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Versatile Approaches for Medical Image Compression: A Review

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Abstract

In this world of evolution, the utilization of the medical technology and huge data generation by the different medical modalities, the storage, transmission and handling of the digital data requires data compression. In past few years, several compression mechanisms, techniques, and algorithms are proposed by many researchers. This paper focuses over the current status of these compression strategies with new hybrid approaches, performance parameters, legal issues and their applications in enhancing the medical technology.

Keywords: Medical image compression;lossy compression;lossless compression;hybrid compression

1. Introduction

In earlier days, the most of the medical imaging test are carried out over the radiological films, but now all of the tests are carried out digitally which increases quantity of digital medical data in last few decades [1]. Nowadays, the electronic health record (EHR) systems are adopted by nearly 84 % of the hospitals according to the report of the office of the National Coordinator for Health Information Technology (ONC). EHR systems are able to store possible digital information such as demographic information, diagnoses, laboratory tests, radiological images and clinical notes, results and prescriptions of the patient related to its treatment [2]. In medical field, the generation of the digital data such as Magnetic Resonance Imaging (MRI), Computed Tomography (CT), Ultrasound (US), Electrocardiography (ECG), Electroencephalograph (EEG), X-rays and Mammograms etc are increasing rapidly, so there is a need for the effective storage and transmission of this digital data. The compression methods are able to process a large set of images or volumetric data for the fast interactivity, searching context dependant images and for quantitative analysis of the data [3]. The performance of the compression approaches should be good so that they are able to tackle the limitation of the bandwidth usage and storage. The researchers provide several compression techniques for the medical compression and these techniques are broadly classified into three main categories: lossy, lossless and hybrid compression techniques. The lossy compression is the mechanism which compress the image with loss of data whereas in lossless there is no loss of the data hence this mechanism used when the information is critical and no loss is acceptable i.e. it is widely used for the medical image compression [4]. Hybrid compression techniques consist of two or more compression techniques to achieve the effective compression of the image. In lossless compression the image we get after the compression is identical to the original image but in lossy compression there is degradation of quality of image after compression [3]. The major purpose for the designing of

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such compression techniques is to compress the images with best possible visual quality, reduced size and no or little loss of the information. The fig 1 represents the various application areas of the compression techniques. In this paper we are dealing only with the compression techniques based on medical images or medical data. In this work, we majorly focus on the three types of compression techniques: Lossy, Lossless and Hybrid techniques in the medical image compression. The rest of the paper is organised as follows: In section 2, we discuss the various compression techniques used to compress the medical images. In Section 3, describes the various performance metrics used to compute the performance of these compression techniques. In Section 4, introduces the various open issues or the research challenges in the field of the medical image compression. Finally, section 5 provides the overall conclusion and the summary of the whole work.

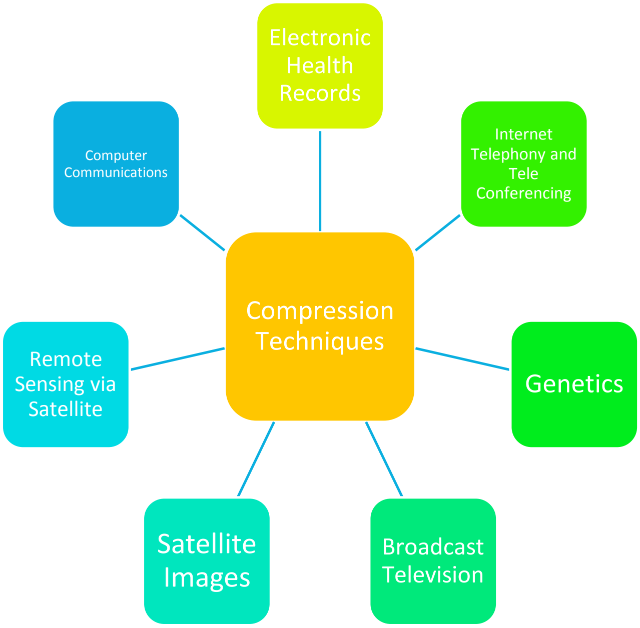

Fig. 1.various application areas of the compression techniques

2. Literature Survey

This section describes the recent literature survey on medical image compression techniques. The whole literature can be categorised into the following three subsections namely lossy, lossless and hybrid describing each of section in efficient manner.

2.1 Lossy Compression Techniques

Bruylants et. al. [5] presented a novel Wavelet based framework that supports JPEG 2000 with its volumetric extension. The presented approach enhances the performance of the JPEG2000 for volumetric medical image compression. In this work, generic codec framework, directional wavelet transforms and generic intra band prediction mode tested for the wide range of compression settings for the volumetric compression. In this paper, three medical modalities (CT, MRI and US) are considered to compute the efficiency of the proposed approach. Ayoobkhan et. al. [6] presented a novel compression method PE-VQ for the lossy compression of medical images. In this approach, to construct codebook the artificial bee colony and genetic algorithms are used to compute the optimal results and prediction error and vector quantization concepts are involved for the effective compression of the images. It is observed that the proposed technique is able to achieve higher PSNR for a given compression ratio in comparison to the other algorithms. Rufai et. al. [7] described a novel lossy compression technique for the medical image compression. The reported approach comprises of singular value decomposition (SVD) and Huffman coding. It is seen from the simulation results that; the reported approach is able to provide better quantitative and visual results in comparison to the other conventional techniques like Huffman coding and JPEG2000. Selvi and

Nadarajan [8] proposed a 2-D lossy compression technique for the compression of the MRI and CT images. The proposed approach relies over the wavelet-based contourlet transform (WBCT) and Binary array technique (BAT). It is concluded that the proposed approach requires less processing time and generate precise output results in comparison to the existing wavelet-based set partitioning in hierarchical and embedded block coders. Sriraam and Shyamsunder [9] introduced a 3D wavelet encoder approach to compress the 3D medical images. Here, the reported approach work is two stages, firstly the encoding can be done with four wavelet transforms named as, Daubechies 4, Daubechies 6, Cohen-Daubechies-Feauveau 9/7 and Cohen-Daubechies-Feauveau 5/3 and at later stage 3-D SPHIT, 3-D SPECK and 3-DBISK. Hosseini and Naghsh-Nilchi [10] described contextual vector quantization for the medical image compression. Here, the medical modality ultrasound is used to simulate the experiment and conclude the results. It is showed that the proposed approach is able to achieve higher compression ratio and PSNR in comparison to the other conventional algorithms (JPEG, JPEG2K, and SPHIT). Bairagi et. al. [11] reported a text-based approach to compress the medical images effectively. The reported mechanism deals with the visual quality rather than the pixel wise fidelity. Prabhu et. al. [12] presented 3-D warped discrete cosine transformation (WDCT) for the compression of the MRI images effectively. The presented approach relies over the concept of 2-D WDCT and in this paper, image coding scheme is used for the large datasets which relies over the concept of 3-D WDCT approach.

2.2 Lossless Compression Techniques

Juliet et. al. [13] discussed a novel methodology, which includes Ripplet transform to provide a good quality of the images and achieves high compression rate. In this work, to attain the higher compression rate the images are represented at different scales and directions. Cyriac and Chellamuthu [14] proposed a Visually Lossless Run Length Encoder/Decoder to solve the expansion problem of the traditional Run Length Encoder/Decoder. In this paper, the proposed technique is able to adequately compress the image and also helps in the faster hardware implementation of the real time applications. Brahimi et. al. [15] describes a novel compression technique in which the signal and the image both get jointly compressed with single codec. The main focus of this approach is to embed the wavelet-decomposed signal into the decomposed image and the resultant image is used for the compression. Arif et. al. [16] proposed an efficient method for the compression of the fluoroscopic images without any loss. In this work, the extracted ROI is compressed with a combination of Run Length and Huffman coding. In this paper, concluded results states that the proposed methodology provides compression ratio 400% in comparison to other conventional techniques. Das and Kundu et. al. [17] reported lossless medical image watermarking (MIW) technique which relies over the concept of the Region of Interest (ROI). The main aim of this work is to provide solutions to the multiple problems regarding the medical data distribution like as security, content authentication, safe archiving and safe retrieval and transfer of data. In this paper seven different modalities are used to depict and compared the results to show that the proposed technique is simple and evident in providing security to the medical database. Lucas et. al. [18] presented a novel lossless compression technique 3-D MRP for volumetric sets of medical images. The presented technique relies over the mechanism of minimum rate predictors (MRPs). In this paper, it is concluded that the presented technique is able to improve the error probability of the MRP algorithm and it attains high compression efficiency over the HEVC and other standard for depth medical signals. Špelič and Žalik [19] proposed a novel an algorithm coined as segmented voxel compression algorithm to compress 3D CT images and for effective transmission of graphical data obtained from CT scanner. This paper describes that firstly Hounsfield scale is used to segment the medical data and then compression is applied. In this work, a prototype mechanism is used to evaluate the efficiency of the proposed algorithm. Anusuya et. al. [20] introduced a novel lossless codec using entropy coder to compress the 3D brain images. In this work MRI modality was used to analyse the efficiency of the proposed algorithm and this work focus on reducing the computation time with the use of parallel computing. Xio et. al. [21] introduced Integer Discrete Tchebichef Transform to compress a variety of images without any loss of data. In this work, the proposed technique is presented on the basis of factorization of $N \times N$ Discrete Tchebichef Transform into N+1 single row elementary reversible matrices with minimum rounding errors. The proposed technique achieved integer to integer mapping for effective lossless compression. In this paper, the medical modalities referred are CT and MRI to evaluate the results and it is concluded that the proposed algorithm is able to achieve higher compression ratio than iDCT. Amri et. al. [22] presented two lossless compression methods coined as wREPro.TIFF (watermarked Reduction/Expansion Protocol coupled with TIFF format) and wREPro.JLS (wREPro coupled with JPEG-LS format). In this work, the presented techniques are used to decrease the image size and encoding algorithms for lossless compression. It is seen that the proposed approach able to preserve the image quality for high compression rates and it also provides various enhancement over conventional JPEG image compression standard. Ramesh and Shanmugam [23] described Wavelet Decomposition Prediction Method for lossless compression of medical images. In this approach, prediction equation of each sub band relies over the correlation analysis. It is observed from the experimental results that the proposed approach provides higher compression rate as compared to SPHIT and JPEG2000 standard. Ibraheem et. al. [24] presented two new lossless compression techniques which rely over the logarithmic computation. The proposed approaches are able to provide enhanced image quality in comparison to the conventional DWT. Avramovic and Banjac [25] introduced a novel lossless compression technique in which simple context-based entropy coder is used. The proposed approach relies over the concept of prediction to remove the spatial redundancy in images and effectively compress the images without any loss of data. It is concluded that the proposed approach is able to achieve same performance for high quality images as the other standardized algorithms. Bairagi [26] reported the concept of symmetry for the compression of the medical images. Here, the presented approach is lossless and able to remove the redundant data from the image effectively and efficiently. In this work, the reported concept is collaborated with the existing techniques to conclude the results. Zuo et. al. [27] presented an improved medical image compression approach IMIC-ROI to effectively and efficiently compress the medical images. The proposed technique relies over the concept of Region of Interest (ROI) and non-ROI regions. It is seen that the presented approach able to achieve higher compression ratio and good values of GSM and SSIM in comparison to other conventional techniques. Srinivasan et. al. [28] described a coder for the effective compression of the electroencephalograph (EEG) signal matrix. The mechanism described consists of two stages, firstly lossy coding layer (SPHIT) and residual coding layer (arithmetic coding). It is concluded that the 2-stage compression scheme is effective and the concept of pre-processing able to provide 6% improvement and 2 stage yields 3% further improvement in the compression. Taquet and Labit [29] reported a Hierarchical Oriented Prediction (HOP) approach for the resolution of the scalable lossless and near lossless compression of the medical images. It is seen that the proposed approach is best used for the near lossless compression since it is able to provide slightly better or equal PSNR for a high bit rate in comparison to JPEG 2000 standard.

2.3 Hybrid Compression Techniques

Mofreh et. al. [30] reported LPC-DWT-Huffman, a novel image compression technique to enhance the compression rate. This reported technique is the mixture of the LPC-Huffman and the DWT- Huffman. It is seen that the reported technique is able to provide higher compression rate as compared to the Huffman and DWT- Huffman. Raza et. al. [31] presented a hybrid lossless compression technique for medical image sequences. It is observed that the reported technique is able to achieve enhanced compression rate as compared to other existing techniques. Eben Sopphia and Anitha [32] propose an improved context-based compression technique for the medical images. The proposed approach relies over the concepts of wavelet transformation, normalization and prediction. In this paper, the proposed approach able to achieve good quality image in comparison to the original image for the selected contextual area. It is observed that the proposed technique able to achieve better performance quantitatively and qualitatively. Parikh et. al. [33] described the use of high efficiency video coding (HEVC) for medical image compression. In this work, three medical modalities (MRI, CT and CR) are used to compute the experimental results and compared these results with JPEG2000. It is observed that the presented method shows increase in compression performance by 54% in comparison to the JPEG2000. Somassoundaram and Subramaniam [34] reported a hybrid approach in which 2D Bi-orthogonal multi wavelet transform and SPECK- Deflate encoder is used. The main purpose of this approach is to diminish the transmitting bandwidth by compressing the medical data. It is seen that the proposed approach is able to achieve higher compression ratio then other conventional algorithms. Haddad et. al. [35] proposed a novel joint watermarking scheme for the medical images. The proposed technique is the combination of JPEG-LS and bit substitution watermarking modulation. It is observed that the proposed technique able to provide the same watermarked images with high security services in comparison to the other techniques. Perumal and Rajasekaran [36] presented a Hybrid algorithm DWT-BP for the medical image compression. In this paper, author compares the DWT coding, Back Propagation Neural Network and hybrid DWT-BP to analyse the performance of the presented approach. It is concluded that the proposed hybrid technique is able to provide better compression ratio and achieves better PSNR. Karthikeyan and Thirumoorthi [37] describe Sparse Fast Fourier Transform, a hybrid technique for the medical image compression. In this work, author also compares the proposed technique with the other three compression methods like Karhunen-Loeve Transforms, Walsh-Hadamard Transform (WHT) and Fast Fourier Transform. It is observed that the proposed technique able to provide enhanced and efficient results in all of the evaluation measures in comparison to the author described methods. Thomas et. al. [38] reported a hybrid image compression approach for the medical images using lossy and lossless mechanism for the telemedicine application. It is observed that the proposed hybrid approach able to achieve higher compression ratio and having less loss of information with the effective use of arithmetic entropy coding. Vaishnav et. al. [39] proposed a novel hybrid technique for the lossy and lossless compression of the medical images. The proposed approach is the combination of the dual tree wavelet transform and arithmetic coding approach. It is seen that the proposed approach is much effective and efficient than the other conventional algorithms like DWT and SPHIT and able to achieve higher PSNR and compression ratio. Rani and Chitra [40] reported a novel hybrid technique for the medical image compression. The reported approach relies over Haar Wavelet Transform (HWT) and Particle Swarm Optimization (PSO). It is observed that the proposed approach is able to achieve higher compression ratio and PSNR. Jiang et. al. [41] presented a hybrid algorithm for the medical image compression. The major goal of the proposed approach is to compress the diagnostic related information with high compression ratio. It is observed that the proposed approach is able to achieve good PSNR and effective running time in comparison to the other described algorithms. Sanchez et. al. [42] described a new mechanism for the compression of the 3-D medical images with the Volume of Interest (VOI) coding. It is observed that, proposed approach able to achieve better reconstruction quality in comparison to the 3-D-JPEG2000 and MAXSHIFT with VOI coding. Hsu [43] proposed a mechanism to separate the tumour form the mammogram with the help of improved watershed transform with prior information. The goal of the proposed mechanism is to efficiently compress the mammogram without compromising the quality of the required region. It is showed from the experimental results that the proposed mechanism reconstructs effectively and efficiently in the application of mammogram compression. Summary of above recent state-of-the-art watermarking methods are demonstrated in Table 2.

3. Performance Parameters

In this work, the compression techniques use a wide number of performance measures to compute their efficiency and performance. Table 1 demonstrates the performance matrices used to check the performance of compression techniques. The metrics used to compute the performance are:

- **Peak Signal to Noise Ratio (PSNR):** PSNR is defined as the ratio of the maximum pixel intensity to the mean square error [4]. The formula used to compute the PSNR is represented as Follows

$$\text{PSNR}= 20log(\frac{2^B-1}{MSE})dB \tag{1}$$

Here, B is the number of bits and MSE is the mean square error

- **Compression Ratio (CR):** Compression ratio (CR) is the ratio of the size of the original image to the size of the compressed image. It can be computed as

$$\text{CR}= \frac{Size\ of\ the\ original\ image}{Size\ of\ the\ compressed\ image} \tag{2}$$

- **Mean Square Error (MSE):** MSE is the description of the cumulative squared error between the compressed image and the original image [37]. It can be computed with the use of following formula

$$\text{MSE}=\frac{1}{MN}\sum_{j=1}^{M}\sum_{K=1}^{N}\left(X_{j,k}-X'_{j,k}\right)^2 \tag{3}$$

Here, M and N are digital image dimensions.

- **Structure Similarity Index (SSIM):** SSIM is used to measure the tendency of similarity between the original image and the compressed image[32]. The formula used to find SSIM is:

$$\text{SSIM}=\frac{(2\mu_f\mu_{-f}+C_1)(2\delta_{f-f}+C_2)}{\left(\mu_f^2+\mu_{-f}^2+C_1\right)\left(\delta_f^2+\delta_{-f}^2+C_2\right)} \tag{4}$$

Here, f is the original image, -f is the reconstructed image C_1 and C_2 are the constants, μ is the average gray value and δ is the variance.

- **Bits Per Pixel (BPP):** BPP is defined as the ratio of the total size of the compressed image to the total number of the pixel in the image [36].

$$\text{BPP}=\frac{Size\ of\ the\ compressed\ image}{Total\ no.\ of\ Pixel\ in\ the\ image} \tag{5}$$

- **Signal to Noise Ratio (SNR):** SNR can be defined as the ratio of the signal power to the noise power. It is measured in dB and can be computed as

$$\text{SNR}=10log\left\{\frac{\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}[f(i,j)^2]}{\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}[|f(i,j)-f^*(i,j)|^2]}\right\} \quad (6)$$

- **Percent rate of distortion (PRD):** It is the measure of the distortion in the reconstructed image. Lesser the value of the PRD the reconstructed image is less distorted [8]. It can be computed with the use of following formula

$$\text{PRD}=\sqrt{\frac{\sum_{x=1}^{M}\sum_{y=1}^{N}[f(x,y)-f'(x,y)]^2}{\sum_{x=1}^{M}\sum_{y=1}^{N}[f(x,y)]^2}}\times 100 \quad (7)$$

Here, $M\times N$ represents size of the image, $f(x,y)$ is the original image and $f'(x,y)$ is the reconstructed image.

- **Correlation Coefficient (CC):** It is used to describe the existing correlation between the original image and the reconstructed image [8]. It can be calculated by,

$$\text{CC}=\frac{\sum_{x=1}^{M}\sum_{y=1}^{N}f(x,y)\times f'(x,y)}{\sqrt{\sum_{x=1}^{M}\sum_{y=1}^{N}(f(x,y))^2}\sqrt{\sum_{x=1}^{M}\sum_{y=1}^{N}(f'(x,y))^2}} \quad (8)$$

Here, $M\times N$ represents size of the image, $f(x,y)$ is the original image and $f'(x,y)$ is the reconstructed image

- **Structural Content (SC):** It is used to depict the comparison between two images inherited in small patches and to determining the common things images have [37]. Higher the value of SC poorer the quality of the image.

$$\text{SC}=\frac{\sum_{j=1}^{M}\sum_{k=1}^{N}X_{j,k}^2}{\sum_{j=1}^{M}\sum_{k=1}^{N}X'^2_{j,k}} \quad (9)$$

Here, M and N are the dimensions of the image

Table1.Various performance matrices used to compute the performance of the compression techniques.

References	Performance Metrices	Formula Representation
Ref [30], Ref [13], Ref [14], Ref [15], Ref [20], Ref [32], Ref [34], Ref [35], Ref [36], Ref [37], Ref [39], Ref [4], Ref [9], Ref [41], Ref [10], Ref [42]	Mean Square Error	$\text{MSE}=\frac{1}{MN}\sum_{j=1}^{M}\sum_{K=1}^{N}(X_{j,k}-X'_{j,k})^2$
Ref [37],	Structural Content	$\text{SC}=\frac{\sum_{j=1}^{M}\sum_{k=1}^{N}X_{j,k}^2}{\sum_{j=1}^{M}\sum_{k=1}^{N}X'^2_{j,k}}$
Ref [8], Ref [41], Ref [10]	Correlation coefficient	$\text{CC}=\frac{\sum_{x=1}^{M}\sum_{y=1}^{N}f(x,y)\times f'(x,y)}{\sqrt{\sum_{x=1}^{M}\sum_{y=1}^{N}(f(x,y))^2}\sqrt{\sum_{x=1}^{M}\sum_{y=1}^{N}(f'(x,y))^2}}$
Ref [30], Ref [4]	Signal to Noise Ratio	$\text{SNR}=10log\left\{\frac{\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}[f(i,j)^2]}{\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}[\|f(i,j)-f^*(i,j)\|^2]}\right\}$
Ref [30], Ref [16], Ref [18], Ref [20], Ref [31], Ref [32], Ref [36], Ref [37], Ref [38], Ref [39], Ref [40], Ref [4], Ref [26], Ref [10], Ref [27], Ref [28]	Compression Ratio	$\text{CR}=\frac{Size\ of\ the\ original\ image}{Size\ of\ the\ compressed\ image}$
Ref [13], Ref [17], Ref [22], Ref [24], Ref [32], Ref [33], Ref [34], Ref [39], Ref [40], Ref [27]	Structure Similarity Index	$\text{SSIM}=\frac{(2\mu_f\mu_{-f}+C_1)(2\delta_{f-f}+C_2)}{(\mu_f^2+\mu_{-f}^2+C_1)(\delta_f^2+\delta_{-f}^2+C_2)}$
Ref [35], Ref [36], Ref [29]	Bits Per Pixel	$\text{BPP}=\frac{Size\ of\ the\ compressed\ image}{Total\ no.\ of\ Pixel\ in\ the\ image}$
Ref [30], Ref [13], Ref [14], Ref [15], Ref [17], Ref [20], Ref [22], Ref [24], Ref [5], Ref [32], Ref [33], Ref [35], Ref [36], Ref [37], Ref [38],	Peak Signal to Noise Ratio	$\text{PSNR}=20log(\frac{2^B-1}{MSE})dB$

Ref [39], Ref [40], Ref [4], Ref [6], Ref [7], Ref [8], Ref [9], Ref [41], Ref [10], Ref [42], Ref [29], Ref [43], Ref [12]		
Ref [15], Ref [8],	Percent rate of distortion	$PRD=\sqrt{\frac{\sum_{x=1}^{M}\sum_{y=1}^{N}[f(x,y)-f'(x,y)]^2}{\sum_{x=1}^{M}\sum_{y=1}^{N}[f(x,y)]^2}}\times 100$

Table 2. Review of various watermarking methods.

Ref.	Technique Used	Compression Type	Method Used	Medical Modality Used	Merits
Ref [30]	Hybrid	Lossless	LPC-DWT- Huffman	Not Mention	Provides Higher Compression Rate
Ref [13]	Lossless	Lossless	Ripplet Transform	MRI and CT	Attains High PSNR and Compression Rate
Ref [14]	Lossless	Lossless	Visually Lossless Run Length Encoder/Decoder	CT and MRI	Provides faster hardware implementation for real time applications.
Ref [15]	Lossless	Lossless	Wavelet-based multimodal compression	X-ray and MRI	Attains High PSNR and Low computational Complexity
Ref [16]	Lossless	Lossless	AutoShaped Lossless Compression	Fluoroscopic Images	Provides Higher Compression Rate
Ref [17]	Lossless	Lossless	Fragile Image Watermarking technique	CT, MRI, USG, X-Ray, Barium study and Mammogram	Secure the Medical metadata and archives Lossless compression
Ref [18]	Lossless	Lossless	3D -Minimum Rate Predictor	CT and MRI	Attains High compression efficiency and improves error probability
Ref [19]	Lossless	Lossless	Segmented Voxel Compression Algorithm	CT	Ease of transferdata and Ease of decompress desired data
Ref [20]	Lossless	Lossless	Lossless codec with Entropy coder	MRI	Reduces the computation time and attains high compression ratio
Ref [21]	Lossless	Lossless	Integer Discrete Tchebichef Transform	CT, MRI and Anatomic Images	Attains High Compression ratio
Ref [31]	Hybrid	Lossless	Super Spatial structure prediction with Inter-Frame coding	CT and MRI	Attains High Compression Ratio
Ref [22]	Lossless	Lossless	wREPro.TIFF and wREPro.JLS	MRI and Computed Radiography	Preserve image quality for high compression rates
Ref [23]	Lossless	Lossless	Wavelet Decomposition Prediction Method	CT and MRI	Avoids Multicollinearity problem and Provides higher compression rate
Ref [24]	Lossless	Lossless	LNS-DWT and Logarithmic DWT	MRI and X-Ray	Provides High PSNR and SIMM
Ref [25]	Lossless	Lossless	Predictive Lossless compression	MRI and CT	Simple approach and able to achieve same performance as other standardized algorithms
Ref [5]	lossy	lossy	Generic codec Framework (JP3D)	CT, MRI and US	JP3D Does not suffer from ambiguity problems
Ref [32]	Lossy and lossless	Lossy and lossless	Normalized wavelet transformation	MRI, US and MRE	Attains Good PSNR in low bits and high Bits
Ref [33]	Lossy and lossless	Lossy and lossless	High efficiencyVideo coding	MRI, CT and CR	Increase compression performance, reduced cost and reduction in complexity
Ref [34]	Hybrid	Lossless	2D Bi-orthogonal multi wavelet transform and Hybrid speck-deflate algorithm	Angiogram sequence	Achieves higher compression ratio
Ref [35]	Hybrid	Lossless	JPEG-Ls and Bit substitution watermarking modulation	US	Provides better security services
Ref [36]	Hybrid	Lossy and lossless	Hybrid DWT-BP	MRI, CT and PET	Provides better compression ratio and archives higher PSNR
Ref [37]	Hybrid	Lossy and lossless	Sparse Fast Fourier Transform	CT	Achieves higher compression ratio, Structural content and PSNR
Ref [38]	Hybrid	Lossy and lossless	Fast-Discrete Curvelet with adaptive arithmetic coding	MRI	Achieves higher compression ratio and less loss of information
Ref [39]	Hybrid	Lossy and lossless	Dual tree Wavelet transform and arithmetic coding	MRI	Achieves better PSNR and compression rate

Ref [40]	Hybrid	Lossy and lossless	Haar Wavelet Transform and Particle Swarm Optimization	MRI, Mammogram and X-ray	Attains higher PSNR and Better compression rate
Ref [4]	Hybrid	Lossless	DPCM-DWT-Huffman	CT	Achieves Higher compression rate
Ref [6]	Lossy	Lossy	PE-VQ compression method	X-ray	Achieves higher PSNR for a given CR
Ref [7]	Lossy	Lossy	Singular value Decomposition and Huffman Coding	MRI	Achieves Better Visual and quantitative results
Ref [8]	Lossy	Lossy	WBCT and BAT compression method	MRI and CT	Less processing time and precise results
Ref [26]	lossless	Lossless	Symmetry based compression	CT and MRI	No -redundant data and better quality of image
Ref [9]	Lossy	Lossy	3D wavelet encoder	MRI and X-Ray	Provide Higher PSNR
Ref [32[	Hybrid	Lossy and lossless	Vector Quantization and wavelet transform	MRI	Achieves Higher PSNR and effective Running time
Ref [10]	Lossy	lossy	Contextual Vector Quantization	US	improved visual quality and ease for transfer of data
Ref [11]	Lossy	Lossy	Text- based mechanism	Brain images	Enhanced visual quality
Ref [42]	Hybrid	Lossy and lossless	Optimized Volume of Interest (3-D Integer Wavelet transform and EBCOT)	MRI and CT	Effective reconstruction quality
Ref [27]	Lossless	Lossless	Improved Medical Image Compression (IMIC-ROI)	Brain images	Achieves Better compression ratio
Ref [28]	Lossless	Lossless	2 stage Coder Mechanism	EEG	Improves compression performance
Ref [29]	Lossless	Lossless	Hierarchical oriented Prediction	CT and MRI	Better PSNR on Noisy images
Ref [43]	Hybrid	Lossy and lossless	Improved watershed transforms and vector quantization with competitive Hopfield neural network	Mammogram	better reconstruction and quality of mammogram
Ref [12]	Lossy	Lossy	3-D Warped Discrete Cosine Transform (WDCT)	MRI	Attains High PSNR for higher bit rate

4. Open Issues/ Research Challenges:

In this manuscript, a large and great variety of compression techniques are explored for the medical image compression. These techniques are able to provide the significant results but some of the open issues in the field of medical image processing are:

- In this work, some of the compression techniques are able to achieve the higher compression rate but much complex in nature and have efficiency and optimization issues.
- Here, some of the techniques are much efficient and effective but consumes large amount of time which is a matter of concern.
- In Medical compression, watermarking techniques are able to compress the images but not able to preserve the quality of it.
- This work, depicts that most compression techniques uses MRI and CT as their modalities but some of these techniques are only able to work on CT and MRI not on other medical modalities.
- In lossy compression, the background noise removal techniques should be improved for the effective and efficient compression.
- In Region of Interest compression, the AutoShaping is done manually by the physician i.e. chances of error should be there.

5. Conclusion

This paper illustrates some of the compression techniques which are used to compress the medical images and these techniques are able to solve the storage and bandwidth limitation problems. After reviewing the literature, it is concluded that performance of the compression technique totally relies over the compression ratio. Higher the compression ratio means better the technique is. Here, it is kept in mind that there should be no loss of the critical information. In this paper, forty manuscripts are studied and arranged into three categories i.e. lossy, lossless and hybrid compression techniques. Further, this paper also describes the compression techniques for handling a large number of problems related to the compression such expansion problem in RLE and transmission problems etc. Here, the performance parameters are also presented which are used to compute the performance of the proposed compression techniques.

Some more aspects to highlight in this manuscript are:

- In the medical image compression, more and more compression techniques are proposed so that the compression of the images should be more effective.
- PSNR, CR and MSE are the parameters which are mostly considered by many researchers to compute the performance of their respective techniques.
- Here, some hybrid compression techniques are able to compress the image in both lossy and lossless manner.
- The literature also highlights that nowadays mostly hybrid techniques are more popular in the field of medical image compression because they inherit the property of lossy and lossless techniques.
- Here, some of the compression techniques are complex in nature and having large computation time, so there is good scope for future work in reducing the computation time of compression techniques.
- In this review, some compression techniques are able to perform on limited modalities hence there is scope of work is in this direction.

References

[1]Liu, Feng, Miguel Hernandez-Cabronero, Victor Sanchez, Michael Marcellin, and Ali Bilgin.(2017) "The current role of image compression standards in medical imaging." *Information* **8(4):** 131.

[2]Shickel, Benjamin, Patrick James Tighe, AzraBihorac, and ParisaRashidi. (2017) "Deep EHR: a survey of recent advances in deep learning techniques for electronic health record (EHR) analysis." *IEEE journal of biomedical and health informatics***22(5):** 1589-1604.

[3]Bhavani, S., and K. Thanushkodi.(2010) "A survey on coding algorithms in medical image compression." *International Journal on Computer Science and Engineering* **2(5):** 1429-1434.

[4]Abo-Zahhad, Mohamed, Reda RagabGharieb, Sabah M. Ahmed, and Mahmoud Khaled Abd-Ellah.(2015)"Huffman image compression incorporating DPCM and DWT." *Journal of Signal and Information Processing* **6(2):** 123-135.

[5]Bruylants, Tim, Adrian Munteanu, and Peter Schelkens.(2015) "Wavelet based volumetric medical image compression." *Signal processing: Image communication* **31**: 112-133.

[6]Ayoobkhan, Mohamed UvazeAhamed, Eswaran Chikkannan, and Kannan Ramakrishnan.(2017) "Lossy image compression based on prediction error and vector quantisation." *EURASIP Journal on Image and Video Processing* ,**1:** 35.

[7]Rufai, Awwal Mohammed, GholamrezaAnbarjafari, and Hasan Demirel.(2013) "Lossy medical image compression using Huffman coding and singular value decomposition." In *2013 21st Signal Processing and Communications Applications Conference (SIU)*, **1**-4. IEEE,.

[8]Selvi, G. Uma Vetri, and R. Nadarajan.(2017) "CT and MRI image compression using wavelet-based contourlet transform and binary array technique." *Journal of Real-Time Image Processing* **13(2)**: 261-272.

[9]Sriraam, Natarajan, and R. Shyamsunder.(2011) "3-D medical image compression using 3-D wavelet coders" *Digital signal processing* **21(1):** 100-109.

[10]Hosseini, SeyedMorteza, and Ahmad-Reza Naghsh-Nilchi.(2012) "Medical ultrasound image compression using contextual vector quantization." *Computers in biology and medicine* **42(7):** 743-750.

[11]Bairagi, Vinayak K., Ashok M. Sapkal, and AnkitaTapaswi.(2013) "Texture-Based Medical Image Compression." *Journal of digital imaging* **26(1)**: 65-71.

[12]Prabhu, K. M. M., K. Sridhar, Massimo Mischi, and HalandurNagarajaBharath.(2013) "3-D warped discrete cosine transform for MRI image compression." *Biomedical signal processing and control* **8(1)**: 50-58.

[13]Juliet, Sujitha, Elijah Blessing Rajsingh, and Kirubakaran Ezra.(2016) "A novel medical image compression using Ripplet transform." *Journal of Real-Time Image Processing* **11(2)**: 401-412.

[14]Cyriac, Marykutty, and C. Chellamuthu.(2012) "A novel visually lossless spatial domain approach for medical image compression." *European Journal of Scientific Research* **71(3)**: 347-351.

[15]Brahimi, Tahar, LarbiBoubchir, Régis Fournier, and Amine Naït-Ali.(2017) "An improved multimodal signal-image compression scheme with application to natural images and biomedical data." *Multimedia Tools and Applications* **76(15)**: 16783-16805.

[16]Arif, ArifSameh, Sarina Mansor, RajasvaranLogeswaran, and Hezerul Abdul Karim.(2015) "Auto-shape lossless compression of pharynx and esophagus fluoroscopic images." *Journal of medical systems* **39(2)**: 5.

[17]Das, Sudeb, and Malay Kumar Kundu.(2013) "Effective management of medical information through ROI-lossless fragile image watermarking technique." *Computer methods and programs in biomedicine* **111(3)**: 662-675.

[18] Lucas, Luís FR, Nuno MM Rodrigues, Luis A. da Silva Cruz, and Sérgio MM de Faria.(2017) "Lossless compression of medical images using 3-d predictors." *IEEE transactions on medical imaging* **36(11)**: 2250-2260.

[19]Špelič, Denis, and BorutŽalik.(2012) "Lossless compression of threshold-segmented medical images." *Journal of medical systems* **36(4)**: 2349-2357.

[20]Anusuya, V., V. SrinivasaRaghavan, and G. Kavitha.(2014) "Lossless compression on MRI images using SWT." *Journal of digital imaging* **27(5)**: 594-600.
[21]Xiao, Bin, Gang Lu, Yanhong Zhang, Weisheng Li, and Guoyin Wang.(2016) "Lossless image compression based on integer Discrete Tchebichef Transform." *Neurocomputing* **214:** 587-593.
[22] Amri, Hedi, Ali Khalfallah, MalekGargouri, NaïmaNebhani, Jean-Christophe Lapayre, and Mohamed-Salim Bouhlel.(2017) "Medical image compression approach based on image resizing, digital watermarking and lossless compression." *Journal of Signal Processing Systems* **87(2)**: 203-214.
[23]Ramesh, S. M., and A. Shanmugam.(2010) "Medical image compression using wavelet decomposition for prediction method." *arXiv preprint arXiv:1002.2418.*
[24]Ibraheem, M. Shaaban, S. Zahid Ahmed, Khalil Hachicha, Sylvain Hochberg, and Patrick Garda.(2016) "Medical images compression with clinical diagnostic quality using logarithmic DWT." In *2016 IEEE-EMBS International Conference on Biomedical and Health Informatics (BHI)*, 402-405. IEEE,
[25]Avramović, Aleksej, and Goran Banjac.(2012) "On predictive-based lossless compression of images with higher bit depths." *telfor journal* **4(2)**: 122-127.
[26] Bairagi, Vinayak K.(2015) "Symmetry-based biomedical image compression." *Journal of digital imaging* **28(6)**: 718-726.
[27]Zuo, Zhiyong, Xia Lan, Lihua Deng, Shoukui Yao, and Xiaoping Wang.(2015) "An improved medical image compression technique with lossless region of interest." *Optik* **126(21)**: 2825-2831.
[28] Srinivasan, K., Justin Dauwels, and M. Ramasubba Reddy.(2011) "A two-dimensional approach for lossless EEG compression." *Biomedical signal processing and control* **6(4)**: 387-394.
[29]Taquet, Jonathan, and Claude Labit.(2012) "Hierarchical oriented predictions for resolution scalable lossless and near-lossless compression of CT and MRI biomedical images." *IEEE Transactions on image processing* **21(5)**: 2641-2652.
[30]Mofreh, Amira, Tamer M. Barakat, and Amr M. Refaat.(2016) "A new lossless medical image compression technique using hybrid prediction model." *Signal Processing: An International Journal (SPIJ)* **10(3)**: 20.
[31]Raza, Mudassar, Ahmed Adnan, Muhammad Sharif, and Syed WaqasHaider.(2012) "Lossless compression method for medical Image sequences using super-spatial structure prediction and Inter-frame coding." *Journal of applied research and technology* **10(4)**: 618-628.
[32]Eben Sophia, Paul, and Jude Anitha.(2017) "Contextual Medical Image Compression using Normalized Wavelet-Transform Coefficients and Prediction." *IETE Journal of Research* **63(5)**: 671-683.
[33]Parikh, Saurin S., Damian Ruiz, Hari Kalva, Gerardo Fernández-Escribano, and VeliborAdzic.(2017) "High bit-depth medical image compression with hevc." *IEEE journal of biomedical and health informatics* **22(2)**: 552-560.
[34]Somassoundaram, T., and N. P. Subramaniam.(2018). "High performance angiogram sequence compression using 2D bi-orthogonal multi wavelet and hybrid speck-deflate algorithm." *Biomedical Research (0970-938X)*.
[35] Haddad, Sahar, GouenouCoatrieux, Michel Cozic, and DalelBouslimi.(2017) "Joint watermarking and lossless JPEG-LS compression for medical image security." *Irbm* **38(4)**: 198-206.
[36]Perumal, B., and M. PallikondaRajasekaran.(2016) "A hybrid discrete wavelet transform with neural network back propagation approach for efficient medical image compression." In *2016 International Conference on Emerging Trends in Engineering, Technology and Science (ICETETS)*: 1-5. IEEE, 2016.
[37]Karthikeyan, Dr T., and C. Thirumoorthi.(2016) "A hybrid medical image compression techniques for lung cancer." *Indian Journal of Science and Technology (IJST)(ISSN (Print): 0974-6846 ISSN (Online): 0974-5645)* **9(39)**: 1-6.
[38]Thomas, Deepak S., M. Moorthi, and R. Muthalagu.(2014) "Medical image compression based on automated ROI selection for telemedicine application." *Int. J. Eng. Comput. Sci* 3 : 3638-3642.
[39]Vaishnav, Megha, ChandrashekharKamargaonkar, and Monisha Sharma.(2017) "Medical image compression using dual tree complex wavelet transform and arithmetic coding technique." *International Journal of Scientific Research in Computer Science, Engineering and Information Technology***2(3)**
[40] Rani, M. Mary Shanthi, and P. Chitra. (2018) "A Hybrid Medical Image Coding Method based on Haar Wavelet Transform and Particle Swarm Optimization Technique." *International Journal of Pure and Applied Mathematics* **118(18)**: 3059-3067.
[41]Jiang, Huiyan, Zhiyuan Ma, Yang Hu, Benqiang Yang, and Libo Zhang.(2012) "Medical image compression based on vector quantization with variable block sizes in wavelet domain." *Computational intelligence and neuroscience* 2012:**5**.
[42]Sanchez, Victor, RafeefAbugharbieh, and PanosNasiopoulos.(2010) "3-D scalable medical image compression with optimized volume of interest coding." *IEEE Transactions on Medical Imaging* **29(10)** : 1808-1820.
[43]Hsu, Wei-Yen.(2012) "Improved watershed transform for tumor segmentation: application to mammogram image compression." *Expert systems with Applications* **39(4)**: 3950-3955.