DOI: 10.21917/ijivp.2012.0058

LOW COMPLEXITY HYBRID LOSSY TO LOSSLESS IMAGE CODER WITH COMBINED ORTHOGONAL POLYNOMIALS TRANSFORM AND INTEGER WAVELET TRANSFORM

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Abstract
In this paper, a new lossy to lossless image coding scheme combined with Orthogonal Polynomials Transform and Integer Wavelet Transform is proposed. The Lifting Scheme based Integer Wavelet Transform (LS-IWT) is first applied on the image in order to reduce the blocking artifact and memory demand. The Embedded Zero tree Wavelet (EZW) subband coding algorithm is used in this proposed work for progressive image coding which achieves efficient bit rate reduction. The computational complexity of lower subband coding of EZW algorithm is reduced in this proposed work with a new integer based Orthogonal Polynomials transform coding. The normalization and mapping are done on the subband of the image for exploiting the subjective redundancy and the zero tree structure is obtained for EZW coding and so the computation complexity is greatly reduced in this proposed work. The experimental results of the proposed technique also show that the efficient bit rate reduction is achieved for both lossy and lossless compression when compared with existing techniques.

Keywords:
Orthogonal Polynomials Transform Coding, Integer Wavelet Transform, Embedded Zerotree Coding

1. INTRODUCTION

In recent years many important applications such as medical imaging, remote sensing, space imaging and image archiving require an efficient lossless image coding scheme. Many Discrete Wavelet Transform (DWT) based coder have been reported in the past years [1-6] for lossless image coding. The DWT with improved Set Partitioning Hierarchical Tree (SPIHT) algorithm for lossless image coding is presented in [1], in which a significant test is performed on direct descents of SPIHT algorithm so as to result in efficient bit rate reduction. V.N Ramasamy et. al.[3] have reported a lossless coding scheme, in which the reversible wavelet transformed coefficients are encoded into two groups viz. significance map and residue map followed by context-based arithmetic coding. A two stage lossless coder is presented in [4], wherein the first stage uses DWT for good energy compaction and decorrelation and residual image are coded in second layer using adaptive reversible integer wavelet packet transform. However the main drawback of DWT based coder is that most of the wavelet coefficients are in floating point numbers which are not well suited for lossless image coding schemes. Hence a low complexity Lifting Scheme (LS) based [7] integer wavelet transform is introduced for lossless image coding [8-12], since a perfect reconstruction is ensured by the structure of LS itself. Embedded Zero tree Wavelet (EZW) Coding is an efficient universal lossless coding scheme since it attempts to optimally encode a source using no prior knowledge of the source. The EZW algorithm is based on the following key concepts: 1) a discrete wavelet transform or hierarchical subband decomposition, 2) prediction of the absence of significant information across scales by exploiting the self-similarity inherent in images, 3) successive-approximation entropy coded quantization, and 4) adaptive arithmetic universal lossless data compression scheme. Many EZW based coder has been reported in various literature [13-16]. In [13], the DWT and EZW algorithm are combined for lossless coding of images. The computational complexity of EZW algorithm is reduced using quadtree splitting and context modeling [14]. In order to increase the compression ratio of EZW coding, the stochastic texture model using Generalized Gaussian Distribution is combined with EZW algorithm [15]. The block based embedded, progressive DCT image compression with EZW algorithm is presented in [16]. In general, the computational complexity of EZW coding algorithm is quite high especially for encoding the lower subband images. In [17], a hybrid coding technique combining the DWT and DCT based JPEG coder [18] is employed for reducing the computational complexity of encoding the lower subband signals in EZW algorithm.

Since most of the lossless image coders are based on complex Discrete Wavelet transform coding scheme, a new low complexity hybrid lossy to lossless coder is proposed in this paper. It takes the advantages of both wavelet transform based coding scheme and simple Orthogonal Polynomials Transform (OPT) based coding scheme [19]. This OPT based coding scheme has resulted from our investigations into some low level feature extraction problems such as detection of textures and edges, in monochrome and color images [20-22]. In these works, a point-spread operator M is designed due to a class of orthogonal polynomials and defined a linear two dimensional transformation to analyze the low level primitives of the image under analysis. Normalization and mapping are used in the proposed work in order to obtain the non linear transformed image data which exploits the subjective redundancy of the image. These non linear transformed data are rearranged in zero tree structure and are encoded with EZW coding technique which achieves progressive lossy to lossless compression.

The rest of the paper is organized as follows; The Orthogonal Polynomials model for the proposed coding is presented in section 2. The basis operators of the proposed transform coding are given in section 3. The Integer Wavelet Transform relevant to the proposed work is given in section 4. The Orthogonal Polynomials Transform based image coding algorithm is presented in section 5. The EZW algorithm is described in section 6. The proposed hybrid lossy to lossless image coder is described in section 7. The measure of performance is given in section 8. The experimental results of the proposed coding and their comparison with existing techniques are presented in section 9, and the conclusion is presented in section 10.

2. ORTHOGONAL POLYNOMIALS MODEL

In order to devise a transform coding for lossless image coder, a linear 2-D image formation system is considered around a Cartesian coordinate separable, blurring, point spread operator in which the image I results in the superposition of the point source of impulse weighted by the value of the object function f. Expressing the object function f *in* terms of derivatives of the image function I relative to its Cartesian coordinates is very useful for analyzing the image. The point spread function $M(x, y)$ can be considered to be real valued function defined for $(x, y) \in X$ x Y, where X and Y are ordered subsets of real values. In case of gray-level image of size (nxn) where X (rows) consists of a finite set, which for convenience can be labeled as {0, 1, …,n-1}, the function $M(x, y)$ reduces to a sequence of functions.

$$M(i, t) = u_i(t), \quad i, t = 0, 1, \ldots, n-1 \tag{1}$$

The linear two dimensional transformation can be defined by the point spread operator $M(x, y)$ ($M(i, t) = u_i(t)$) as shown in Eq.(2).

$$\beta'(\zeta,\eta) = \int_{x\in X}\int_{y\in Y} M(\zeta,x)\,M(\eta,y)\,I(x,y)\,dxdy \tag{2}$$

Considering both X and Y to be a finite set of values {0, 1, 2… n –1}, Eq. (2) can be written in matrix notation as follows,

$$\left|\beta'_{ij}\right| = \left(|M| \otimes |M|\right)^t |I| \tag{3}$$

where, $\otimes$ is the outer product, $|\beta'_{ij}|$ are n^2 matrices arranged in the dictionary sequence, $|I|$ is the image , $|\beta'_{ij}|$ are the coefficients of transformation and the point spread operator $|M|$ is

$$|M| = \begin{vmatrix} u_0(t_1) & u_1(t_1) & \cdots & u_{n-1}(t_1) \\ u_0(t_2) & u_1(t_2) & \cdots & u_{n-1}(t_2) \\ & & \vdots & \\ u_0(t_n) & u_1(t_n) & \cdots & u_{n-1}(t_n) \end{vmatrix} \tag{4}$$

Consider a set of orthogonal polynomials $u_0(t), u_1(t),\ldots,u_{n-1}(t)$ of degrees 0,1,2,…,n-1 respectively to construct the polynomial operators of different sizes from Eq.(4) for $n \geq 2$ and $t_i = i$. The generating formula for the polynomials is as follows,

$$u_{i+1}(t) = (t-\mu)\mu_i(t) - b_i(n)u_{i-1}(t) \text{ for } i \geq 1 \tag{5}$$

$$u_1(t) = t-\mu, \text{ and } u_0(t) = 1,$$

where, $b_i(n) = \dfrac{\langle u_i, u_i\rangle}{\langle u_{i-1}, u_{i-1}\rangle} = \dfrac{\sum_{t=1}^{n} u_i^2(t)}{\sum_{t=1}^{n} u_{i-1}^2(t)}$ and $\mu = \dfrac{1}{n}\sum\limits_{t=1}^{n} t.$

Considering the range of values of t to be $t_i = i$, i = 1, 2, 3…n,

$$b_i(n) = \frac{i^2\left(n^2 - i^2\right)}{4\left(4i^2-1\right)}, \quad \mu = \frac{1}{n}\sum_{t=1}^{n} t = \frac{n+1}{2}$$

The point-spread operators $|M|$ of different size can be constructed from Eq.(4) using the above orthogonal polynomials for $n \geq 2$ and $t_i = i$. For the convenience of point-spread operations, the elements of $|M|$ are scaled to make them integers.

3. ORTHOGONAL POLYNOMIALS BASIS

For the sake of computational simplicity, the finite Cartesian coordinate set X, Y is labeled as {1, 2, 3}. The point spread operator in Eq.(3) that defines the linear orthogonal transformation for image coding can be obtained as $|M| \otimes |M|$, where $|M|$ can be computed and scaled from Eq.(4) as follows.

$$|M| = \begin{vmatrix} u_0(x_0) & u_1(x_0) & u_2(x_0) \\ u_0(x_1) & u_1(x_1) & u_2(x_1) \\ u_0(x_2) & u_1(x_2) & u_2(x_2) \end{vmatrix} = \begin{vmatrix} 1 & -1 & 1 \\ 1 & 0 & -2 \\ 1 & 1 & 1 \end{vmatrix} \tag{6}$$

The set of polynomial basis operators O_{ij}^n $(0 \leq i, j \leq n\text{-}1)$ can be computed as,

$$O_{ij}^n = \hat{u}_i \otimes \hat{u}_j^t$$

where, $\hat{u}_i$ is the $(i + 1)^{st}$ column vector of $|M|$.

The complete set of basis operators of sizes (2×2) and (3×3) are given below,

Polynomial basis operators of size (2×2) are,

$$\left[O_{00}^2\right] = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}, \left[O_{01}^2\right] = \begin{bmatrix} -1 & 1 \\ -1 & 1 \end{bmatrix},$$

$$\left[O_{10}^2\right] = \begin{bmatrix} -1 & -1 \\ 1 & 1 \end{bmatrix}, \left[O_{11}^2\right] = \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

Polynomial basis operators of size (3×3) are,

$$\left[O_{00}^3\right] = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}, \left[O_{01}^3\right] = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix},$$

$$\left[O_{02}^3\right] = \begin{bmatrix} 1 & -2 & 1 \\ 1 & -2 & 1 \\ 1 & -2 & 1 \end{bmatrix}, \left[O_{10}^3\right] = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix},$$

$$\left[O_{11}^3\right] = \begin{bmatrix} 1 & 0 & -1 \\ 0 & 0 & 0 \\ -1 & 0 & 1 \end{bmatrix}, \left[O_{12}^3\right] = \begin{bmatrix} -1 & 2 & -1 \\ 0 & 0 & 0 \\ 1 & -2 & 1 \end{bmatrix},$$

$$\left[O_{20}^3\right] = \begin{bmatrix} 1 & 1 & 1 \\ -2 & -2 & -2 \\ 1 & 0 & 1 \end{bmatrix}, \left[O_{21}^3\right] = \begin{bmatrix} -1 & 0 & 1 \\ 2 & 0 & -2 \\ -1 & 0 & 1 \end{bmatrix},$$

$$\left[O_{22}^3\right] = \begin{bmatrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{bmatrix}.$$

Having designed the orthogonal polynomials model, the integer wavelet transform for the proposed image coder is presented in the next section.

Table.1. Several Forward Transform of IWTs

IWT	Forward transform of IWT
5/3	$d[n]=d_0[n]-\lfloor 1/2(s_0[n+1]+s_0[n]\rfloor$
	$s[n]=s_0[n]+\lfloor 1/4(d[n]+d[n-1])+1/2)\rfloor$
13/7	$d_i[n]=d_0[n]-s_0[n]$
	$s[n]=s_0[n]+\lfloor 1/16(8d_i\rfloor[n]+d_i[n-1])-d_i[n+1])+1/2$
	$d[n]=d_i[n]+\lfloor 1/16(s[n+2]-s[n-2]+6(s[n-1]-$

	$s[n+1]+1/2\rfloor$
6/14	$d[n]=d_0[n]+\lfloor 1/16((s_0[n+2]+s_0[n-1]-9(s_0[n+1]+s_0[n])+1/2\rfloor$
	$s(n)=s_0[n]+\lfloor 1/32(d(d[n]+d[n-1]-(d[n+1]+d[n-2])+1/2\rfloor$

4. INTEGER WAVELET TRANSFORM

In this section a lifting scheme (LS) based DWT called reversible Integer Wavelet Transform is described for the proposed lossless image coding scheme. The lifting scheme [23] is a flexible technique that has been applied to the construction of wavelets through an iterative process of updating a subband from an appropriate linear combination of the other subband. The reversible integer wavelet transform has the following advantages: Firstly, IWT has lower computational complexity than DWT because of LS scheme. Secondly, through the use of appropriate techniques a perfect reconstruction is possible. Finally, the memory storage requirements are reduced since integers are used instead of real numbers. In LS, the integer wavelet transforms can be described [5] through polyphase matrix using Euclidean Algorithm and the analysis filters *A(z)* are given as,

$$A(z)=\prod_{i=1}^{m}\begin{bmatrix}1 & s_i(z)\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ t_i(z) & 1\end{bmatrix}\begin{bmatrix}K & 0\\ 0 & 1/K\end{bmatrix} \tag{7}$$

where, $S_i(z)$ and $t_i(z)$ are the Laurent polynomials and K is the constant value. From the analysis filters, the general Interpolating Biorthogonal Integer Wavelet Transform (IB-IWT) is describes as,

$$A(z)=\prod_{i=1}^{m}\begin{bmatrix}1 & s(z)\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ t(z) & 1\end{bmatrix}. \tag{8}$$

The IB-IWT is the efficient low complexity Integer Wavelet Transform for image compression. The several forward transform of IB-IWTs are described in Table.1.

In Table.1, the *x/y* notation is used to indicate that the underlying filter bank has low pass and high pass analysis filters of lengths x and y. In the forward transform equations, the input signal, low pass subband signal and high pass subband signal are denoted as $x[n]$, $s[n]$ and $d[n]$ respectively. For convenience, the quantities $s_0[n]$ and $d_0[n]$ are defined as $s_0[n] = x[2n]$ and $d_0[n] = x[2n+1]$.

5. ORTHOGONAL POLYNOMIALS TRANSFORM BASED IMAGE CODER

The Orthogonal Polynomials Transform based image coder partitions the input image into non overlapping blocks of size (nxn) with i rows and j columns (where, $1 \leq i \leq n$ and $1 \leq j \leq n$) and the Orthogonal Polynomials based transform coding is applied as described in section 2. After the proposed orthogonal polynomials based transform coding (OPT) is performed, the quantization is implemented using a quantization matrix, whose formula, as in JPEG is given below,

$$\text{Quantized value }(i, j)=\text{round}\left[\frac{OPT(i,j)}{Quantum(i,j)}\right] \tag{9}$$

where, $OPT(i, j)$ is transform coefficient matrix obtained with the orthogonal polynomials transformation. The quantum value matrix $Quantum(i, j)$ is obtained through an integer, called *quality_factor*. Depending upon the requirement of the quality of reconstructed image vis-à-vis compression ratio, the *quality_factor* can be made adaptive and be specified by the user. The relationship between $Quantum(i, j)$ and the *quality_factor* is $Quantum(i, j) = 1+ ((1 + i + j)*quality\_factor)$. The *quality_factor* which is a user input is generally in the range 0–25, and specifies the quantum value, for every element position in the original polynomial transform coefficient matrix. The *quality_factor* is chosen in such a way that it can discard higher frequency coefficients elegantly. That is, when the quality is high, the quantum value corresponding to the higher frequency coefficient sample positions shall be high so that the quantized value can be zero. The quantized transform coefficients are then subjected to bit allocation scheme using variable length coding. For this purpose the quantized transform coefficients are reordered using zigzag scanning to form a 1D sequence. Due to the fact that DC coefficients of the proposed orthogonal polynomials based coding have high magnitude and the DC values of neighboring blocks are not differing substantially, the DC values are subjected to difference pulse code modulation (DPCM). The first element of the zigzag sequence represents the difference pulse code modulated DC value and among the remaining AC coefficients, the non-zero AC coefficients are Huffman coded using variable length code (VLC) that defines the value of the coefficient and the number of preceding zeros. Standard VLC tables specified in the JPEG baseline system are used for this purpose. Since the Huffman coded binary sequences are instantaneous and uniquely decodable, the compressed image can be decompressed easily in a simple look-up table manner. The rearranged array of transform coefficients is reordered into 2D block from the 1D regenerated zigzag sequence with dequantization, after taking care of DPCM DC coefficients and we reconstruct the sub image under analysis by using the polynomials basis operators, defined in section 3.

6. EZW ENCODER

The Embedded Zerotree Wavelet coding (EZW) is a simple, effective progressive image coding algorithm and can be used for both lossless and lossy compression systems. This algorithm works well with the proposed coding scheme because the zero tree structure is effective in describing the significance map of the transform coefficients, as it exploits (i) the inherent self similarity of the subband image over the range of scales, and (ii) the positioning of majority of (near) zero valued coefficients in the higher frequency subbands. The EZW algorithm applies Successive Approximation Quantization (SAQ) in order to provide multi-precision representation of the transformed coefficients and to facilitate the embedded coding. The algorithm codes the transformed coefficients in decreasing order in several scans. Each scan of the algorithm consists of two passes: significant map encoding and refinement pass. The dominant pass scans the subband structure in zigzag, right-to-left and then top-to-bottom within each scale, before proceeding to the next higher scale of subband structure as presented in Fig.1. For every pass, a threshold (T) is chosen against which all the coefficients are measured and encoded as one of the following four symbols,

- Significant positive – If the coefficient value is greater than threshold T
- Significant negative – If the magnitude of the coefficient value is greater than threshold T
- Zero tree root – A coefficient is encoded as zero tree root if the coefficient and all its descendents are insignificant with respect to threshold T
- Isolated zero – If the coefficient is insignificant but some of its descendents are significant.

The initial threshold is obtained as, $T_0 = 2^{\lfloor \log_2 C_{\max} \rfloor}$, where C_{max} is the maximum coefficient in the subband structure. The successive approximation quantization uses a monotonically decreasing set of thresholds and encodes the transformed coefficients as one of the above four labels with respect to any given threshold. For successive significant pass encoding, the threshold is lowered as $T_K = \frac{T_{K-1}}{2}$ and only those coefficients not yet found to be significant in the previous pass are scanned for encoding, and the process is repeated until the threshold reaches zero, and results in complete encoded bitstreams.

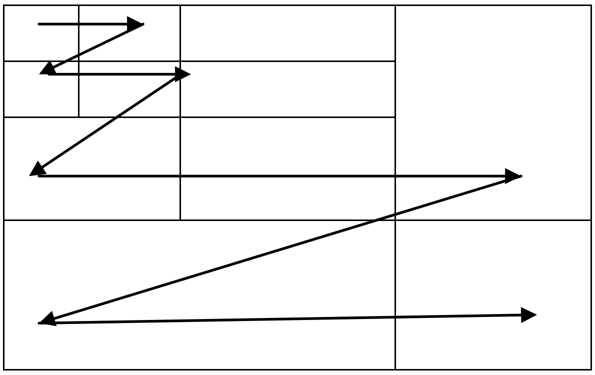

Fig.1. EZW subband structure scanning order

7. PROPOSED HYBRID LOSSY TO LOSSLESS IMAGE CODER

In this proposed algorithm, the input image is first transformed into frequency domain using quadtree partition based Integer Wavelet Transform as described in section 4 and the four subbands viz. Low-Low(LL), Low-High(LH), High-Low(HL) and High-High(HH) are obtained as $T_{LL}(i, j)$, $T_{LH}(i, j)$, $T_{HL}(i, j)$ and $T_{HH}(i, j)$. Next, the low subband image $T_{LL}(i, j)$ is applied with OPT based coder and the reconstructed image is obtained as described in section 5 and is designated as $T'_{LL}(i, j)$. Then the residual image $T''_{LL}(i, j)$ of LL subband is the difference between original image $T_{LL}(i,j)$ and the reconstructed image $T'_{LL}(i, j)$ is obtained as follows,

$$T''_{LL}(i, j) = T_{LL}(i, j) - T'_{LL}(i, j) \tag{10}$$

After obtaining the residual image of LL subband, the normalization is done for all the four subbands $T''_{LL}(i, j)$, $T_{LH}(i, j)$, $T_{HL}(i, j)$ and $T_{HH}(i, j)$ as follows,

$$T^n_{LL}(i, j) = \frac{T''_{LL}(i, j)}{T'_{LL}(i, j) + K} \tag{11}$$

$$T^n_{LH}(i, j) = \frac{T_{LH}(i, j)}{T'_{LH}(i, j) + K} \tag{12}$$

$$T^n_{HL}(i, j) = \frac{T_{HL}(i, j)}{T'_{HL}(i, j) + K} \tag{13}$$

$$T^n_{HH}(i, j) = \frac{T_{HH}(i, j)}{T'_{HH}(i, j) + K} \tag{14}$$

where, K is the constant value used to make the normalized coefficients less than one. Since the human eye is more sensitive to noise in an uniform background than in a region of high contrast, the absolute values of normalized coefficients are modified as follows,

$$\left| y^n_k(i, j) \right| = \left| y^n_{k-1}(i, j) \right| \times \left[2 - \left| y^n_{k-1}(i, j) \right| \right] \quad k = 1, 2, ..., L \tag{15}$$

where, $y^n_0(i, j)$ is the value of normalized coefficient of $T^n_{LL}(i, j)$, $T^n_{LH}(i, j)$, $T^n_{HL}(i, j)$ and $T^n_{HH}(i, j)$, and L is an integer constant which changes with different subbands.

After normalization and mapping, the four subbands are generated and designated as $y^n_{LL}(i, j)$, $y^n_{LH}(i, j)$, $y^n_{HL}(i, j)$ and $y^n_{HH}(i, j)$ which are then located in the corresponding position of $T_{LL}(i, j)$, $T_{LH}(i, j)$, $T_{HL}(i, j)$ and $T_{HH}(i, j)$ in the wavelet decomposition.

Again, the $y^n_{LL}(i, j)$ subband is rearranged into four subimages as,

$$y^n_{LL1}(i, j) = y^n_{LL}(2i, 2j) \tag{16}$$

$$y^n_{LL2}(i, j) = y^n_{LL}(2i+1, 2j) \tag{17}$$

$$y^n_{LL3}(i, j) = y^n_{LL}(2i, 2j+1) \tag{18}$$

$$y^n_{LL4}(i, j) = y^n_{LL}(2i+1, 2j+1) \tag{19}$$

This rearrangement is further applied on $y^n_{LL1}(i, j)$ subband and so on to obtain the hierarchical representation of $y^n_{LL}(i, j)$, $y^n_{LH}(i, j)$, $y^n_{HL}(i, j)$ and $y^n_{HH}(i, j)$ and the EZW algorithm is applied on this zero tree structured transformed coefficients as described in section 6. The proposed Low Complexity Hybrid Lossy to Lossless Image Coder (LCHLLIC) is detailed as an algorithm hereunder,

The Proposed Algorithm:

Input: Gray scale image of size

image_width $\times$ *image_height* and 2-D polynomials operator $|M|$.

Output: Encoded image with proposed algorithm.

BEGIN

Steps:

1. Get the input image and apply the quadtree partition based IWT to get four subband images $T_{LL}(i, j)$, $T_{LH}(i, j)$, $T_{HL}(i, j)$, $T_{HH}(i, j)$.
2. Apply the OPT based coding on low subband $T_{LL}(i, j)$ image and get the reconstructed baseband image $T'_{LL}(i, j)$.

3. Find the residual image $T''_{LL}(i, j)$ from original subband image $T_{LL}(i, j)$ and reconstructed subband $T'_{LL}(i, j)$ using the following equation,
$$T''_{LL}(i, j) = T_{LL}(i, j) - T'_{LL}(i, j)$$
4. Obtain the non linear transformed subbands $y^n_{LL}(i, j)$, $y^n_{LH}(i, j)$, $y^n_{HL}(i, j)$ and $y^n_{HH}(i, j)$ using normalization and mapping and replace the corresponding location $T_{LL}(i, j)$, $T_{LH}(i, j)$, $T_{HL}(i, j)$ and $T_{HH}(i, j)$ in the wavelet decomposition as described in this section.
5. Rearrange the low subband coefficients $y^n_{LL}(i, j)$ into further four subimages and the process is repeated to obtain a hierarchical zero tree representation of $y^n_{LL}(i, j)$, $y^n_{LH}(i, j)$, $y^n_{HL}(i, j)$ and $y^n_{HH}(i, j)$.
6. Apply EZW algorithm as described in section 6 on the zero tree transformed coefficients to achieve either lossy or lossless compression.

END.

8. MEASURE OF PERFORMANCE

A very logical way of measuring how well a compression algorithm compresses a given set of data is to look at the ratio of the number of bits required to represent the data before compression, to the number of bits required to represent the data after compression. The ratio, called compression ratio is used to evaluate the transform based lossy to lossless image coding techniques. In this proposed work, the reconstruction differs from the original data and this difference is quantified using fidelity and quality. If the fidelity or quality of reconstruction is high, then the difference between the reconstruction and the original is small. A widely used measure of reconstructed image fidelity for an (*N*x*M*) size image is the average mean-square error [24] defined as,

$$e^2_{ms} = \frac{1}{NM}\sum_{i=1}^{N}\sum_{j=1}^{M} E\left(I_{i,j} - I'_{i,j}\right)^2 \tag{20}$$

where, $\{I_{i,j}\}$ and $\{I'_{i,j}\}$ represents the (*N*x*M*) original and reproduced images respectively. Experimentally the average mean-square error is often estimated by the average sample mean-square error in the given image defined by,

$$e^2_{ms} = \frac{1}{NM}\sum_{i=1}^{N}\sum_{j=1}^{M}(I_{i,j} - I'_{i,j})^2 \tag{21}$$

There are two definitions of signal to noise ratio (*SNR*) that are used corresponding to the above error. These are defined as,

$$SNR = 10\log_{10}\frac{(\text{peak to peak value of the original image data})^2}{e^2_{ms}}\,(\text{dB}) \tag{22}$$

$$SNR' = 10\log_{10}\frac{\sigma^2_u}{e^2_{ms}}\,(\text{dB}) \tag{23}$$

where, σ^2_u is the variance of the original image. Although SNR' is more widely used as a measure of *SNR* in signal processing literature, (since it is related to signal power and noise power) and is perhaps more meaningful because it gives 0 dB for equal signal and noise power, *SNR* is used more commonly in the image coding field. Often the original image raw data is given as discrete samples quantized to a relatively large number of gray levels. Typically the number of levels is 256 (or 8 bits) so that the peak value is 255. Hence the Eq.(22) becomes,

$$PSNR = 10\log_{10}\left[\frac{255^2}{e^2_{ms}}\right] \tag{24}$$

where, *PSNR* stands for Peak Signal to Noise Ratio. The computation time of proposed low complexity coder is measured in mille seconds (ms).

9. EXPERIMENTS AND RESULTS

The proposed algorithm has been tested with more than 2000 monochrome images of different types. Some sample images which are of size (128x128) with pixel values in the range (0-255) are shown in Fig.2.(a)-(b). The input image is first applied with integer wavelet transform and four subbands *LL*, *LH*, *HL* and *HH* images are obtained. The OPT based image coder is applied on *LL* subband as described in section 5 and the reconstructed image is obtained. The residual *LL* subband image from original and reconstructed values is obtained using difference operation. The residual *LL* subband and other subbands are normalized as described in section 7. The normalized subbands are mapped to the original IWT subbands and the *LL* subband image is rearranged again for four subband images. This process is repeated for hierarchical zero tree structure and EZW coding is applied as described in section 6. For lossy compression the EZW algorithm is terminated at the desired bit-rate using the threshold function in EZW algorithm. The experiments are conducted in Intel Core(2)-Quad, 2.3GHz speed processor system and the results for various bit-rates of the proposed algorithm with PSNR values obtained are presented in Table.2 for lossy image coding. For the rate of 0.1bpp, the proposed algorithm achieves a PSNR value of 31.57dB and 30.24dB for boat and baboon images respectively. Similarly for the bit-rate of 0.25bpp, the proposed algorithm achieves 34.72dB and 33.68dB for boat and baboon images. The decoding process is the reverse process of encoding and the reconstructed image for bit-rate of 0.25bpp for original images Fig.2.(a)-(b) are shown in Fig.3.(a)-(b). For the bit-rate of 1.0 bpp, the proposed algorithm achieves PSNR values 41.24dB and 40.27dB for the same standard images. Since the proposed algorithm encodes the image with reduced computational complexity, the computation time is also measured and included in Table.2.

The performance of the proposed algorithm is compared with combined DCT and IWT (DCT+IWT) transformations and the experiments are conducted on the same computer system. For the rate of 0.1bpp, the (DCT+IWT) algorithm achieves 30.17dB and 29.25dB PSNR values for boat and baboon images respectively. Similarly for the bit-rate of 0.25bpp, the (DCT+IWT) algorithm achieves 33.05dB and 32.10dB for boat and baboon images. For the bit-rate of 1.0bpp, the (DCT+IWT) algorithm achieves 40.38dB and 39.87dB for the same standard images. The experiment results for various test images for different bit rates are included in Table.2. From the results, it is evident that the proposed hybrid algorithm with (OPT+IWT) gives better results in terms of PSNR and computation time when compared with (DCT+IWT). The proposed algorithm is also experimented for lossless image coding and compared with existing techniques viz. improved SPIHT [1], JPEG-LS [18] and Context-based Adaptive Lossless Image Codec (CALIC) [25] and results are reported in Table.3. The boat and baboon images are encoded in 4.215 bpp and 4.352 bpp with proposed algorithm and the results are shown in Fig.4. The improved SPIHT algorithm encodes the same images in 4.354bpp and 4.652bpp, the JPEG-LS algorithm encodes in 4.653bpp and 4.759bpp and the CALIC algorithm encodes in 4.362bpp and 4.459bpp for the same standard images.

(a) boat (b) baboon

Fig.2. Original test images

(a) boat (b) baboon

Fig.3. Results of proposed lossy image coder when bpp is 0.25 and PSNR values are (a) 34.72dB (b) 33.68dB

(a) boat (b) baboon

Fig.4. Results of proposed lossless image coder

Table.2. PSNR Values and Computation Time Obtained with Proposed (OPT+IWT) Algorithm and (DCT+IWT) Technique

Bit-Rate	Images	Proposed algorithm with OPT and IWT		Proposed algorithm using DCT and IWT	
		PSNR	C.T	PSNR	C.T
0.1	**boat**	31.57	0.775	30.17	154.75
	baboon	30.24	0.950	29.25	146.98
	parrot	30.68	0.843	29.46	173.28
	fruits	30.31	0.923	29.58	164.36
	pepper	30.60	0.886	29.71	159.04
0.25	**boat**	34.72	156.73	33.05	325.75
	baboon	33.68	176.80	32.10	336.04
	parrot	33.51	165.90	32.75	303.70
	fruits	32.80	135.22	31.48	341.23
	pepper	33.60	146.85	32.66	315.77
0.5	**boat**	37.34	201.57	36.75	456.90
	baboon	36.75	227.40	35.05	423.91
	parrot	36.18	235.83	35.14	431.47
	fruits	35.60	212.69	34.67	430.78
	pepper	36.04	205.86	35.33	405.62
0.75	**boat**	39.79	378.01	38.82	642.67
	baboon	38.22	358.42	37.75	580.35
	parrot	38.04	369.51	37.33	632.69
	fruits	37.42	334.05	36.59	601.93
	pepper	38.90	392.18	37.24	578.42
1.0	**boat**	41.24	522.54	40.38	857.91
	baboon	40.27	651.27	39.87	812.04
	parrot	40.96	578.03	39.70	768.59
	fruits	39.70	604.68	38.51	863.12
	pepper	40.75	599.30	39.34	789.16

Table.3. Bit-Rate of Lossless Image Coding with Proposed Algorithm and Comparison with Existing Techniques

Images	Proposed algorithm	Improved SPIHT	JPEG-LS	CALIC
boat	4.215	4.354	4.653	4.362
baboon	4.352	4.537	4.759	4.459
parrot	4.024	4.125	4.369	4.358
fruits	3.914	4.017	4.312	4.895
pepper	3.980	4.332	4.450	4.570

10. CONCLUSION

A new low complexity lossy to lossless hybrid image coder with combined orthogonal polynomials transform and integer wavelet transform is proposed in this paper. The lifting based IWT is implemented for subband decomposition and progressive lossy to lossless compression is achieved using EZW subband algorithm. In order to reduce the computational complexity for encoding the lower subband signals using EZW algorithm, a new integer based Orthogonal Polynomials transform coding is applied on lower subbands and residual *LL* subband is obtained. The Normalization and mapping is done on all the subbands to avoid the subjective redundancy and subbands reorganization and hence the hierarchical subband zero tree structure is utilized for EZW algorithm. The proposed hybrid technique is fast and encodes the image at lower bit rate when compared with existing technique.

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