ISSN:0975-9646

Gunpreet Kaur / (IJCSIT) International Journal of Computer Science and Information Technologies, Vol. 5 (2) , 2014, 2586-2591

Advanced Approaches for Medical Image Compression

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Abstract: Medical diagnostic data produced by hospitals has increased exponentially. With the coming era of digitized medical information and film-less imaging, it has been a challenge to deal with the storage and transmission requirement of enormous data. Compression is one of the indispensable techniques to solve this problem; with this the wavelet-based approaches have been the mainstream in the signal compression community. Wavelets are especially suitable for applications where scalability and tolerable degradation are important. Thus, many wavelet-based image compression algorithms have been developed, resulting in practical advances such as: continuous-tone and bit-level compression, lossless and lossy compression, progressive transmission by pixel, accuracy and resolution, region of interest coding and others. This paper aims to discuss some of the latest and efficient, wavelet based compression techniques followed by comparison in order to do justice to the three, namely: memory requirement, bandwidth constraint, and battery resource constraint.

Keywords: DWT, ROI, Differential-SPIHT, Adaptive SPIHT, JPEG2000, ROI coding.

I. INTRODUCTION

Medical images are a special category of images in their characteristics and purposes. These are generally acquired from special equipments, such as computed tomography (CT), magnetic resonance (MRI), ultrasound (US), X-ray diffraction, electrocardiogram (ECG), and positron emission tomography (PET). Since storage space demands in hospitals are continually increasing, compression of the recorded medical images is the need of the hour. On the other hand, many medical professionals are convinced that the future of health care will be shaped by digital radiology and technologies such as telemedicine. Applications of this type demand lower data rates as are achievable with lossless schemes [1]. This shows the need for efficient and widely accepted techniques for medical image compression. In practice, the compression of medical images must be lossless because a minor loss may result in a serious consequence. Therefore, only lossless techniques are accepted, which limits the amount of compression to a factor of 3. Progressive image transmission is an interesting feature in many practical applications such as telemedicine, teleastronomy or database retrieval among others. Some of the advantages of a progressive image transmission are that it allows interrupting the transmission when the quality of the received image has reached a desired accuracy or when the receiver recognizes that the image is not interesting or only needs a specific portion of the complete image or images. A possible solution is to offer such image compression techniques which allow an image to be selectively compressed [2]. Parts of the image that contain crucial information (region of interest (ROI)) are compressed in a lossless way whereas regions containing unimportant information are compressed in a lossy manner. This leads to considerably higher compression ratios as compared to pure lossless schemes while critical information is preserved. This property is especially useful for medical image coding applications. Region Of Interest(ROI) coding is a prominent feature of some image coding systems aimed to prioritize specific areas of the image through the construction of a codestream that, decoded at increasing bit-rates, recovers the ROI first and with higher quality than the rest of the image. Keeping in mind this pace, work on any format other than DICOM [3], especially when it comes to medical imaging would be vague.

In order to actuate clinical applications, so that the image is both stored and compressed to facilitate transmission, also not affecting the clinical diagnosis, there is the need for the lossy and lossless methods of traditional compression. These two are compromised to find a suitable entry point for the new release-the international standard JPEG2000 [4] that support both lossy and lossless compression, while JPEG can only do lossy compression. JPEG2000 wavelet-based arithmetic entropy coding techniques and the latest technology, are trying to make the image compressed, which will not only have a higher compression ratio to facilitate memory transfer, in addition, the JPEG2000 error stability, to better ensure the image quality. Among other features, JPEG2000 provides lossy-to-lossless and ROI coding, which are especially relevant to the medical community.

Compressions based on wavelet transform [5] are the state-of-the-art compression technique used in medical image compression. For medical images it is critical to produce high compression performance while minimizing the amount of image data so the data can be stored economically. The wavelet-based compression scheme contains transformation, quantization, and lossless entropy coding. Image processing applications require wavelets that are two-dimensional. This problem reduces down to designing 2D filters. Wavelets are ideal for this. Technology in medical imaging is so rapidly advancing that the pressure to keep up pace in all the allied technology is tremendous. Some recent studies of compressed medical images performed compression using the standard discrete wavelet transform (DWT) coding algorithm combined with scalar quantization and loseless (typically Huffmann and run-length) coding [3] with selective image compression. Since medical images also cannot afford any loss of quality in the reconstructed image, in that case, Yang Hu and William A. Pearlman [6] have firmly recommended a new approach to exploit temporal correlations for image sequence coding, while maintaining single frame, random access decoding, in comparison to SPIHT, a fast and an efficient method to compression performance. The wavelet transform based image compression algorithms are recognized as a better method to compress, archive and communicate medical images, therefore the

JPEG2000 algorithm proposed by P.G. Tohoces, et al. [7] with the varying encoding options available for medical image compression has been accepted image compression option by DICOM. Two of the most important features of JPEG2000 for the medical community are support for lossy-to-lossless compression, and Region Of Interest coding, as stated by Joan Bartrina-Rapesta et al.[8] with a new ROI coding method that is able to prioritize multiple ROIs at different priorities, guaranteeing lossy-to-lossless coding.

This paper presents methodology and key features of some of the efficient techniques especially used for medical image compression, namely Differential-SPIHT, JPEG2000, Adaptive SPIHT and Region Of Interest coding through component priority. In Section 2, preliminaries about wavelet transform of an image are discussed. The Section 3 gives an outline of the wavelet based coding methods. The Section 4 discusses the unique features of the underlying techniques. The Section 5 concludes the paper

II. PRELIMINARIES

Wavelet-based image processing methods in general have gained much attention in the biomedical image community. Most medical images have smooth color variations, with the fine details being represented as sharp edges in between smooth variations. The low frequency components (smooth variations) constitute the base of an image, and the high frequency components (the edges which give the detail) add upon them to refine the image, thereby giving a detailed image. Separating the smooth variations and details of the image can be done in many ways.

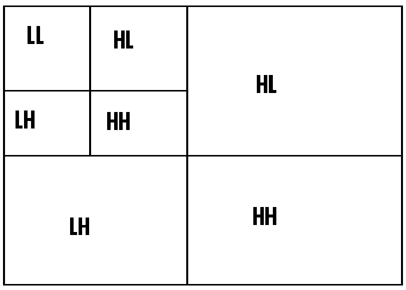

Fig.1. Image decomposition using 2-D Wavelets

One such way is the decomposition of the image using a Discrete Wavelet Transform (DWT) [9], [10]. Wavelets are being used in a number of different applications

III. WAVELET BASED CODING METHODS

1. Differential – SPIHT

Differential-SPIHT (Set Partitioning in Hierarchical Trees) [6] is one the latest medical image compression techniques proposed by William A. Pearlman in the year 2010. It is an extension of the well-known SPIHT [9] algorithm, a highly refined version of the EZW algorithm that produces an embedded bit stream from which the best reconstructed images in the *mean square error* sense can be extracted at various bit rates. The key idea of Differential-SPIHT is the reuse of the significance map. The block diagram of the presented scheme is given in Figure 2. Let Frame X be a *reference-frame* and coded with conventional 2D SPIHT. Frame Y is called a *map-frame*, since it is coded using the significance map *map* (X) and sign data *sign* (X) of Frame X, as shown in Figure 3.

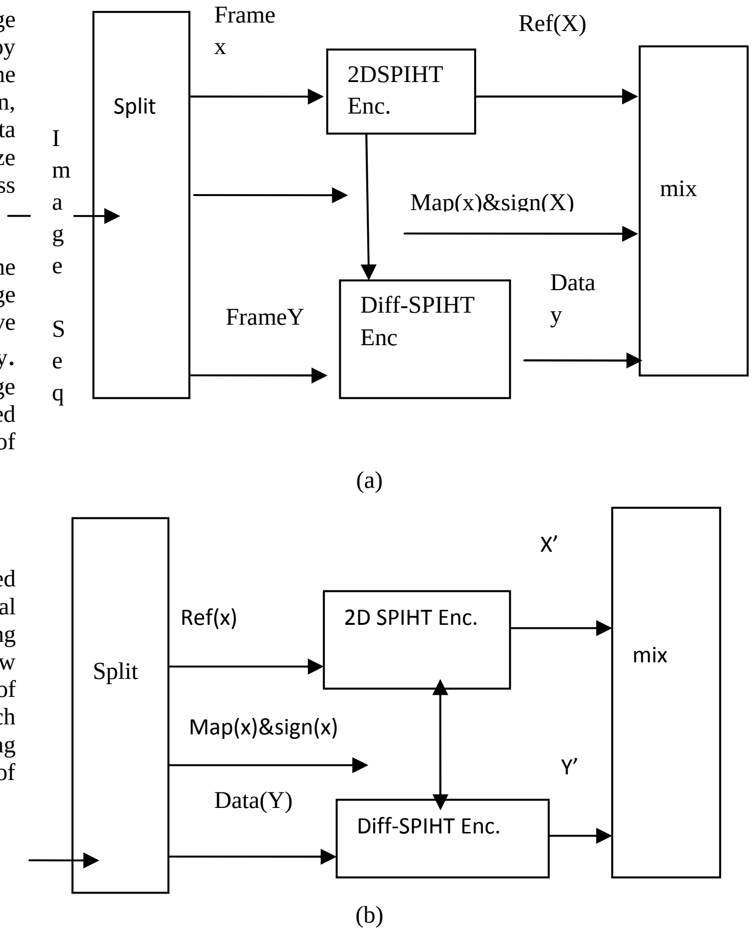

Fig.2. New Scheme (a) encoder (b) decoder

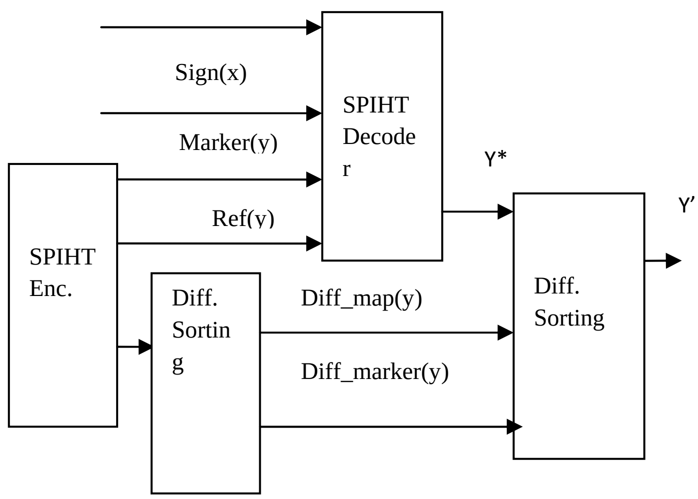

Fig.3. Differential-SPIHT

In Differential-SPIHT (Figure 3) encoding, Frame Y is first performed with SPIHT* encoder. Different from conventional SPIHT, there is no significance test to generate a new significance map. Instead, SPIHT* reads in the significance map of X, map(X), to iteratively identify the significance positions for Y. At each iteration, the selected positions of Y are exactly the same as those of X. Most Y coefficients in these positions are also significant due to the high correlation between X and Y. However, there are other possible cases, because of the difference of X and Y.

To be concrete, assume (i, j) is a selected position at the iteration with threshold T. The coefficient C_Y (i, j) involves sign in magnitude. For the sign, it may be the same or different from the sign of C_X (i, j), which is available for SPIHT* from sign (X). For the magnitude, it may be insignificant ($|C_Y (i, j)|<T$), it may be just significant ($T<=|C_Y (i, j)|<2T$), or it may be super significant ($|C_Y (i, j)|>=2T$).

Instead of a signed bit output in the conventional 2D SPIHT, a marker is outputted to indicate the specific case to which (C_Y (i, j) belongs. The markers are Huffman coded based on statistics gathered from simulations on sequences missa and salesman. These marker code words are denoted by marker (Y) in Figure 3. The coefficient is updated to be $|C_Y (i, j)|$ or ($|C_Y (i, j)|-T\times m$) for the insignificance and (just /super) significant cases, respectively where m= $\lfloor |C_Y (i, j)|/T \rfloor$.

In the refinement pass of SPHIT*, given $T=2^n$, the bits in the n-th bit plane of the coefficients previously found significant are outputted as ref (Y). Then, update the coefficients by setting the bits in the n-th bit plane to be 0's. Restricted by the input significance map, SPIHT* has the same number of iterations as SPIHT, which produces the map. The Y in Figure 3 denotes the frame with updated coefficients after SPIHT*.

In Differential –Sorting, the threshold is set to be T_{last}, and the sorting is enacted on the initial spatial- orientation tree. The significance tests are performed as in conventional SPIHT. The significance map bits convey the positions of significant coefficients of Y* and are expressed as diff_map (Y). For each significant coefficients, instead of the sign bit output for conventional SPIHT, a marker code is outputted to indicate the sign and the magnitude. Different from marker (Y) in SPIHT*, these markers indicate the sign (+ or -) directly, and there is no such case that the magnitude is insignificant. Another Huffman code is designed for the markers according to statistics gathered from simulations. These code words are indicated by diff_marker (Y) in Figure 3.

In Differential-SPIHT decoding, Differential-Sorting follows SPIHT* decoding to ensure that all the significant coefficients will be reconstructed.

2. JPEG2000

JPEG2000 is superior to the standard JPEG in having higher compression ratio, embedded bit stream, multiple resolution representations, error resilience, and region of interest coding [9]. JPEG2000 [7], [12] combines embedded block coding with optimized truncation (EBCOT) technique with lifting integer wavelet transform to offer plenty of advanced features. It is able to provide a high performance lossless medical image compression that is superior to JPEG standard at low bit rate. Two ROI coding methods, scaling-based and Maxshift are supported in part 1 of JPEG2000 [12]. The scaling-based has the advantage of allowing partial coding of the background region to the coding of the entire ROI, but it must transmit the side information of ROI at an additional coding cost. In the Maxshift method, the ROI bit stream is arranged in front of the background bit stream, so that the bit stream does not need to transmit additional side information to locate the ROI. The following figure focuses on the JPEG encoding procedure.

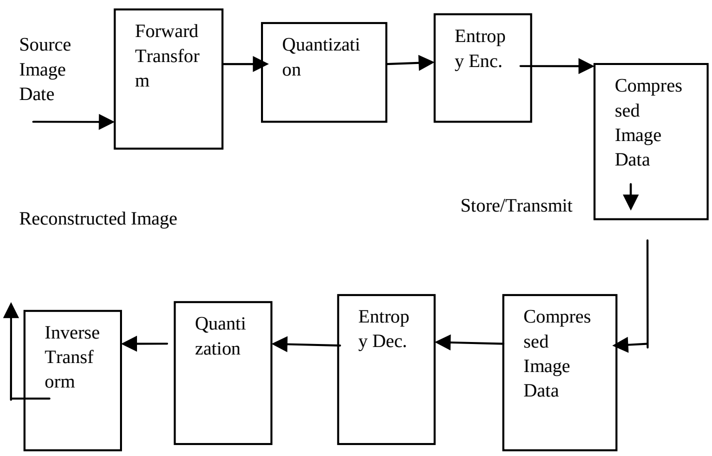

Fig.4. JPEG Encoding

The encoding procedure [4] is as follows:

- The source medical image is decomposed into components.
- The image and its components are decomposed into rectangular tiles. The tile-component is the basic unit of the original or reconstructed image.
- The wavelet transform is applied on each tile. The tile is decomposed in different resolution levels.
- These decomposition levels are made up of sub bands of coefficients that describe the frequency characteristics of local areas (rather than across the entire tile-component) of the tile component.
- Markers are added in the bit stream to allow error resilience.
- The code stream has a main header at the beginning that describes the original image and the various decomposition and coding styles that are used to locate, extract, decode and reconstruct the image with the desired resolution, fidelity, region of interest and other characteristics.
- The optional file format describes the meaning of the image and its components in the context of the application.

3. Adaptive SPIHT

The set partitioning in hierarchical trees (SPIHT) [9] is a very suitable method for compression of medical images as it offers a decent compression ratio. The SPIHT [3] method, involves (1) exploitation of the hierarchical structure of the wavelet transform, by using a tree-based organization of the coefficients; (2). Partial ordering of the transformed coefficients by magnitude, with the ordering data not explicitly transmitted but recalculated by the decoder; and (3) ordered bit plane transmission of refinement bits for the coefficient values. The Adaptive SPIHT compression scheme provides selective compression on medical images by compressing the ROI using JPEG2000 and the rest of the image by standard SPIHT, making it energy efficient. It involves following two phases:

(a) Energy efficient SPIHT on non-ROI

This leads to a fully embedded bit stream with the maximum value coefficients at first and the minimum value coefficients at the end of the stream, making this scheme applicable on the non- ROI image. This is the region which must be exploited to make the compression energy efficient. Discrete wavelet transform is the transform made use of. As this part of the medical image is of no diagnostic importance all the high frequency bands can be completely eliminated and only the low frequency components of the transform level be sent further. The advantage that remains out of doing this is that the compression time, the reconstruction time and peak signal to noise ratio is considerably reduced, along with an enhanced compression ratio.

(b)JPEG2000 on the ROI

The most important information lies in the Region of Interest. Quality after reconstruction is of outmost importance in case of medical images. The JPEG algorithm [12], [14] ensures quality .Power consumptions are greatly ruled by the varying implementations of the JPEG algorithms. Compression here cannot be afforded to be made energy efficient as this will lead to loss of detailing information. As the ROI selected is very small in size, in that case, instead of partitioning the bits into blocks, as for Embedded Block Code for Optimized Truncation (EBCOT), the bits are Huffman [6] or Run length coded directly, after the discrete wavelet transform has been applied. We can afford the decrease in bit rate on account of this for the sake of quality which is compromised by blocking artifacts whenever we go for splitting the image into blocks for any computation. The encoding and decoding computational complexities is drastically reduced as these are extremely simple methods of encoding.

4. JPEG2000 ROI coding through component priority

(a) Overview and coding mechanisms

Most JPEG2000 [4] implementations require four main coding stages to produce a compliant code stream [13]: sample data transformations, sample data coding, rate-distortion optimization, and code stream re-organization. The main operations related to ROI coding in JPEG2000 are the fractional bit plane coding process carried out in sample data coding, and the rate-distortion optimization stage. The JPEG2000's fractional bit plane coder is based on Embedded Block Coding with Optimized Truncation (EBCOT) [14]. The main idea behind this coding paradigm is to code small sets of wavelet coefficients (called code blocks) independently, and to optimally truncate the bit streams generated for these code blocks to form the final code stream. The bit stream generated for each code block can be truncated at the end of each coding pass, which produces several truncation points that can be potentially employed by the rate-distortion optimization stage.

The aim of the rate-distortion optimization stage is to manage the bit rate and/or the distortion of the final code stream. When the user specifies a desired bit rate, the rate-distortion optimization stage maximizes the quality of the final code stream; when the desired quality is specified, the bit rate of the code stream is minimized. The Post Compression Rate-Distortion optimization (PCRD) [15] is the most common method to conduct this optimization process. PCRD uses the bit rate and the distortion of potential truncation points of bit streams to pose the optimization problem through a generalized Lagrange multiplier for a discrete set of points.

To prioritize a specific area of an image, JPEG2000 ROI coding methods identify first those samples belonging to the ROI in the wavelet domain, called ROI coefficients. Then, ROI coefficients are prioritized in order to recover them at higher quality than the rest of the image, the background. To carry out this prioritization process, JPEG2000 provides two main mechanisms: either modifying wavelet coefficients, or modifying distortion estimates.

Methods based on modifying wavelet coefficients take advantage of the fractional bit plane coder by means of the multiplication of ROI coefficients by a desired priority, say U, in the wavelet domain. Through this multiplication the magnitude of ROI coefficients is higher than that of the background, thus the bit plane coder encodes first ROI coefficients. To speed up the prioritization process, U is commonly chosen to be a power of 2, thus the multiplication is implemented as a bit-shift operation and is conceptually seen as a bitplane shift. The JPEG2000 standard supports two methods based on this mechanism: the MaxShift [15] and the Scaling [2] based method. The main difference between them is that the Scaling allows the user to choose U, whereas in MaxShift U is chosen to shift up all ROI coefficients above the background. For the Scaling method, the ROI shape must be rectangular or elliptic, and it is explicitly transmitted to the decoder, whereas Max- Shift allows any ROI shape and it does not need to explicitly transmit it since it is implicitly coded within the bit stream.

(b) ROI coding through component priority

Two relevant features of JPEG2000 for this purpose are: support for multi-component images, and component scalability. Component scalability stands for the ability of the coding system to allow the access and manipulation of components in the compressed domain without needing to decompress the image. These features are employed by the proposed ROI coding Through Component Priority (ROITCOP) to allocate each ROI in a component where the non-ROI area is set to zero. Then, through the use of rate-distortion optimization techniques these components are prioritized at desired priorities, generating a multi-component image with each ROI prioritized at will.

The JPEG2000 core coding system requires two additional operations in the coding pipeline, and a slight modification of the PCRD method. It is noted that the ROITCOP requires a JPEG2000 encoder that implements some rate-distortion optimization method. Figure 5 depicts these two operations, called generate components, and join components. *Generate components* is an operation carried out in the encoder that defines as many components as ROIs have the image (referred to as ROI-components), plus one component for the background (referred to as BG-component). The operation *Join Components* sets the magnitude of each ROI coefficient to that recovered at the ROI-component with highest priority containing that ROI coefficient. The magnitude of BG coefficients is set to that recovered at the BG-component. For these Multi-Component (MC) images, a MC-PCRD is applied to combine the bitstreams from all components, minimizing the overall distortion. To correctly prioritize the desired ROI-components, a modification to MC-PCRD is introduced, updating the distortion estimates for specific codeblocks and components according to

$$D_{c,i}^{mj} = \begin{cases} U'_c * D_{c,i}^{n} & \text{if } c \in \text{ROI}, \quad D^{nj}_{c,i} \text{ otherwise} \end{cases}$$

where $D_{c,i}^{mj}$ denotes the distortion of component *c* for code block *i* at truncation point *nj*, and U'_c denotes the priority for ROI-component *c*. This operation modifies the distortion estimation for all ROI-components. With the use of ROITCOP method, perfect fine-grain accuracy is achieved. Only two methods compliant with JPEG2000 are able to achieve comparable accuracy, MaxShift [11] and Scaling [6], though they suffer from the dynamic range problem. The proposed ROITCOP [8] method is able to prioritize several ROIs at once, with each ROI at a different priority. The maximum number of ROIs is 16,384-C, where C is number of the components of the original image. This restriction is imposed by the maximum number of components allowed in JPEG2000, but it is large enough for most applications. Though ROITCOP forces the encoding of the background area in ROI-components – which contain nothing –, the coding performance of the final code stream is almost not penalized since these areas are efficiently signaled within the code stream through headers. Headers within the code stream indicate which data is included for each code block.

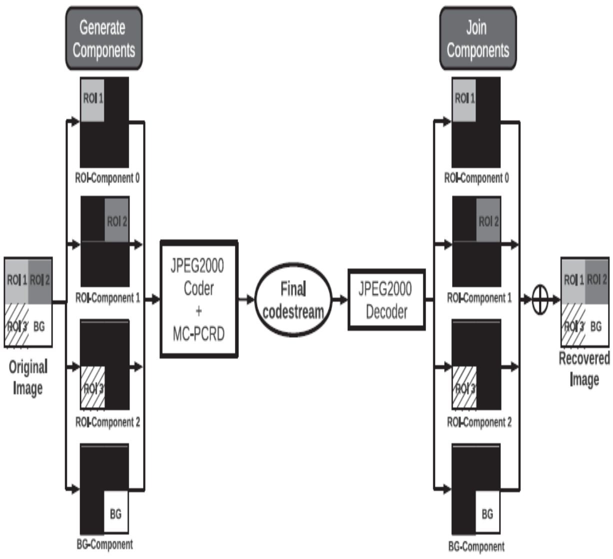

Figure 5. Operations for the JPEG2000 ROI coding method. Two operations are added in coder/decoder pipeline: generate components and join components

IV. DISCUSSION

This paper has presented and reviewed four different medical image compression techniques. Combined with reversible integer transform, Differential-SPIHT is able to compress losslessly, which is required by medical images. Without interacting within the frames, multiple map frames referring to the same reference frame can be coded in parallel. There is no latency or propagation error in case of Differential-SPIHT. It also maintains low computational complexity and finally reduces the memory requirements by buffering only the significance map, instead of group of frames.

On the other hand, JPEG2000 provides Region of Interest coding which allows region dependent fidelity constraints to different regions of the image as a single entity. This property is especially suitable for image coding applications, where the image consists of regions that can be encoded at different bit rates, such as compression of medical images.

The Adaptive SPIHT compression technique aims to imply selective medical image compression in a straight forward way-blocks containing ROI are compressed using the JPEG2000 methodology and the remaining blocks are compressed with the concept of Set

Partitioning in Hierarchical Trees (SPIHT). The advantage remains out of doing this is that the compression time, the reconstruction time and peak signal to noise ratio is considerably reduced.

The key feature of the JPEG2000 ROI coding through component priority is to allocate each ROI in a component and set coefficients of the non-ROI area of that component to zero.ROI coding is fundamental in scenarios such as telemedicine, providing progressive lossy-to-lossless coding that is able to exactly and losslessly recover the desired region.

Table I describe the various important features of approaches discuss in this paper

TABLE I

Technique	Features
Differential-SPIHT	Random access to any frame or slice is assured Lossless compression, which is required by medical images Multiple map frames can be coded in parallel Low computational complexity Low memory requirement No PSNR Loss
JPEG2000	ROI Coding High Compression Ratio Embedded bit stream Lossless compression Multiple resolution representations Error resilience
Adaptive SPIHT	High PSNR Energy efficient compression Selective ROI Coding Run-length or Huffman coding is applied, instead of EBCOT block partition Reduced Compression and Reconstruction time
JPEG2000 ROI coding through component priority	Achieves very high fine gain accuracy It is able to decode the ROI and the background in a lossy-to-lossless mode Enables the definition of multiple ROIs with different degrees of priority It is able to recover the desired ROI It is compliant with JPEG2000 standard

V. CONCLUSIONS

In this paper, we have laid stress on the major wavelet-based coding techniques; such techniques can be applied in medical imaging to offer better utilization of available bit-rate, since high fidelity shall be maintained only for relatively small regions of diagnostic relevance rather than for the entire image. Differential-SPIHT has become a novel approach to exploit inter-frame correlation, in comparison to the conventional SPHIT for the same reconstruction PSNR. Adaptive SPIHT provides an intelligent medical image compression, without detoriation of the image quality, allowing the medical to be compressed selectively. JPEG2000 has been accepted to be one of the image compression standards by DICOM, because of its advantageous features in comparison to JPEG. In contrast to this, ROI coding through component priority is compliant with JPEG2000, to bring to the medical communities the advantages of ROI coding.

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