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An Image Compression Algorithm Using the Bloc-Based Subband DCT and Wavelet Transform with the Improved SPIHT Coder

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Abstract **- In this paper, we propose an image compression algorithm that uses a bloc based subband discrete cosine transform and the wavelet transform with an improved modified set partitioning in hierarchical trees (SPIHT) coding algorithm. The proposed transform uses the bloc-based discrete cosine transform to decompose the image into multiresolution subbands where the discrete wavelet transform is then used to code the low frequencies. The modified SPIHT coding method is used to progressively code the transformed coefficients. The obtained results show the efficiency of the proposed hybrid method in terms of the peak signal-to-noise ratio (PSNR) and visual quality.**

Index Terms - compression, coding, discrete cosine transform, wavelet transform, SPIHT.

I. Introduction

Today, images are present everywhere and peoples always request better quality and resolution to view their images, videos and also HDTV channels. Currently, applications such as telemedicine, e-commerce, remote sensing and telecommunication deal with huge amounts of digital images. The first problems in such applications is a) the transmission time over limited network bandwidth and b) the storage requirements which are in growth with the advance of image acquisition technologies especially in embedded systems where the resources are limited.

Image compression is to reduce image capacity by eliminating or reducing data redundancy in the image. This operation can be done in lossy or lossless manner depending on applications requirements [1]. Lossless methods must reconstruct compressed images without distortion. These methods are generally limited in term of obtained compression ratios. With the lossy methods, we can achieve higher performances with an acceptable visual degradation in the reconstructed images.

Most known lossy image compression algorithms are based on transforms [2]. The representation of the image in another domain offers many advantages such as decorrelation and energy compaction in fewer coefficients. Wavelets have had a growing impact on signal, image processing and compression, due mainly to their good nonlinear approximation performance for piece wise smooth functions in one dimension [3] [4].. Unfortunately, this is not the case in higher dimensions. The major drawback for wavelets when processing images is the limited ability to capture directional information. To overcome this deficiency, researchers have recently proposed some multiscale and directional transforms that can represent intrinsic geometric structures in natural images. Some examples include the steerable pyramid, [5], brushlets [6], complex wavelets [7], curvelets [8], bandelets, [9] and the contourlet transform (CT) [10].

In our previous work [11], we have proposed a hybrid discrete cosine transform – discrete wavelet transform natural image compression, where the results outperforms wavelets results in certain cases. The proposed transform uses at the first stage the multilevel sub-band DCT to analyze the input images in many subbands, and the wavelet transform is used at the second stage to decompose the low-resolution subband image obtained by the subband DCT. In this paper, we propose another scheme of the previously hybrid transform which uses a bloc DCT of reduced size. This will reduce the complexity and time consumption of the method since the bloc DCT is of lower complexity and gives better performances in term of objective and subjective image quality.

The modified SPIHT algorithm that is used in [11] is applied on the transformed image. The algorithm uses a significant pixels adjustment (SPA) method that is based on error estimation of significant coefficients upon the coding algorithm. After, during the decoding stage, the estimated error is used to refine the reconstructed significant coefficients, this operation will reduce the distortion between original and reconstructed coefficients and hence improve the original SPIHT method.

The outline of the paper is as follows. Section 2 presents the proposed scheme for image transformation. A short description of the modified set partitioning in hierarchical trees (SPIHT) algorithm is shown in section 3. Numerical results of the implementation of the proposed method with some examples of reconstructed test images are shown and commented on in section 4, and finally a conclusion is presented.

II. THE PROPOSED HYBRID TRANSFORM

The proposed hybrid transform uses two known transforms: the subband discrete cosine transform (DCT) applied on the input image and the discrete wavelet transform (DWT) which is used at the approximation obtained by the previous transform.

For single level decomposition the following steps are needed. Firstly, the DCT is used for subband decomposition similar to the wavelet transform which produces in each level of decomposition four subbands (LL, LH, HL and HH). The input image is initially transformed using the two-dimensional discrete cosine transform (2D – DCT), and then the obtained coefficients are partitioned horizontally and vertically into four parts: the upper-left quarter as subband 1, the upper-right quarter as subband 2, the lower-left quarter as subband 3 and the lower-right quarter as subband 4. Then, the approximation (A) is obtained by inverse transformation of subband 1. For the other three parts (subband 2, 3 and 4), each part is partitioned on nxn blocs who are separately transformed back using the inverse two-dimensional discrete cosine transform (2D – IDCT) and then interlaced to obtain three detail subbands (Dh, Dv and Dd). Finally, we obtain four subbands: the approximation part (A), and the other three parts which are high-pass sub images that represent the details (Dh, Dv and Dd).

The obtained transformed image after decomposition by the subband DCT is similar to the result of single level wavelet transform of an image in term of the obtained subbands. After each level, we have four subbands: the approximation (A), the horizontal detail (Dh), the vertical detail (Dv) and the diagonal detail (Dd).

The explained process can be iterated on approximation subband for multilevel decomposition, and then we obtain a multiresolution representation of the image using the subband discrete cosine transform.

In the proposed hybrid transform, the discrete wavelet transform (DWT) is used after the decomposition by the subband discrete cosine transform. As a result, the last obtained approximation by the subband DCT is then decomposed by the discrete wavelet transform. Finally, we have a multiresolution representation of the input image using the subband DCT and the DWT. The proposed hybrid transform uses two levels of the subband DCT followed by three levels of the DWT for images with 512×512 pixels.

III. SPIHT CODING METHOD

III.1. Brief description

The SPIHT algorithm is a highly refined version of the embedded zerotree wavelet (EZW) algorithm. It was introduced in Said and Pearlman [12]. Some of the best results – highest PSNR values for given compression ratios – for a wide variety of images have been obtained with SPIHT. Consequently, it is probably the most widely used wavelet-based algorithm for image compression [13]-[14], providing a basic standard of comparison for all subsequent algorithms.

The SPIHT algorithm is an efficient method for both lossy and loss-less natural image coding. The principles of the SPIHT algorithm are partial ordering of the transform coefficients by magnitude with a set partitioning sorting algorithm, ordered bit plane transmission and exploitation of self-similarity across different layers. By following these principles, the encoder always transmits the most significant bit to the decoder.

The outline of the full coding algorithm is as follows:

1) Initialization: Set the list of significant points (LSP) as empty. Set the roots of similarity trees in the list of insignificant points (LIP) and the list of the insignificant sets (LIS). Set the threshold $T_0 = 2^n$ with $n = \left\lfloor \log_2 \left(\max \left\{ \left| c_{i,j} \right| \right\} \right) \right\rfloor$.
2) Sorting pass:
   a. In LIP: Each coefficient in the LIP is checked and the significant coefficients are moved to the LSP. The sign bits of the significant coefficients are encoded.
   b. In LIS: If an entry in the LIS is significant, a one is sent and then its two offspring are checked like an entry in the LIP. If an entry in the LIS is insignificant, a zero is sent.
3) Refinement pass: Each old entry of LSP is checked. If it is significant under current threshold, a one is sent and its magnitude reduced by the current threshold. If it is insignificant, a zero is sent.
4) Decrement n by 1 and return to step 2 until the target bit rate is reached.

III.2. Significant pixels adjustment (SPA) technique [11]

The SPIHT decoder performs an additional task to update the reconstructed coefficients. For the value of n when a coordinate is moved to the LSP, it is known that $2^n \le \left| c_{i,j} \right| < 2^{n+1}$. So, the decoder uses that information, plus the sign bit that is input after the insertion in the LSP, to set $\hat{c}_{i,j} = \pm 1.5 \times 2^n$. Similarly, during the refinement pass the decoder adds or subtracts 2^{n-1} to $\hat{c}_{i,j}$ when it inputs the bits of the binary representation of $\left| c_{i,j} \right|$. In this manner the distortion gradually decreases during both the sorting and refinement passes [12]. So, we can say that every reconstructed coefficient is adjusted by the half of the current threshold in order to reduce the distortion.

In the proposed algorithm, we have used prior information of the provided error of the transmitted coefficients for the adjustment process. The estimated error can be used in the decoding algorithm to optimize the difference between the original coefficients and the reconstructed ones, and consequently reduce the distortion measure of the entire image.

During the sorting and refinement passes, the absolute error $\left| e_{i,j} \right|$ of each coefficient is estimated progressively by subtracting the coded value from the exact value. At the end of the coding operation, and when the desired bit rate is reached, we obtain the error $\left| e_{i,j} \right|$ of each coefficient. Then, we use the final list of significant pixels (LSP) and the obtained absolute error *e* for the evaluation of the provided distortion of all the significant pixels which are coded or transmitted. Finally, the estimated error is used in the decoding algorithm with the sign of the reconstructed coefficients to reduce the distortion measure of each reconstructed coefficient.

Thus, after that the absolute error $\left| e_{i,j} \right|$ of each coefficient $c_{i,j}$ is determined, we calculate the mean value of the error of all coded significant coefficients by the following expression:

$$E = \frac{1}{K} \sum_{k=1}^{K} \left| e_{i,j} \right| \qquad (1)$$

where *K* denotes the number of coefficients in the final LSP list, and $e_{i,j}$ is the produced error of the coefficient $c_{i,j}$.

In the decoding algorithm, all the significant reconstructed pixels are adjusted using the predetermined value of the error *E*. Each coefficient in the final LSP list is updated in the end of the algorithm by the following expression:

$$\hat{c}_{i,j} = \hat{c}_{i,j} + sign\left(\hat{c}_{i,j}\right) \times E \qquad (2)$$

The obtained value by Equation (1) is an image dependent value in contrast of the original SPIHT method which uses a fixed value that depends only on the current threshold. This proposed method optimizes the distortion measure for each image according to the provided error during the coding algorithm.

VI. EXPERIMENTAL RESULTS

In this section, we present numerical results obtained by the implementation of the above described algorithm. We have used the *Barbara*, *Fingerprint* and *Texture* images for the evaluation of the proposed algorithm, all of (512×512) pixels. Five levels of decomposition are performed, two levels of the subband DCT and three levels of the wavelet decomposition using the 9/7 bi-orthogonal filters that have proved to offer the best such tradeoff for image compression. The size bloc used for partitioning subbands is 32x32. The symmetric extension on image edges is used. The modified SPIHT method is used without the arithmetic coding stage which can improve the performances but with additional complexity. The distortion is measured by the peak signal-to-noise ratio:

$$PSNR = 10 \log_{10}\left(\frac{255^2}{MSE}\right) \; dB \qquad (3)$$

where *MSE* denotes the mean squared-error between the original and reconstructed images respectively.

For the comparison purpose, all test images are coded at different bit rates (form 0.1 to 0.5 bpp) using the wavelet transform and the proposed hybrid transform. For the wavelet transform, five levels of decomposition are performed using the 9/7 bi-orthogonal filters. The obtained PSNR measures of *Barbara*, *Fingerprint* and *Texture* images are presented in Tables 1, 2 and 3 respectively.

Table 1: PSNR results comparison of the *Barbara* image

Bitrate (bpp)	DWT	Hybrid DCT – DWT [13]	Proposed
0.1	23.94	24,19	**24,88**
0.2	26.19	26,88	**27,16**
0.3	27.91	**28,70**	28,49
0.4	29.53	**30,38**	29,68
0.5	30.80	**31,56**	31,02

Table 2: PSNR results comparison of the *Fingerprint* image

Bitrate (bpp)	DWT	Hybrid DCT – DWT [13]	Proposed
0.1	20,94	**21,29**	**21,29**
0.2	23,65	24,25	**24,35**
0.3	25,53	26,17	**26,40**
0.4	26,86	27,41	**27,57**
0.5	27,98	28,48	**28,67**

Table 3: PSNR results comparison of the *Texture* image

Bit rate (bpp)	DWT	Hybrid DCT – DWT [13]	Proposed
0.1	13,28	13,46	**13,50**
0.2	14,74	15,01	**15,20**
0.3	15,98	16,34	**16,37**
0.4	16,94	17,33	**17,49**
0.5	17,75	18,25	**18,45**

According to the results summarized in the Tables 1, 2 and 3, the important observation which can be drawn is the improvements of the proposed hybrid transform against the wavelet transform.

The proposed hybrid algorithm provides better results for all used bit rates when compared with the wavelet SPIHT coder. In Table 1, we see that the improvements of the hybrid transform SPIHT coder are present only for 0.1 and 0.2 for *Barbara* image but when the rate increase the results in [13] are better. In tables 2 and 3, the proposed hybrid transform provide better results with all tested bitrates with maximum of 0.20 dB of gain in PSNR.

In Figures 1 and 2, the rate – distortion curves of the wavelet SPIHT coding scheme, the hybrid transform in [13] and the proposed transform for *Fingerprint* and *Texture* images are shown respectively.

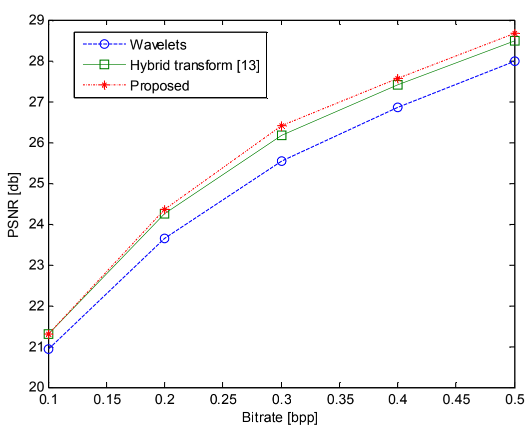


Figure 1: Rate - distortion results of *Fingerprint* image.

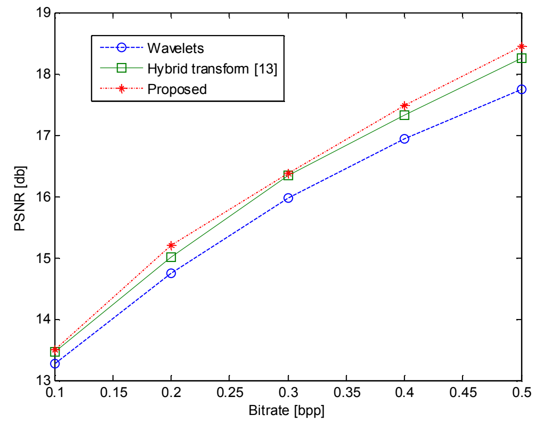
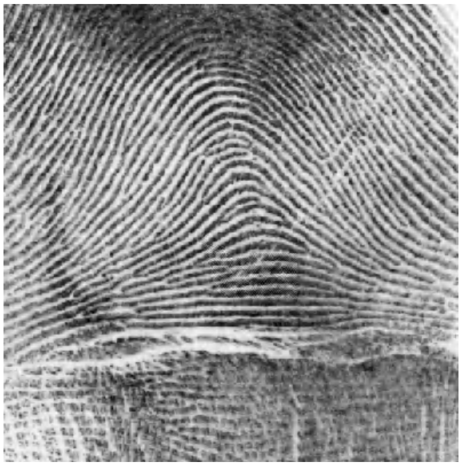


Figure 2: Rate - distortion results of *Texture* image.

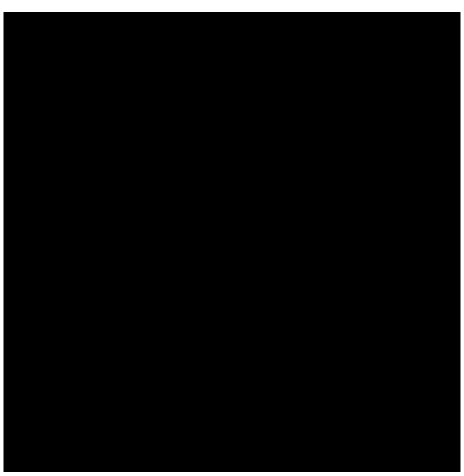
A motivating aspect of image compression algorithms is the subjective quality, where the visual quality of reconstructed images is very significant. To illustrate this feature, we present below some results, where the original and reconstructed images are shown. Figure 3 and 4 show the results of compression/decompression of *Fingerprint* and *Barbara* images respectively. The reconstructed images at 0.2 bpp, which correspond to compression ratio of CR = 40, are visually of accepted quality.



(a)

(b)

Figure 3: Decompression results of *Fingerprint* at 0.2 bpp.



(a)

(b)

Figure 4: Decompression results of *Barbara* at 0.2 bpp.

We note that the proposed hybrid transform uses two well-known transforms that have fast algorithms for implementation and which have been used in many applications.

V. CONCLUSION

In this paper, we have proposed a hybrid transform which uses the bloc-based subband DCT and wavelets for image compression. The subband DCT is firstly applied to decompose the image into multiresolution subbands, where the approximation image is then transformed using the wavelet decomposition. The use of small blocs can reduce the complexity and processing time.

Numerical results obtained by the proposed hybrid method are very competitive. The method gives better results in terms of the PSNR measure and the obtained gains are important in comparison of wavelets. The results can outperform our previously proposed hybrid transform. Moreover, the comparison in terms of the visual quality of the reconstructed images using the DWT and the hybrid DCT – DWT shows the superiority of the proposed method to retain the geometric features.

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