Bilateral symmetry, Human visual system, MRI and CT images, Just noticeable distortion, Perceptually lossless compression

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ANALYSIS AND COMPARISON OF SYMMETRY BASED LOSSLESS AND PERCEPTUALLY LOSSLESS ALGORITHMS FOR VOLUMETRIC COMPRESSION OF MEDICAL IMAGES

Modern medical imaging techniques produce huge volume of data from stack of images generated in a single examination. To compress them several volumetric compression techniques have been proposed. Performance of these compression schemes can be improved further by considering the anatomical symmetry present in medical images and incorporating the characteristics of human visual system. In this paper a volumetric medical image compression algorithm is presented in which perceptual model is integrated with a symmetry based lossless scheme. Symmetry based lossless and perceptually lossless algorithms were evaluated on a set of three dimensional medical images. Experimental results show that symmetry based perceptually lossless coder gives an average of 8.47% improvement in bit per pixel without any perceivable degradation in visual quality against the lossless scheme.

1. INTRODUCTION

Volumetric medical image compression techniques have an important role in telemedicine and Picture Archiving and Communication Systems (PACS) as it minimizes the data storage requirement and the data transmission time leading to, saving in transmission and PACS implementation cost. Number of three dimensional (3D) image compression techniques for volumetric medical images have been proposed so far, for exploiting the redundancies among pixel values of the image in the 3D space. Most of the algorithms use 3D decorrelating transformations or prediction methods to remove slice redundancy in 3D medical images.

Part-2 of Joint Photographic Experts Group (JPEG)-2000 [13] apply 1D reversible 5/3 wavelet transform across image slices, followed by JPEG 2000 on the resulting transformed slices to compress 3D data. Since most of the medical image slices are relatively symmetrical, V. Sanchez et. al. [11] implemented a compression algorithm which exploits the anatomical symmetries present in structural medical images. Same authors modified this algorithm [10] by adding a inter-slice Differential Pulse Code Modulation (DPCM) prediction method to exploit the

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correlation between slices. They used 2D integer wavelet transform to decorrelate the data, an intraband prediction method to reduce the energy of the sub-bands exploiting inherent symmetry characteristics of medical image data and an embedded block coder to achieve high lossless compression gain and resolution scalability. S. Amraee et. al. [2] eliminates both intra-slice and inter-slice correlations with block matching routines considering symmetrical characteristics of these images.

The Context based Adaptive Lossless Image Codec (CALIC) use a large number of modeling contexts with non-linear predictor to make the codec adaptive for the varying texture patterns and local gradients in the image through an error feedback mechanism [16]. Embedded coding of Zero-trees of Wavelet coefficients (EZW) propose an efficient way of arranging the bits of the wavelet coefficients for progressive transmission and is a desirable property of image compression applications [3]. Its performance is improved in 3D Context Based EZW (CB EZW) by using context based adaptive arithmetic coding to encode image volumes by exploiting redundancies between image symbols [3]. Existing classical medical image data compression approaches achieve lossless compression ratio ranging from 2:1 to 4:1.

Even though these methods provide perfect reconstruction of image, they are not efficient in terms of achieved compression ratio. Lossy compression methods are another class of solutions available for the compression of 3D medical images [9], [6] providing lower bit rate than that of lossless coders at the cost of degradation in image quality. Quality of the reconstructed image is very critical as it may affect the diagnosis.

An alternative solution to both the compression schemes is Perceptually Lossless Coder (PLC), which discards visually irrelevant information along with other static redundancies present in 3D image space to improve the compression ratio at the same time maintaining the perceptual quality of reconstructed image. David Wu et al. used this approach to compress Magnetic Resonance Imaging (MRI), Computed Tomography (CT) and computed radiography medical image data sets [15]. They developed a novel algorithm for visual pruning (VP) function which is built on the JPEG 2000 coding framework. The VP function is combined with an advanced model of the Human Visual System (HVS) to identify and to remove visually insignificant/irrelevant information. Also this algorithm offers the benefits of simplicity and modularity.

MRI, CT and ultrasound are commonly used volumetric medical image acquisition systems as they support in detecting diseases or abnormalities in the body even though they generate huge data volume. Basically human structural anatomy has approximate bilateral symmetry. This salient feature is reflected in axial and coronal view of MRI and CT images. Symmetry present in region of interest of MRI/CT image data and human visual perception feature can further improve the performance of algorithm.

In this paper we have proposed symmetry based perceptually lossless compression technique with lossless methods for 3D MRI and CT medical images and compared with lossless schemes. Perceptually lossless coder uses inter-slice block matching to remove inter-slice redundancies, symmetry based intra-slice block matching to explore intra-slice correlations and HVS dependent Just Noticeable Distortion (JND) model to eliminate visually insignificant information. Experimental evaluations show that symmetry based perceptually lossless coder gives better efficiency compared to lossless compression for the same set of volumetric medical images.

This paper is organized as follows: A brief discussion on lossless image compression, perceptually lossless image compression, symmetry based lossless image compression and symmetry based perceptually lossless image compression methods are given in Section 2. Experimental results are evaluated for the mentioned different methods in Section 3 and conclusions are given in Section 4.

2. VOLUMETRIC MEDICAL IMAGE COMPRESSION

In this Section symmetry based PLC is developed from the basic lossless image compression scheme for 3D medical images by incorporating symmetry and perceptual qualities to improve the performance.

2.1. LOSSLESS IMAGE COMPRESSION

This method attempts to remove the inter-slice redundancy present in the MRI and CT images by means of inter-slice block matching algorithm followed by arithmetic coding technique as shown in Fig. 1. Inter-slice block matching algorithm is applied on non-overlapping block of size 8×8 with a search window of size 16×16 in the reference frame. Sum of absolute difference is selected as the criterion for the best match. Adaptive arithmetic coding is applied on residuals of block matching routine.

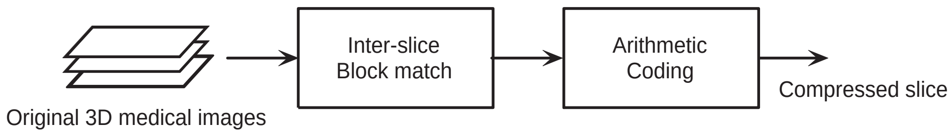

Fig. 1. Block diagram of lossless image compression.

2.2. PERCEPTUALLY LOSSLESS IMAGE COMPRESSION

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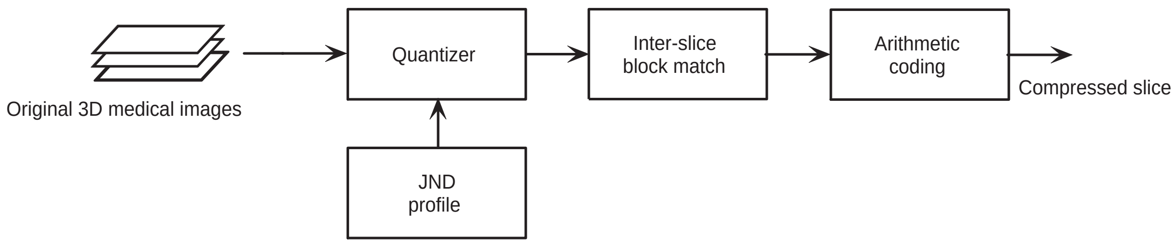

Fig. 2. Block diagram of perceptually lossless image compression.

Eliminating visually irrelevant information from the image data along with numerical redundancies not only improves compression ratio but also maintains the perceivable visual quality of the image. In order to achieve this, a model of HVS is added to encode the image at the feasible minimum bit rate such that it is indistinguishable from original image. So a HVS based spatial domain JND model which explores both edge and non edge regions along with luminance and texture masking is used to assess the perceptual redundancy [17] at each location of the image. Block diagram of perceptually lossless image compression is shown in Fig. 2.

The visibility threshold for grey scale images depends on many factors. Here the JND threshold value is dependent on average background luminance, spatial luminance gradient and texture masking. It is established that human visual perception is sensitive to luminance contrast rather than the absolute luminance value [17]. Also the distortion in very dark regions tend to be less seen than that present in regions of better luminance. So high perceptibility threshold are assigned to either very bright or dark areas and low values in regions of medium grey values. The spatial luminance gradient indicates that the increase in the spatial heterogeneity in the background luminance reduces the visibility of stimuli.

Edge accommodative texture masking in spatial domain, is also added to meet the HVS characteristics better. An increase in the texture heterogeneity in the background will accommodate more reduction in the visibility of distortion. Accordingly textured area can mask more deformity than smooth regions. Also error present in edge regions is more prominent compared to non-edge areas due to the fact that edge texture drags more attention in a classic HVS. This model explores both edge and non-edge regions along with luminance masking and texture masking.

Perceptually redundant information is eliminated from the image through JND dependent quantizer, restricting all the quantization errors below the distortion threshold value to maintain the visual quality of reconstructed image.

2.3. SYMMETRY BASED IMAGE COMPRESSION

Human body has bilateral symmetry and this inherent feature is retained in most of the medical image slices. Symmetry based image compression method takes advantage of this bilateral symmetry in the medical images to improve the compression further. Symmetry detection determines the predominant axis of symmetry [8]. Block diagram of symmetry based lossless image compression and perceptually lossless image compression are shown in Fig. 3 and Fig. 4 respectively. Intra-slice block matching is carried out on residual image after inter-slice block matching by splitting it along the axis of symmetry. Intra-slice block matching algorithm is similar to inter-slice block matching algorithm.

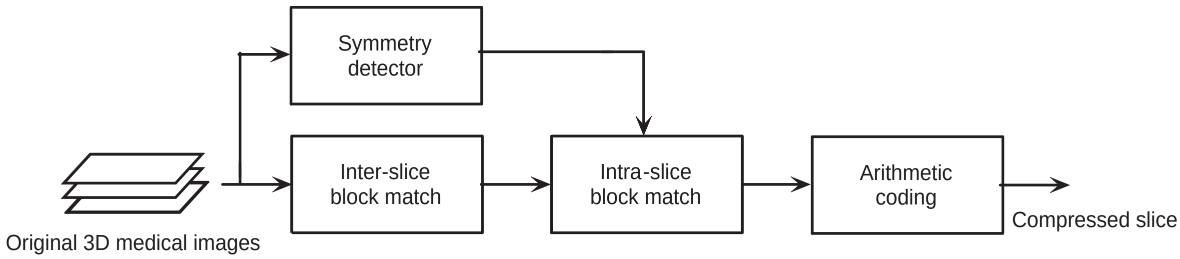

Fig. 3. Block diagram of lossless image compression with symmetry.

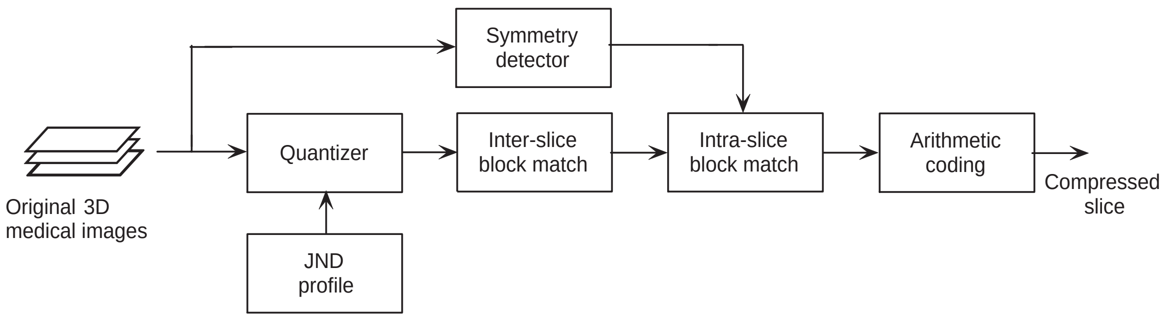

Fig. 4. Block diagram of perceptually lossless image compression with symmetry.

3. PERFORMANCE ANALYSIS

Medical image compression algorithms were evaluated on an 8 bit data set of volumetric symmetric MRI and CT images. Details of these image data sets are summarized in Table 1.

Volume 1 to 5 are from Mallinckrodt Institute of Radiology, Image Processing Lab [3] and Volume 6 is from BrainWeb: simulated brain database [4].

Table 1. Details of the volumetric medical images used in the assessment.

Volume number	Image	Resolution (W×H) (in pixel)	Slices	Dynamic range (bpp)
1	CT Skull	256×256	192	8
2	CT Carotid	256×256	64	8
3	MRI Liver t1	256×256	48	8
4	MRI Liver t2	256×256	48	8
5	MRI Pedchest	256×256	64	8
6	MRI Brain	216×176	35	8

Simulation is carried out for all the discussed compression schemes. We implemented the proposed method in Matlab® 2015a 8.5.0 on an Intel® Core™ i7 Processor. Table 2 lists the average bit rate obtained by all compression methods for the test data sets. Lossless compression method of Fig. 1 removes only the redundancy between slices of volumetric medical data since block matching algorithm is applied between successive image slices. The achieved lower bit rate in case of symmetry based lossless compression compared to lossless technique is due to removal of even redundancy present within the image slice using intra-slice block matching routine for the symmetric image data sets as symmetry detection and intra-slice block matching are added to lossless compression algorithm.

Table 2. Bit per pixel (bpp) of volumetric image compression algorithms.

Volume number	Lossless without symmetry	Lossless with symmetry	PLC without symmetry	PLC with symmetry
1	1.783	1.766	1.728	1.652
2	1.683	1.654	1.601	1.508
3	2.383	2.353	2.310	2.282
4	1.795	1.794	1.792	1.791
5	1.645	1.592	1.386	1.336
6	5.573	5.383	4.599	4.495

Even though symmetry property of medical images is not considered in perceptually lossless method, compression efficiency is better than lossless methods due to improved quantization of pixel values. Degradation in the perceivable visual quality is avoided by using a JND dependent quantizer, instead of uniform quantizer. JND model decides the amount of distortion that can be introduced at each pixel position of each image slice. It is due to the fact that human visual perception is less sensitive to distortion in very dark regions than that present in regions of better luminance and also textured area in an image can mask more deformity than smooth regions. Symmetry based perceptually lossless algorithm gives the best performance among all the four techniques since it considers symmetry based redundancy, redundancy between slices and perceptual redundancy. Results obtained are compared among different cases as follows:

Case-1: Lossless compression without and with symmetry:- Bit rate is improved by 1.76% on an average in case of lossless compression with symmetry compared to lossless compression without symmetry.

Case-2: Perceptually lossless without and with symmetry:- Obtained percentage improvement in bit per pixel is 2.88% on an average in case of perceptually lossless compression with symmetry compared to perceptually lossless compression without symmetry.

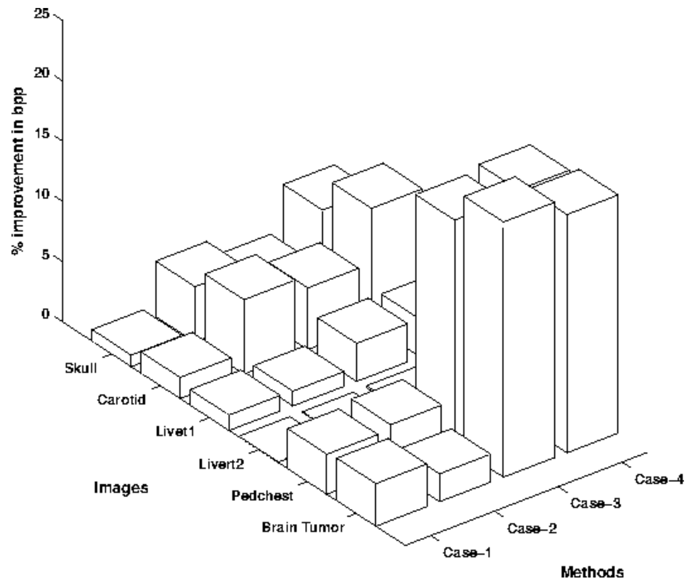

Fig. 5. Percentage improvement in bpp among different compression methods.

Case-3: Lossless and perceptually lossless without symmetry:- An average 7.37% of improvement in bit rate is observed in case of perceptually lossless compression without symmetry compared to lossless compression without symmetry.

Case-4: Lossless and perceptually lossless with symmetry:- Maximum improvement in bit rate is obtained as symmetry based perceptually lossless compression method exploits static, symmetry and perceptual redundancies. The bit rate is improved by 8.47% on an average in case of perceptually lossless compression with symmetry compared to lossless compression with symmetry.

Percentage improvement in bit rate for test image data sets with all the cases is shown in Fig. 5. The efficiency of the PLC has been examined by comparing bit rate with other 3D lossless compression techniques available in the literature- namely CALIC [16], 3D JPEG [1], 3D EZW [3] and 3D CB EZW [3]. Table 3 compares bit rates of the 5 compression techniques.

Table 3. Comparison of bit rates (bpp) of PLC with symmetry with other methods.

Volume Number	CALIC [16]	3D EZW [3]	3D CB EZW [3]	3D JPEG [1]	PLC with symmetry
1	2.725	2.357	2.200	3.112	1.652
2	1.654	1.601	1.527	1.965	1.508
3	3.047	2.545	2.398	3.125	2.282
4	2.243	1.944	1.822	2.622	1.791
5	2.810	2.176	2.022	2.768	1.336

To assess the quality of reconstructed image Peak Signal to Noise Ratio (PSNR) and Relative Error (RE) are generally used, but they do not correlate closely with subjective quality sensed by HVS. HVS based performance metrics Visual Signal to Noise Ratio (VSNR) [5], Visual Information Fidelity (VIF) [12] and Structural Similarity index (SSIM) [14] are also used to measure the quality. It has been proved through Receiver Operating Characteristic analysis that SSIM provides a closer match to subjective assessments [7]. Table 4 gives the evaluation metrics for the reconstruction quality metrics such as PSNR, VSNR, VIF, SSIM and RE. There is no perceivable degradation in the images reconstructed using the proposed coder (Fig. 6).

Table 4. Quality metrics of reconstructed image in case of PLC with symmetry.

Volume number	PSNR (dB)	VSNR (dB)	VIF	SSIM	RE
1	51.42	47.94	0.9565	1	0.619
2	53.46	50.89	0.9710	0.999	0.511
3	42.67	46.69	0.8937	0.994	3.244
4	51.20	47.04	0.9597	1	0.703
5	43.32	54.28	0.8337	0.991	11.716
6	45.75	∞	0.9468	0.998	1.429

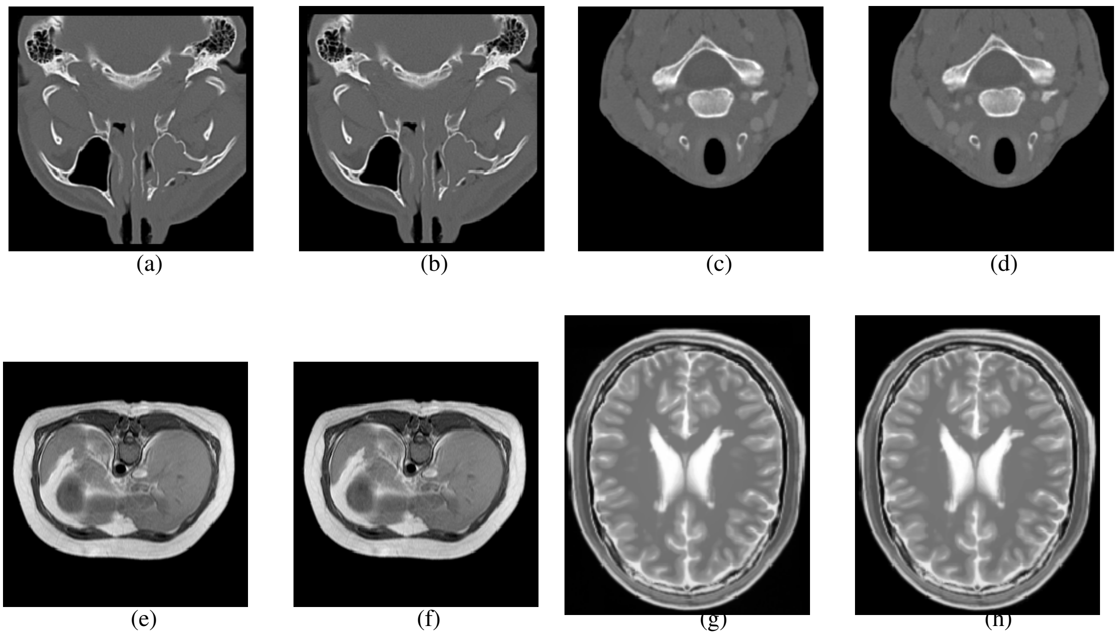

Fig. 6. Visual clip of original and reconstructed images. (a) CT Skull original: Slice number 50 (b) CT Skull reconstructed (PSNR=51.4 dB) (c) CT Carotid original: Slice number 30 (d) CT Carotid reconstructed (PSNR=53.5 dB) (e) MR Liver t2 original: Slice number 30 (f) MR Liver t2 reconstructed (PSNR=51.3 dB) (g) MR Brain original: Slice number 20 (h) MR Brain reconstructed (PSNR=45.7 dB).

4. CONCLUSION

Lossless compression techniques provide perfect reconstruction, but however fail to achieve good compression. In contrast, lossy compression techniques achieve good compression, but are unacceptable for medical images due to poor quality. Hence, this paper proposed a perceptually lossless coder for medical images, that promises good compression like lossy coder without losing any medically significant data. This work exploits symmetry property in the symmetric images thus neglecting spatially redundant information. Perceptually lossless coder considers a JND model based on HVS that eliminates visually insignificant information.

The proposed method has been tested on standard datasets and its performance has been compared with lossless, symmetry based lossless and perceptually lossless schemes. This explains the contribution of each technique to the proposed compression method. Observing the results, it can be concluded that combining them all together gives the best compression. Developed compression methods use pixel based visual model. It does not decorrelate image into different frequency levels to remove more redundancies like wavelet based approach. Embedding wavelet based visual model in the compression algorithm may offer significant improvement in compression performance.

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BIBLIOGRAPHY

[1] AIT-AOUDIA S., BENHAMIDA F. Z., YOUSFI M. A. Lossless compression of volumetric medical data. Computer and Information Sciences, 2006. Springer, pp. 563–571.

[2] AMRAEE S., KARIMI N., SAMAVI S., SHIRANI S. Compression of 3D MRI images based on symmetry in prediction-error field. IEEE International Conference on Multimedia and Expo, 2011. pp. 1–6.

[3] BILGIN A., ZWEIG G., MARCELLIN M. W. Efficient lossless coding of medical image volumes using reversible integer wavelet transforms. Proceedings of Data Compression Conference, 1998. pp. 428–437.

[4] BRAINWEB. Simulated brain database. 2014.

[5] CHANDLER D. M., HEMAMI S. S. VSNR: A wavelet-based visual signal-to-noise ratio for natural images. IEEE Transactions on Image Processing, 2007, Vol. 16. IEEE, pp. 2284–2298.

[6] GAUDEAU Y., MOUREAUX J.-M. Lossy compression of volumetric medical images with 3D dead-zone lattice vector quantization. Annals of telecommunications, 2009, Vol. 64. Springer, pp. 359–367.

[7] KOWALIK-URBANIAK I., BRUNET D., WANG J., KOFF D., SMOLARSKI-KOFF N., VRSCAY E. R., WALLACE B., WANG Z. The quest for diagnostically lossless medical image compression: a comparative study of objective quality metrics for compressed medical images. SPIE Medical Imaging, 2014, Vol. 9037. pp. 1–17.

[8] LOY G., EKLUNDH J. O. Detecting symmetry and symmetric constellations of features. Computer Vision, 2006. Springer, pp. 508–521.

[9] RAMASWAMY A., MIKHAEL W. A mixed transform approach for efficient compression of medical images. IEEE Transactions on Medical Imaging, 1996, Vol. 15. IEEE, pp. 343–352.

[10] SANCHEZ V., ABUGHARBIEH R., NASIOPOULOS P. 3D scalable lossless compression of medical images based on global and local symmetries. 16th IEEE International Conference on Image Processing, 2009. pp. 2525–2528.

[11] SANCHEZ V., ABUGHARBIEH R., NASIOPOULOS P. Symmetry-based scalable lossless compression of 3D medical image data. IEEE Transactions on Medical Imaging, 2009, Vol. 28. IEEE, pp. 1062–1072.

[12] SHEIKH H. R., BOVIK A. C. Image information and visual quality. IEEE Transactions on Image Processing, 2006, Vol. 15. IEEE, pp. 430–444.

[13] TZANNES A. Compression of 3-dimensional medical image data using part 2 of JPEG 2000. Aware. Inc, Nov, 2003.

[14] WANG Z., BOVIK A. C., SHEIKH H. R., SIMONCELLI E. P. Image quality assessment: from error visibility to structural similarity. IEEE Transactions on Image Processing, 2004, Vol. 13. IEEE, pp. 600–612.

[15] WU D., TAN D. M., BAIRD M., DECAMPO J., WHITE C., WU H. R. Perceptually lossless medical image coding. IEEE Transactions on Medical Imaging, 2006, Vol. 25. IEEE, pp. 335–344.

[16] WU X., MEMON N. CALIC-a context based adaptive lossless image codec. IEEE International Conference on Acoustics, Speech, and Signal Processing, 1996, Vol. 4. pp. 1890–1893.

[17] YANG X., LING W., LU Z., ONG E. P., YAO S. Just noticeable distortion model and its applications in video coding. Signal Processing: Image Communication, 2005, Vol. 20. Elsevier, pp. 662–680.