JPEG2000 STANDARD FOR MEDICAL IMAGE APPLICATIONS

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Abstract: A new standard of still image compression is characterised in the context of medical applications. Wide spectrum of JPEG2000 features is analysed with respect to its application potential to improve the performance of modern medical services (*i.e.* telemedicine, PACS, radiology information systems, wireless personal/home health care systems). Image data security techniques, error resilience technologies, client-side interactive Region of Interest (ROI) transmission and decoding (*e.g.* for teleconsultation with very large radiography exams), and storage of multiple image data sets are considered in detail. Selected tests of coders realized according to parts I and II of JPEG2000 for different modality test images are presented to evaluate the compression efficacy of this standard. Exemplary results of encoding process optimisation by wavelet transform and subband decomposition selection and screen-shots of software interfaces designed for these tests are also presented.

Keywords: image compression, JPEG2000, medical images, wavelet coding, medical information systems

1. Introduction

New image acquisition and digitalisation technologies have brought about a revolution in medical imaging. An increasing number of medical images is created directly or indirectly in digital form. This has led to the development of digital archives, clinical PACS (picture archiving and commumnication systems), as well as telemedicine networks and RIS (radiology information systems), facilitating enterprise wide information communication. Digitally acquired images have given specialists access to new depths of perspective on the data being acquired. The impact is far-reaching and continues to grow. Medical image compression leads to significant technological advances in teleradiology and PACS by applying toolkits for the handling, storage, viewing and transmission of medical images.

The ability to obtain the most compact image data representation of the required (safe or accepted) quality level of the reconstructed image has been the most common criterion for the majority of compression technology applications. Nowadays, the development of new archiving and transmission technologies is driven by the requirements of flexible functionality of compression tools in many applications. A clear hierarchy of the information structure, different kinds of progression in data reconstruction, conversion or transmission, manipulation of embedded data streams, lossy-to-lossless fluent going through and many other features are sought after.

Wavelet-based image compression has been recognized as a useful means to efficiently archive and electronically transport and distribute medical images [1, 2]. The adoption of this kind of compression by the medical industry in the last few years has been so extensive that today some form of the wavelet algorithm is used by all of the major medical imaging system providers. This class of algorithms is now available to a wider medical system user base with the approval of JPEG2000 as an accepted image compression option by the DICOM (digital imaging and communications in medicine) Working Group 4 (*viz.* the compression group). An important reason for this acceptance was that it allows transmission of images with improving resolution and quality, which will be extremely useful in teleradiology and in some PACS network environments. The adoption of JPEG2000 as a standard by the ISO and its inclusion into DICOM is a validation of the newer technology and the logical result of the desire for a more advanced yet standardized method of compression and transmission of medical images.

This paper reviews the JPEG2000 standard based on the wavelet compression paradigm. The requirements of medical imaging systems concerning compression tools are compared with the capabilities of the JPEG2000 encoding system, its particular functions, parameters and application possibilities or conditions. Exemplary applications are completed with experiments intended to investigate the compression efficiency and usefulness of the standard coders. The main idea is to highlight the promising potential of JPEG2000 and the most beneficial features of the new standard to verify its use for medical applications.

1.1. The standard JPEG2000

JPEG2000 [3] is a new, state-of-the-art image compression standard designed for a broad range of applications, including the compression and transmission of medical images. The new standard is based on state-of-the-art wavelet technology and a layered file format that offer flexible lossy-to-lossless compression, irreversible compression that preserves image accuracy, and advanced functionality of image data management systems.

Great effort has been made by the JPEG committee to deliver a new standard for today's and tomorrow's applications, by providing higher efficiency for features (especially superior low bit-rate performance) which exist in previous compression standards and supporting additional features that do not exist in others. Image compression technology was extended to such emerging applications as digital libraries, multimedia, internet, color fax, digital photography, mobile, e-commerce, medical imaging and volumetric imaging.

A JPEG2000-based system for storing and retrieval of digital medical images has significantly increased the system's flexibility and performance. For example, system administrators can designate different levels of compression for different imaging modalities (what enables them to design compression strategies to optimize image storage while also supporting important image quality requirements). The acquired image can be compressed and saved in a lossless, near lossless or an acceptably irreversible form. Multiple smaller portions of data can be extracted from very high quality compressed files and progressively decoded and viewed from networked clients. Progressive decode/view can be achieved. An image outline can be displayed almost immediately after only a small portion of the file has been received (R-D optimization of data stream causes the perceptibility of decoded structures). As more data is received, the resolution or quality of the image will be automatically refined. For bandwidth-constrained applications, only the additional quality or resolution layers need be transmitted (interactive ROI-oriented image transmission, *etc.*).

According to the "Call for contributions for JPEG2000" [4] it was intended to provide a set of features vital to many high-end and emerging image applications by taking advantage of new, modern technologies. Specifically, this new standard addresses areas where current standards fail to produce the best quality or performance. It also provides capabilities to markets that currently do not use compression. JPEG2000 is still in progress but many current, fixed features seem to be really promising for medical applications.

1.2. Wavelet compression paradigm

Wavelets tend to be very efficient in representing the features of medical images, so by using wavelet-based image decomposition improved compression performance may be achieved in comparison to JPEG (based on discrete cosine transform (DCT), applied earlier in DICOM). Recent clinical studies have shown that wavelet compression is comprehensively superior to other similar compression methods. Higher quality of reconstruction has been verified in many reported experiments. Wavelet-based encoding provides a means of compressing radiology images even up to the ratio of 40 : 1 while preserving its diagnostic accuracy. This makes wavelet an ideal compression method for teleradiology and picture archiving applications.

The basic transform coding paradigm means decorrelation and compaction of energy into as few coefficients as possible. An ordered array of transform coefficients is quantized with a priority according to their order. Wavelet compression goes beyond this traditional paradigm known from the old JPEG. Because wavelets are spatially as well as spectrally compact, effective selection of elements to code and thus quantization and information ordering could be achieved. The choice of data ordering form is a non-linear process, where local features of transform bases and the processing procedure are fitted adaptively to local features of a signal. It means that the compression procedure is much more flexible (user-defined progression, scalability, embedding) and more efficient, especially in the range of low bit rates where such selection plays a crucial role in coding [5]. JPEG2000 is based on this extended paradigm, which means significantly increased possibilities of the compressed data stream formation (see Figure 1).

2. Compression tools for medical image applications

Basic requirements for compression methods applied in medical imaging systems have been compared with the relevant features of the JPEG2000 codec (**co**der–**dec**oder). Adopted ideas and the already developed and realised standard algorithms

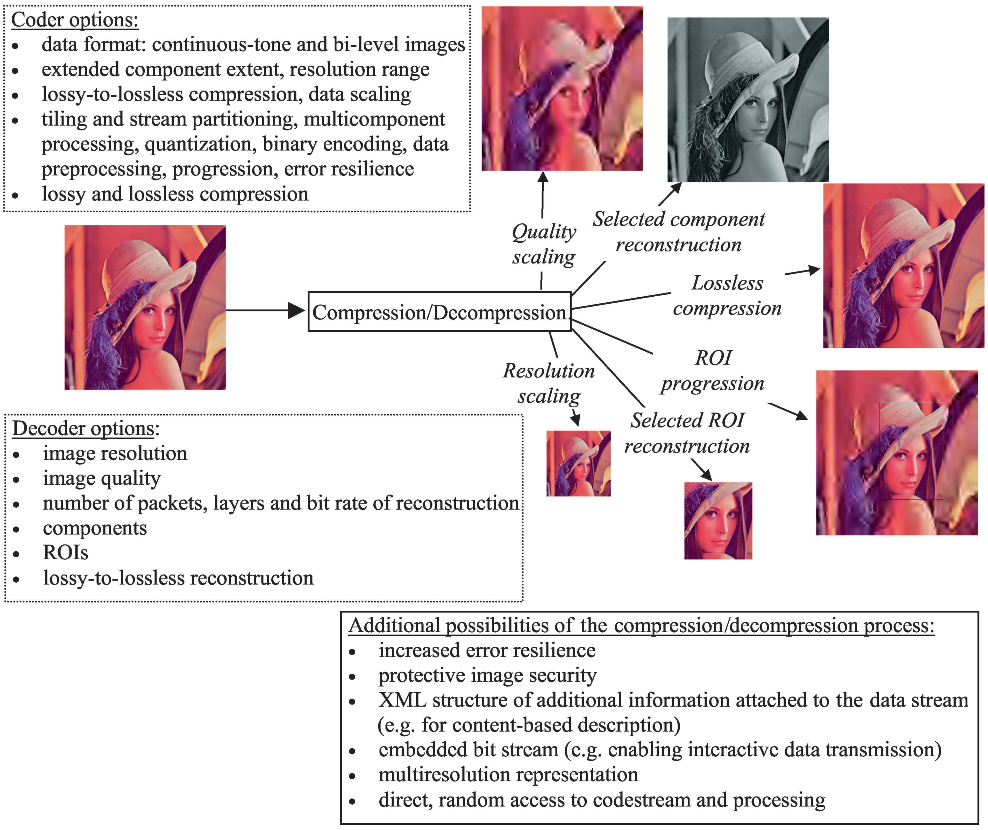

Figure 1. Compression scheme of JPEG2000 (according to part I) based on the wavelet paradigm. Test image Lenna is used

seem to meet these requirements making JPEG2000 important for further performance improvement of image information management and interchange tools.

2.1. Requirements of medical imaging

Clinical PACS, as well as teleradiology and RISs require the archiving and transmission of huge amounts of medical image data. Therefore, efficient compression of high quality images generated from various medical imaging systems such as digital x-ray, CT, MR, mammography, PET, ultrasound, angiography is crucial for these applications. Medical image compression enables significant technology advancement by applying toolkits for the handling, storage, viewing, indexing and interchange of medical images.

The following features of compression tools are mostly required for these applications:

- fast and efficient lossless compression (which reconstructs the image as numerically identical to the original, thus facilitating accurate diagnosis at the expense of lower compression ratios) for a highly differential class of images (different imaging modalities, greyscale, colour, compound and multicomponent images, still images, temporal image sequence, volume image data);

- fast and efficient lossy compression (preserving diagnostic accuracy, despite the hesitations of the scientific community that such techniques might lead to errors in diagnosis, or imposed by several legal and regulatory issues) for a differential class of images;
- ROI-oriented processing (often there are parts of an image that are of greater importance than others – we need to define certain ROIs in the image to be coded and transmitted first, without any loss or in a better quality and less distortion than the other, background information in the image); ROI encoding allows important image features to be preserved, decreasing the bit rate without sacrificing diagnostically important details; when combined with progressive display, ROI-oriented progression of encoding and interchange allows the image's foreground to be transmitted and displayed first, followed by the background;
- maximum flexibility, *i.e.* a wide spectrum of compression capabilities well fitted to particular requirements of viewing and storage systems by selecting the proper parameters of compression/decompression (*e.g.* user-defined profiles) such as ROIs, scale (resolution or quality level) dependent on output device capabilities, accepted range of bit rates, order of progression, *etc.*;
- full reversibility, so that original image quality is always available to radiologists and other users for certain applications, limited realisation (time and data structure) complexity;
- reliable security protection and error resilience for transmission applications.

2.2. The advantages of JPEG2000

Among many different capabilities of wavelet-based multilayered embedding compression, JPEG2000 provides various features which are advantageous for medical imaging applications. Particularly, JPEG2000:

- uses wavelets, a diagnostically proven method for medical image compression, so professionals can be assured of its accuracy and reliability; it also supports bit depths of up to 38 bits per channel, and up to 16 384 channels;
- enables lossless and lossy compression: provides superior lossy to lossless compression in a single codestream, naturally available during its progressive transmission and decoding. (For medical imaging, where loss (or irreversibility) is not always tolerated and reversibility of the stored or transmitted representation is sometimes necessary such image archival, where diagnostic accuracy is vital for preservation and case-dependent, but the highest quality is not necessary for display, printing or network applications, will find JPEG2000 quite useful due to its lossy-to-lossless capability.);
- enables ROI-oriented encoding that enhances the accuracy of diagnostically important features. (Its inherent multiresolution capability, layered data format allowing image quality and resolution scalability, and progressive decoding and visualisation reduce waiting time for image exam on-line interchange, which is useful for radiology teleconsultations with experts and image database system applications.);
- applies metadata boxes that allow vendor-specific and non-image data (*e.g.* exam descriptions, selected or processed data for indexing in the wavelet domain) to be embedded within the compressed data file (stream);

- enables interactive image transmission and decoding (where selected coding parameters are changed in the encoding process according to the user's request dependent on the initially perceived image features) in the client-side architecture (for teleconsultation, telediagnosis, teleconferences, *etc.*), developed in part 9 of the standard: "JPEG interactive protocols and API" (JPIP);
- enables storing multiple images in one data file or stream (applicable to compression of dynamic studies, temporary correlated image sequences, *e.g.* ultrasound dynamic exams) and fast, direct, random codestream access and processing, fast preview, *etc.*, as developed in part 3 of the standard: "Motion JPEG";
- supports improved three-dimensional (3-D) data compression with volumetric wavelet transformation for volumetric, spatially correlated image data exams, *e.g.* multiple slice CT or MR exams, as being developed in part 10: "Volumetric imaging" (JP3D);
- initiates an error resilience technology (several tools based on different approaches are provided) making the transmitted (shared) digital images safer and more reliable (image compression and transmission in wireless environments for such applications as home care, mobile patient monitoring, panic button emergency systems, *etc.*, developed in part 11: "JPEG wireless applications" (JPWL));
- develops security techniques, a possibility of conditional data access, authentication and IPR protection for all stored and transmitted images, as developed in part 8: "Security aspects" (JPSEC).

Moreover, JPEG2000 is advantageous as an established standard. The support of the newer ISO/ITU standard called JPEG2000 was added to the DICOM standard in November 2001, with the publication of Supplement 61: "JPEG2000 Transfer Syntaxes". Both the JPEG2000 lossless and lossy compression algorithms have been accepted for use. Consequently, many vendors of codecs for medical imaging systems included JPEG2000 in their products. JPEG2000 plug-ins provide easy viewing and progressive decoding of JPEG2000 files from popular Web browsers. As an open international standard, JPEG2000 provides a level of global interoperability unachievable with proprietary compression schemes. Standardization is beneficial for many reasons, but one with particular resonance for medical professionals is that using an open standard makes future data migration unnecessary, even if the images are to be kept for decades.

2.3. Short review of possible applications

Teleradiology applications are designed to assure fast image information access by efficient, interactive and progressive transmission of image data. The accessed data are used for primary diagnosis, interactive consultation and retrieval of reference (external) or internal databases. The philosophy is to develop and provide a flexible, scalable, feature-rich telemedicine system that meets the healthcare needs. An image compression standard applied for this purpose should enable the realization of these ideas. The advantage of the majority of interactive client-server technologies is the speed at which the desired information, *e.g.* the regions of interest of any image, will be delivered and viewed. ROIs or other image features (resolution level, mode of progression, error resilience technology, *etc.*) are selected on the client side in interactive transmission sessions. This saves storage cost on the server, reduces server load and reduces download time and cost to user.

The typical procedure of a JPEG2000-based teleradiology application is as follows. Images are acquired in a standard uncompressed form. JPEG2000 is used to create a compressed version of each image accessible on the server side. The images are made available in an encoded form for download or streaming. The client has to install a JPEG2000 decompressor (*e.g.* a Java applet). The required image is transferred from the server as a compressed datastream and is then gradually decompressed to the original format just before calling the associated viewing application. The initial outline of the image presented by this viewing application becomes more detailed bit by bit, according to the progress of data receipt. Assuming an interactive data transmission protocol, the server application encodes the image and transmits the datastream bit by bit. The received, decoded and viewed image data may be simultaneously interpreted and the client may change encoding parameters at any time (mostly ROI definition) or even stop this client-server operation. Using the new technology, radiologists can now have faster access to distributed image databases, for primary evaluation and diagnosis, interactive consultation (*e.g.* to provide health care service where it is unavailable, *i.e.* islands, rural areas, crisis situation areas, *etc.*) and for the subsequent retrieval of archived images.

The important functions of personal/home care systems are as follows: to help a senior or disabled family member or friend remain safe and secure in their own home or other place every day, to make your senior living/assisted living property more secure and cost-effective, and to improve your facility communications. Two important things one has to support in these applications are wireless transmission (with performance improved by several options of error resilience) and display of images to a device of the hand-held computer class. The plug-ins are designed to take full advantage of JPEG2000's higher compression to cut image transmission time, conserve wireless bandwidth and store more images in the hand-held's limited memory. The plug-ins also perform progressive display and support interactive pan and zoom to display high-resolution images on a small screen.

Moreover, the important questions of PACS design are: a) how can we quickly distribute images and reports among physicians throughout an institution? b) how can we effectively manage the storage and archiving of image data? c) how can we effectively manage the flow of image data in a given hospital? Lossy image compression methods are used in PACS and teleradiology systems to decrease the time and cost of image transmission and storage. Web-based PACS platforms are an integrated collection of strategic clinical tools that collectively allow institution-wide PACS and image management. Tying these tools together is an on-demand real-time work list, which is the key to their functionality. It allows radiologists to accomplish two tasks that they cannot accomplish with previously used PACS: it allows them to handle workflow internal and external to the department and to communicate the results of their work as a report and set of images to an expanding base of clients. The aim to develop and provide scalable, feature-rich PACS that meet the healthcare needs of organizations of all sizes could be realized by application of JPEG2000 tools (including JPIP and JPSEC). The fundamental system function is to enable radiologists from different locations to perform collaborative diagnoses by reading exactly the same images, sharing selective image information as soon as possible, processing the same areas in order to extract additional diagnostic information, and – finally – to achieve the necessary agreement.

To summarize, JPEG2000 supports faster transmission results and progressive transmission/decompression/reconstruction, interactive image data interchange, selectable compression on the client side and image modality oriented compression, which are especially important for telemedical applications.

3. Experiments

Only selected, exemplar study results of JPEG2000's usefulness for medical applications are reported. We have tested the efficiency of a JPEG2000 lossless coder in comparison with state-of-the-art coders like CALIC [7], JPEG-LS [8] and others. The results of compression of 8 representative medical test images of different modalities are presented in Table 1. The wavelet basis and the subband decomposition scheme have been selected according to the possibilities given in part II of the standard in order to increase compression efficiency for each test image (procedures from [9] have been applied). The mean reduction of bit rate in comparison with fixed decomposition from part I of JPEG2000 is 2.5% and the maximum bit rate decrease is close to 13%. Another wavelet-based compression scheme called SPIHT [10] showed similar compression effectiveness and possibilities of wavelet decomposition optimisation but the flexibility of the JPEG2000 scheme is significantly wider than the one established procedure of SPIHT compression. Generally, the efficiency of lossless wavelet coding is similar to JPEG-LS (lossless and near-lossless compression standard of the JPEG committee) and slightly inferior to CALIC (known as reference, the most effective reversible image coder with hierarchical, multi-context prediction and

Table 1. Lossless compression of medical test images; bit rate values (bits per pixel) are presented; the following coders were used: JPEG2000 [6] (according to part I, with 5/3 filter bank and Mallat decomposition, and according to part II, with optimized wavelet decomposition), SPIHT (with optimized wavelet decomposition), JPEG-LS and CALIC, with Huffman coding (H) and arithmetic coding (A)

Image	Fetures	JPEG2000 (p. I)	JPEG2000 (p. II)	SPIHT	SPIHT (opt)	JPEG-LS	CALIC-H	CALIC-A
Cr	$1744\times2048\times10$b	5.34	5.34	5.27	5.25	5.31	8.93	5.16
Ct	$512\times512\times12$b	3.98	3.47	3.71	3.64	3.82	7.62	3.61
Mri	$256\times256\times11$b	5.94	5.77	5.84	5.81	5.91	9.56	5.72
Us	$512\times448\times8$b	3.04	2.83	3.16	2.93	2.63	2.70	2.56
Us_m	$256\times256\times8$b	5.00	4.89	4.87	4.83	4.92	4.85	4.77
Xray	$2048\times1680\times12$b	6.07	6.04	5.95	5.93	5.99	9.28	5.91
Mamm1	$2672\times3709\times12$b	6.95	6.93	6.80	6.77	6.79	9.83	6.79
Mamm2	$1179\times2435\times14$b	8.33	8.30	8.15	8.12	8.18	9.85	8.06
Average		5.58	5.44	5.47	5.41	5.44	7.83	5.32

(a)
(b)
(c)

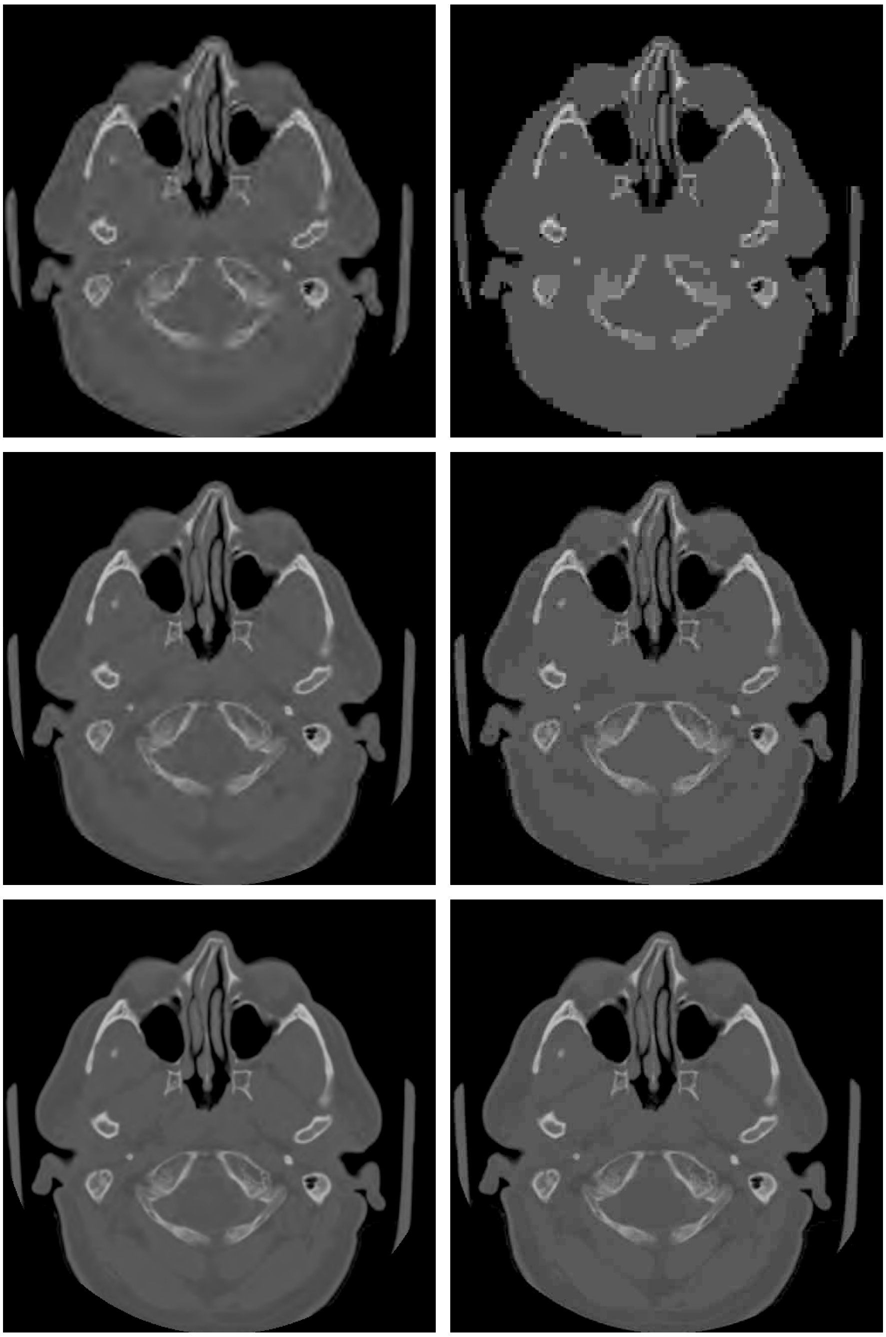

Figure 2. CT test image compressed by JPEG2000 (left) and JPEG (right) coders to: (a) 0.05bpp, (b) 0.1bpp, (c) 0.2bpp

entropy coding). The tendency of the achieved results is in agreement with the results of other experiments using larger sets of medical test images [11, 12].

The results of irreversible JPEG2000 compression are presented in Figure 2 where the efficiency of this standard is compared to JPEG, also used for medical

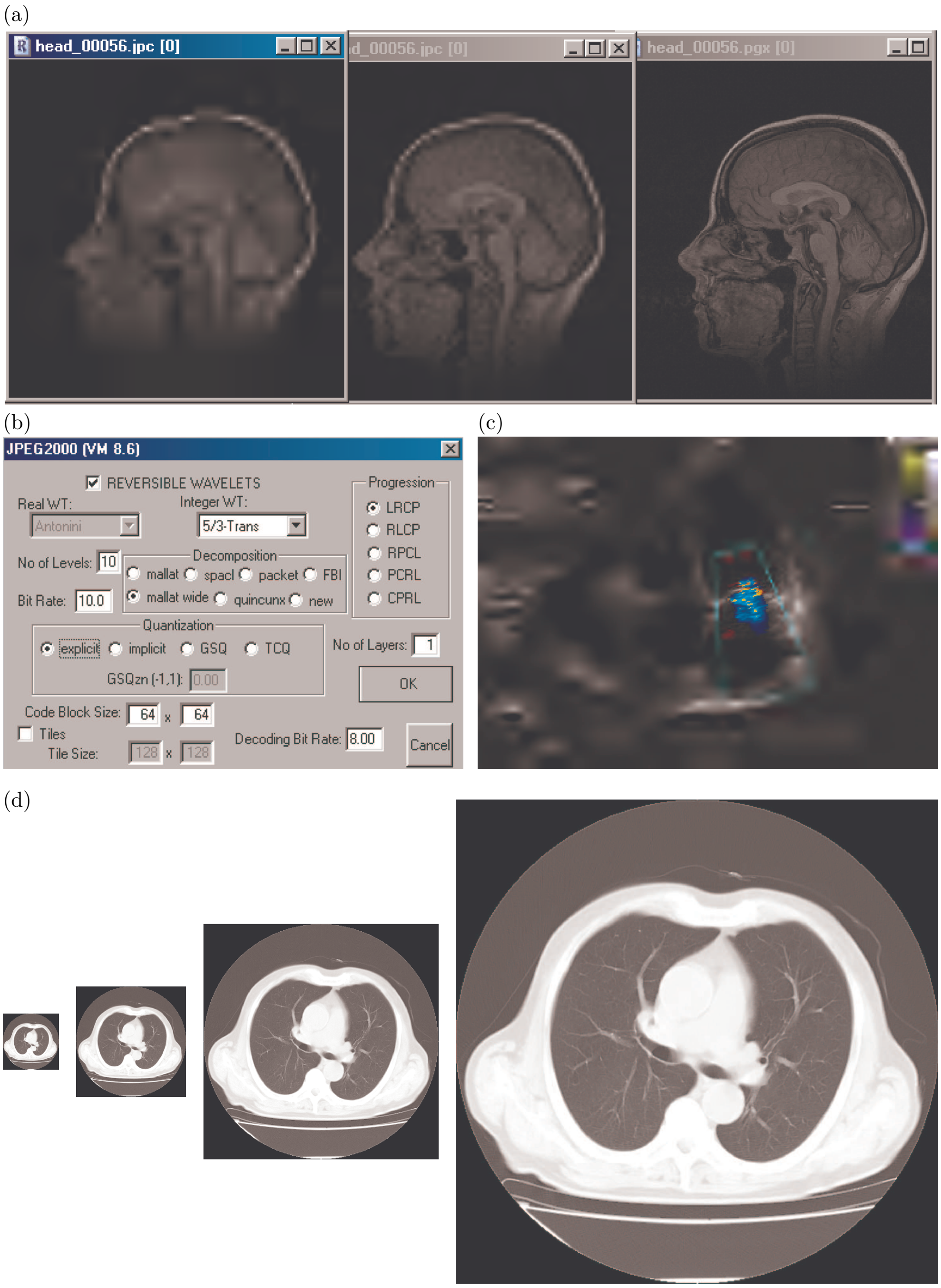

Figure 3. Examples of flexible reconstruction of compressed JPEG2000 data streams: (a) three phases of MR image decoding (progression according to reconstruction of the first 1, 5 and 11 packets of data stream, respectively); (b) exemplary interface for JPEG2000 parameter selection; (c) US image reconstructed in accordance with ROI-oriented progression (initial stage of transmission: high quality coloured Doppler map as foreground and smooth outline of morphology structures as the less important background), (d) decoding a CT image with progression of resolution

(e)

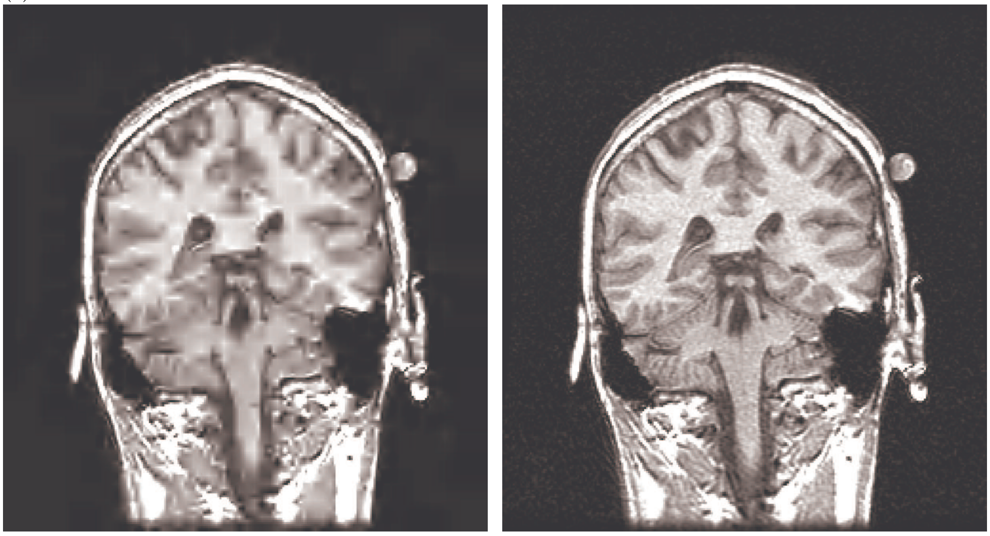

Figure 3 – continued. Examples of flexible reconstruction of compressed JPEG2000 data streams: (e) decoding a MR image with quality progression of a multilayered data stream

applications (included in the DICOM standard). Visible and peak signal to noise ratio (PSNR) measured image quality improvement of images compressed according to JPEG2000 has been noted. Examples of JPEG2000 compression and decompression flexibility extending the areas of medical applications are presented in Figure 3. Interfaces of the used software have been constructed for standard software packets, JasPer and JJ2000 [13], and applied in multiple stand-alone and networked systems [14].

4. Conclusions

The potential of the JPEG2000 standard in context of medical applications is promising. Therefore, the knowledge of JPEG2000 features and capabilities completed with a wide range of application tools is useful and worth of study for the radiological community. Considerable capabilities of application of this standard in medical imaging systems, confirmed by DICOM, rely on the high compression efficiency, wide functionality and fast and clear adaptability to the users' requirements.

Further development of the JPEG2000 standard will create new capabilities of using newer information technologies for image-based diagnosis. Improved interactive protocols and wireless applications supported by dependable error resilience technologies allow enhanced teleconsultation and retrieval of medical image databases, make possible long distance interactive diagnosis in rural areas and constant collaboration with prominent radiology centres and supporting experts. Distributed systems of reference image information interchange and computer aided diagnosis with architectures based on large-scale technologies, like GRID, may be developed and enhanced.

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