

LT-DCT Hybrid Scheme for Image Coding

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Received June 22, 2010; Revised March 21, 2011; Accepted 11 June 2011

Published online: 1 January 2012

Abstract: This paper describes an efficient lifting based hybrid image coding (LB-HIC) scheme. The proposed scheme is based on using the lifting transform (LT) in conjunction with the discrete cosine transform (DCT) to provide coding performance superior to the popular image coders. The proposed method uses combination of the DCT coding and the high performance of the set partitioning in hierarchical tree (SPIHT) coding. The modification process provides a new subband image data containing almost the same information of the original one but having smaller values of the lifting coefficients. Simulation results of the proposed method demonstrate that, with small addition in the computational complexity of the coding process, the peak signal-to-noise ratio (PSNR) performance of the proposed algorithm is much higher than that of the SPIHT test coder and some of famous image coding techniques.

Keywords: Image compression; Image coding; Lifting transform; Embedded coding; JPEG 2000; DCT; SPIHT.

1 Introduction

Even though the memory capacities of computers have increased as new technologies are emerging, the requirement for more storage space is also increasing as more data are needed to be stored. In the case of image data, the spatial and colour resolutions are increased for the betterment of image quality, thus requires more space to store images. Image compression either lossy or lossless is one of the solutions to meet the storage requirements. In a lossy compression scheme, the image compression algorithm should achieve a tradeoff between compression ratio and image quality. One of the solutions of this problem is to code the image based on the feature extraction [1]. In this method, the pixels are classified in the pre-processing step to code each block of pixels related to its significant. It does not need to send any information about the classification process to the decoder. Another solution to this goal is the object based image coding or the region of interest (ROI) image coding. The general theme is to preserve the quality for diagnostically important regions,

whereas the rest of the image (background) is highly compressed. ROI coding usually supports progressive transmission by quality, which may further reduce the transmission time and storage cost. Object-based/ROIs can also be useful in applications such as web browsing, or image retrieval. The detection of ROIs has been studied by various researchers [2- 4].

The object-based Discrete Cosine Transform (DCT) coder produces annoying visual degradation, i.e. the block effect between blocks with the visibility of this effect depending upon local image characteristics. In recent years, much of the research activities in this area have been focused on the distribution of the wavelet coefficients of the image to achieve an embedded image coding. From the most famous and successful techniques is Shapiro's embedded zerotree of wavelet coefficients method (EZW) [5], which exploits the existing zero-correlation across subband images. In practice, to reach a better coding performance of the EZW algorithm, more scales are required and to obtain

higher resolution reconstructed images, the complexity of the algorithm will be relatively high. To reduce the computational complexity of the EZW algorithm, Egger et. al. [6] proposed a two-band based wavelet decomposition scheme. The most important development of the EZW algorithm is the Set Partitioning in Hierarchical Trees (SPIHT) coding technique [7]. SPIHT outperforms EZW in both compression efficiency and speed. Even without arithmetic coding it is more efficient than EZW whose compression efficiency is to some extent due to the use of arithmetic coding. SPIHT is less efficient in coding performance than the embedded block coding with optimized truncation (EBCOT) [8], the main wavelet-based image coding algorithm of the JPEG-2000 standard [9, 10]. SPIHT does not employ any explicit rate-distortion optimization, so it has lower computational complexity than the EBCOT algorithm. EBCOT exploits the dependency between the wavelet coefficients exist inside each subband. The set partitioning embedded block coder (SPECK) [11] is used as a low complexity image coding option of the JPEG-2000 (SPHP) [12, 13]. A higher complexity variant of SPECK, called embedded zero-block coding (EZBC) is introduced by Hsiang and Woods [14]. T. Rajkumar and M. L. [22] presented the application of ROI coding in the field of telemedicine. First, the ROIs and their respective resolutions must be specified by the user. After this, the input image is partitioned and the ROI are extracted from each of the tiles using the tiling method. The extracted tiles belong to various ROI(s) and their residual background. SPIHT encoding is performed after transforming each and every tile using lifting wavelet. Then the final ROI encoded image data is obtained by integrating the SPIHT encoded tiles into a single unit. By integrating the encoded ROI image data appropriately the background is made to come after the ROI tiles which appear first in the encoded image data. The ROI then reconstructs the image such that the background tile is decoded only after decoding the ROI. The resolution available in the header of the encoded data is used to decode the tiles. The ROI tiles are displayed in the corresponding co-ordinates after the decoding phase using the co-ordinate details.

Another class of image coding techniques is the hybrid image coding [15, 16, 17]. In these techniques, instead of using one transformation a combination of two image transformations are used to get better coding performance. Yu and Mitra [15] introduced a computationally efficient hybrid image

coding scheme. The hybrid coding method is based on the nonlinear modification of the wavelet coefficients in the first level using the DCT of the approximation (LL) band image. The EZW coding is applied to the modified wavelet coefficients followed by adaptive arithmetic coding representation to generate the symbol stream. S.Parveen Banu and Dr.Y.Venkataramani [17] proposed a hybrid image compression technique for efficient storage and delivery of data. It is based on decomposing the data using daubechies-4 wavelet in combination with the lifting scheme and entropy encoding. This scheme is concerned with the compression ratio, bits per pixel and peak signal to noise ratio. Experimental results illustrate that the proposed scheme is efficient and feasible in terms of compression ratio, bits per pixel and peak signal to noise ratio. Haiping et. al. [18] presented an algorithm for hyperspectral image compression. It carries DCT on spectral bands to exploit the spectral correlation and then DWT on every eigen image to exploit the spatial correlation. After that, 3D-SPIHT (three-dimensional Set Partitioning in Hierarchical Trees) is performed for encoding. Experiments were done on the OMIS-I (Operational Modular Imaging Spectrometer) image.

Usama [16] proposed a highly scalable hybrid image coding scheme (HS-HIC). The proposed hybrid coding scheme combines simply modification of the data in the wavelet domain and the SPIHT coding. The modification of the subband image data is done based on the transformation of the high-frequency subband (details) in the wavelet domain. It is based on linear modification of 9-subband image data within three-layer in the wavelet domain. Except the image data in LL3, all other image data will be linearly modified based on the Discrete Fourier Transform (DFT) components. The modified data is then located in the corresponding position and the simple SPIHT coder followed by adaptive arithmetic coder is applied on the resulting hierarchical representation to generate the symbol stream. A comparison of the most famous image coding methods can be summarized as follows. The SPIHT method is considered the best image coding technique in terms of decoded image quality, progressive rate control and transmission and the simplicity of the coding process. The EZW method provides several dB's of signal-to-noise ratio improvement for the most real world still images at low bit-rate over the discrete cosine transform (DCT) based JPEG still image coding standard. The SPECK method produces very competitive PSNR results. The JPEG2000 method

achieves PSNR results slightly below those of the EZBC method, but appears to provide some perceptual advantage in the reconstructed images, especially in preserving detail information. In this work, the idea of the proposed method is based on the same idea introduced in [15]. The proposed scheme is based on using the lifting transform (LT) in conjunction with the discrete cosine transform (DCT) to provide coding performance superior to the popular image coders. The proposed method uses combination of the DCT coding and the high performance of the set partitioning in hierarchical tree (SPIHT) coding.

The remainder of this paper is organized as follows. In section 2, the basic of the SPIHT algorithm is described. The Lifting Scheme is introduced in Section 3. Section 4 introduces the proposed algorithm. Simulation results are introduced in Section 5. Finally, concluding remarks are given in Section 6.

2 The set partitioning in hierarchical tree (SPIHT) coding algorithm

In recently, the wavelet-based image encoding algorithms considerably improve the compression rate and the visual quality, therefore many researches proposes many different methods for encoding the wavelet-based images.

The SPIHT [7] algorithm is an efficient method for lossy and lossless coding of natural images. The SPIHT algorithm adopts a hierarchical quad-tree [23] data structure on wavelet-transformed image. The energy of a wavelet-transformed image is concentrated on the low frequency coefficients. A tree structure, called spatial orientation tree (SOT), naturally defines the spatial relationship of the hierarchical pyramid. Fig. 1 shows how a spatial orientation tree is defined in a pyramid constructed with recursive four subbands splitting. The coefficients are ordered in hierarchies. According to this relationship, the SPIHT algorithm saves many bits that specify insignificant coefficients.

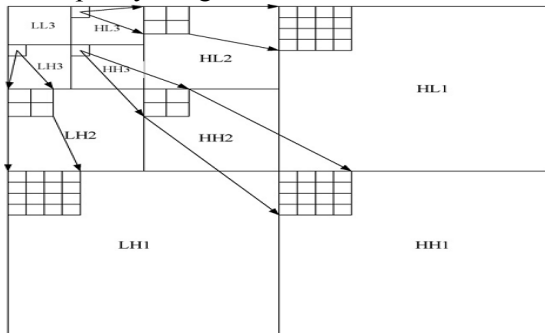


Fig. 1 Parent-child relationship.

In the SPIHT coding algorithm, after the wavelet transform using 9/7 tap wavelets from Antonini et al. [19] is applied to an image, the main algorithm works by partitioning the wavelet decomposed image into significant and insignificant partitions based upon the following function

$$S_n(T) = \begin{cases} 1, & \max_{(i,j) \in T} \{|b(i,j)|\} \geq 2^n \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

where $S_n(T)$ is the significance of the set of coordinates T , and $b(i,j)$ is the coefficient value at coordinate (i,j) . There are two passes in the algorithm, the sorting pass and the refinement pass. The sorting pass is performed on the list of insignificant sets (LIS), list of insignificant pixels (LIP) and the list of significant pixels (LSP). The LIP and LSP consist of nodes that contain single pixels while the LIS contains nodes that have descendants. The maximum number of bits required to represent the largest coefficients in the spatial orientation tree is obtained and designed as n_{max} and is given by

$$n_{max} = \left\lceil \log_2 \left(\max_{(i,j)} \{|b(i,j)|\} \right) \right\rceil \quad (2)$$

During the sorting pass, those coordinates of the pixels which remain in the LIP are tested for significance by using equation (1). The result $S_n(T)$ is sent to the output. Those that are significant will be transferred to the LSP as well as have their sign bit output. Sets in the LIS will also have their significance tested and if found to be significant, will be removed and partitioned into subsets. Subsets with a single coefficient and found to be significant will be added to the LSP, or else they will be added to the LIP.

During the refinement pass, the n -th most significant bit of the coefficients in the LSP is output. The value of n is decreased by 1 and the sorting and refinement passes occur again. This continues until either the desired rate is reached or until $n=0$ and all nodes in the LSP have all their bits output.

It is clear from equation (1) and (2) that the coding performance of the SPIHT coding algorithm is highly related to the distribution of the $b(i,j)$ in the $3P+1$ subband images, where P is the number of scales.

So, the normalization of the filter coefficients is indeed an efficient bit allocation scheme to put more bits in coding of lower frequency subband images. Moreover, to reach the higher coding performance, more scales in the lifting

decomposition are required. The main disadvantage of the SPIHT coding algorithm is that the error in one bit of the coded bit stream will result in a noticeable error in output of the decoder.

3 Lifting Scheme

The simplest lifting scheme is the lazy wavelet transform, where the input signal is first split into even and odd indexed samples.

$$(Oddj-1, Evenj-1) = Split(sj)$$

When the samples are correlated, it is possible to predict one from the other. The odd samples are predicted from the even samples, which, in the case of the Haar transform, are the even values themselves. The difference between the actual odd samples and the prediction becomes the wavelet coefficients. The operation of obtaining the differences from the prediction is called as a lifting step. The update step follows the prediction step, where the even values are updated from the input even samples and the updated odd samples. They become the scaling coefficients, which will be passed on to the next stage of the transform. This is the second lifting step. The forward and inverse lifting transform is shown in Figure 2(a) and (b).

$$\begin{aligned} dj-1 &= Oddj-1 - P(Evenj-1) \\ sj-1 &= Evenj-1 + U(dj-1) \end{aligned}$$

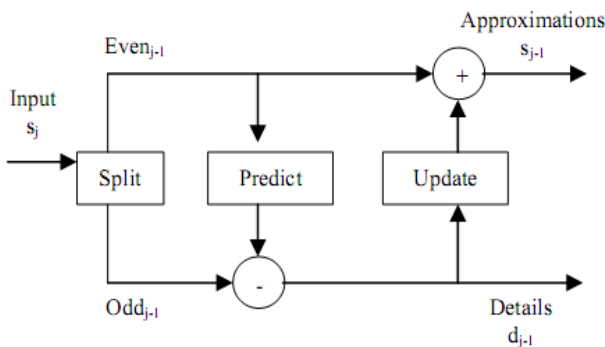


Fig. 2(a): Forward Lifting Transform

The odd elements are replaced by the differences and the even elements by the averages. The computations in the lifting scheme are done in-place, which saves a lot of auxiliary memory and computation time. The lifting scheme can be used to produce integer coefficients and so it is exactly reversible. The averages are the coarser representations of the signal and the differences are the extra information required to go from the coarser representation to the original [21]. If the signal is smooth, the detail components will be

small and they can be ignored. Then the coarse representation is an approximation of the original and also a compressed version of it with some distortion. The process can be the average component of the signal being the input to the next stage till the number of samples reduces to one. This last sample represents the average component of the entire image. The total number of coefficients after the transform equals the number of coefficients before the transform.

The inverse transform gets back the original signal by exactly reversing the operations of the forward transform; finally, with a merge in place of a split operation. The number of samples in the input signal must be a power of two, and in each succeeding step, it is reduced by half, till the last step produces one sample.

$$\begin{aligned} Evenj-1 &= sj-1 - U(dj-1) \\ Oddj-1 &= dj-1 + P(Evenj-1) \end{aligned}$$

Finally, $sj = Merge(Evenj-1, Oddj-1)$

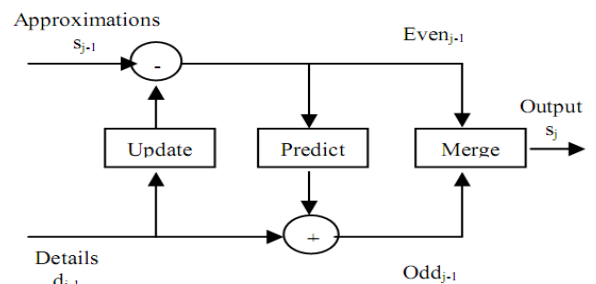


Fig. 2(b): Inverse Lifting Transform

4 Proposed lifting based hybrid image coding (LB-HIC) algorithm

In this work, combination of the DCT coding and the high performance of the set partitioning in hierarchical tree (SPIHT) coding is used. The modified data size is exactly the same size as the original one and containing almost the same original information but having smaller values. The proposed hybrid coding algorithm is described next. First, one-level of the lifting transform is applied on the input image. This process will generate 4-subband data $(x_{ll}, x_{lh}, x_{hl}, x_{hh})$ in this layer. Next, the baseband image $x_{ll}(i, j)$ is compressed using the DCT coding method, and its reconstructed image is designed as $x'_{ll}(i, j)$. The difference between $x_{ll}(i, j)$ and $x'_{ll}(i, j)$ is the residual basedband image $x''_{ll}(i, j)$, i.e.

$$x''_{ll}(i, j) = x_{ll}(i, j) - x'_{ll}(i, j). \quad (3)$$

Weber's law indicates that for a wide range of image intensity, the ratio of the just-noticeable difference (j.n.d) to the image intensity is a constant. To make use of this phenomenon in the proposed coding algorithm, the subband image $x_{ll}''(i, j)$, $x_{lh}''(i, j)$, $x_{hl}''(i, j)$ and $x_{hh}''(i, j)$ will be normalized as indicated below:

$$\begin{aligned} x_{ll}^n(i, j) &= \frac{x_{ll}''(i, j)}{x_{ll}'(i, j) + k} & x_{lh}^n(i, j) &= \frac{x_{lh}''(i, j)}{x_{lh}'(i, j) + k} \\ x_{hl}^n(i, j) &= \frac{x_{hl}''(i, j)}{x_{hl}'(i, j) + k} & x_{hh}^n(i, j) &= \frac{x_{hh}''(i, j)}{x_{hh}'(i, j) + k} \end{aligned} \quad (4)$$

Where k is a constant used to minimize the number of the sorting passes in the SPIHT coder, and will be determined as follows:

$$K = \left| (Max(X_{ll}'') - 2 * Max(X_{ll}')) / 2 \right| \quad (5)$$

As in predictive image coding [20], the absolute values of the normalized coefficients will be modified as follows:

$$y_p^n(i, j) = y_{p-1}^n(i, j) \times [2 - y_{p-1}^n(i, j)] \quad p = 1, \dots, q \quad (6)$$

Where $y_0^n(i, j)$ is the value of the normalized coefficients $x_{ll}^n(i, j)$, $x_{lh}^n(i, j)$, $x_{hl}^n(i, j)$ and $x_{hh}^n(i, j)$, and q is an integer constant which may change with different subbands. After normalization and mapping, four sub-images are generated and designated as $y_{ll}^n(i, j)$, $y_{lh}^n(i, j)$, $y_{hl}^n(i, j)$ and $y_{hh}^n(i, j)$, which are then located in the corresponding positions of $x_{ll}(i, j)$, $x_{lh}(i, j)$, $x_{hl}(i, j)$ and $x_{hh}(i, j)$ in the wavelet decomposition. Then, the data in $y_{ll}^n(i, j)$ is rearranged into four sub-images,

$$\begin{aligned} y_{ll1}^n(i, j) &= y_{ll}^n(2i, 2j) \\ y_{ll2}^n(i, j) &= y_{ll}^n(2i + 1, 2j) \\ y_{ll3}^n(i, j) &= y_{ll}^n(2i, 2j + 1) \\ y_{ll4}^n(i, j) &= y_{ll}^n(2i + 1, 2j + 1) \end{aligned} \quad (7)$$

This rearrangement is further applied on $y_{lh}^n(i, j)$ and so on to obtain hierarchical representation of $y_{ll}^n(i, j)$, $y_{lh}^n(i, j)$, $y_{hl}^n(i, j)$ and $y_{hh}^n(i, j)$ to be coded by the SPIHT coder. SPIHT image coding without adaptive multilevel arithmetic coding is finally applied on the resulting hierarchical representation to generate symbol streams.

5 Simulation results

The performance of the proposed techniques is introduced in this section. Various kinds of gray images with size of 512×512 pixels and 8 bpp are selected as a test data. The performance is evaluated by the peak signal-to-noise ratio (PSNR) in dB and the perceptual quality of the reconstructed images. The proposed method is compared with JPEG, JPEG2000, EZBC, SPIHT, EZW, SPECK, Yu and Mitra [15], and the HS-HIC [16].

The 9-tap low-pass filter and the 7-tap high-pass filter are used to decompose the input image into four sub-images. The resulting baseband image was coded with the object-base DCT coder followed by adaptive arithmetic code at moderate bit rates. The constant k in the normalization was automatically calculated from equation (5) and the rearrangement in equation (7) was performed to obtain a 6-scale hierarchical data structure.

In the simulation results the exact number of bits used is selected as follows:

For Lena image we used 32446 bits in DCT coding, and 322 bits in SPHIT coding so that the total bit rate per pixel (bpp) is 0.125. To achieve total bit rate per pixel (bpp) is 0.25, we used 65214 bits in DCT coding, and 322 bits in SPHIT coding. The total bit rate per pixel of 0.5 bpp is achieved using 130750 bits in DCT coding, and 322 bits in SPHIT coding.

For Barbara image we used 32397 bits in DCT coding, and 371 bits in SPHIT coding so that the total bit rate per pixel (bpp) is 0.125. To achieve total bit rate per pixel (bpp) is 0.25, we used 65181 bits in DCT coding, and 355 bits in SPHIT coding. The total bit rate per pixel of 0.5 bpp is achieved using 130475 bits in DCT coding, and 597 bits in SPHIT coding.

For Goldhill image we used 25530 bits in DCT coding, and 7238 bits in SPHIT coding so that the total bit rate per pixel (bpp) is 0.125. To achieve total bit rate per pixel (bpp) is 0.25, we used 65214 bits in DCT coding, and 322 bits in SPHIT coding. The total bit rate per pixel of 0.5 bpp is achieved using 109312 bits in DCT coding, and 21760 bits in SPHIT coding.

Table 1 shows the resulting PSNR values at different bit rates and the reconstructed images using different image coders are shown in Fig.3 and Fig.4. The results clearly show that the LB-HIC coding performance is better than the other image

coding performance (about 0.15- 4dB) with the current images used.

Table 1: Comparative analysis of coding efficiency

Image		Lena	Barbara	Goldhill
No. of background block=		64	66	0
No. of foreground block=		960	958	1024
CR=16 (bpp=0.5)	HS-HIC [16]	38.262	32.383	33.439
	Yu & Mitra [15]	38.280	33.523	34.4228
	JPEG	35.88	31.73	32.38
	JPEG 2000	37.27	32.87	33.24
	EZBC	37.47	32.15	33.47
	SPECK	37.1	31.54	33.03
	EZW	36.28	30.53	32.87
	SPIHT	37.25	32.10	33.13
	LB-HIC	38.059	33.958	36.2965
CR=32 (bpp=0.25)	HS-HIC [16]	35.092	28.129	30.57
	Yu & Mitra [15]	35.003	31.592	32.9558
	JPEG	32.49	27.77	29.78
	JPEG 2000	34.15	28.89	30.53
	EZBC	34.35	28.25	30.74
	SPECK	34.03	27.76	30.5
	EZW	33.17	26.77	30.31
	SPIHT	34.14	28.13	30.56
	LB-HIC	35.718	31.566	33.2101
CR=64 (bpp=0.125)	HS-HIC [16]	33.86	25.16	28.98
	Yu & Mitra [15]	32.249	29.030	29.5140
	JPEG	28.9	24.1	26.9
	JPEG 2000	30.71	25.24	28.31
	EZBC	31.33	25.33	29.09
	SPECK	31.02	24.93	28.39
	EZW	30.23	24.03	28.24
	SPIHT	31.10	24.86	28.48
	LB-HIC	33.223	31.225	31.9243



(a) LB-HIC at 0.125 bpp.



(b) Yu & Mitra [15] at 0.125 bpp.

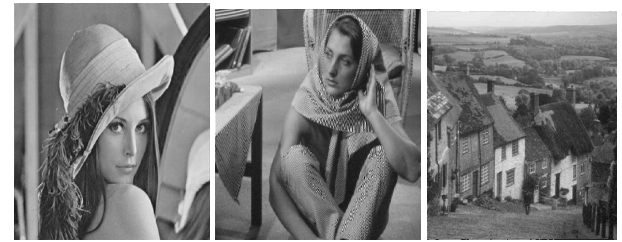


(c) SPIHT at 0.125 bpp.

Fig. 3 The results of SPIHT, Yu and Mitra [15], and LB-HIC image coder at 0.125 bpp bit rate.



(a) LB-HIC at 0.5 bpp.



(b) Yu & Mitra [15] at 0.5 bpp.

Fig. 4 The results of Yu and Mitra [15] and LB-HIC image coder at 0.5 bpp bit rate.

6 Conclusions

In this paper, lifting based hybrid image coding algorithm is introduced. The proposed algorithm works much more efficiency than the SPIHT coding method. The new distribution of the lifting coefficients provides reduction in computational complexity. For low bit rate image coding only one sorting pass in the lifting domain is applied. The simulation results indicate that the PSNR performance of the proposed algorithm is much higher than that of SPIHT, EZW, SPECK, EZBC, and the JPEG-2000 test coder. The advantage in performance of LB-HIC lays in the LT maps with small coefficients in all subband image data.

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