A DCT-Based Embedded Image Coder

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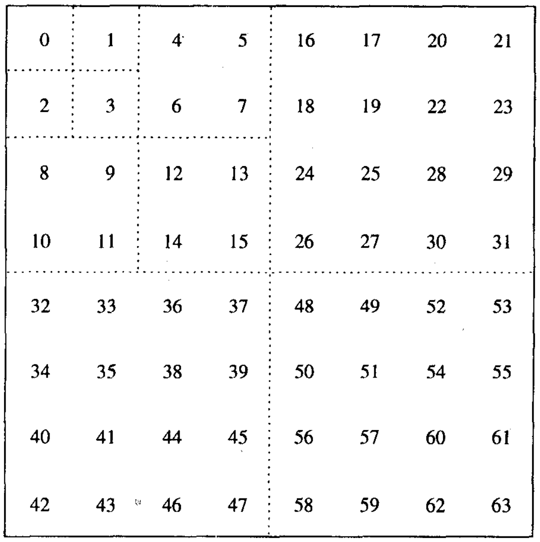
***Abstract*—Since Shapiro published his work on embedded zerotree wavelet (EZW) image coding [1], there have been increased research activities in image coding centered around wavelets. In this letter, we first point out that the wavelet transform is just one member in a family of linear transformations, and the discrete cosine transform (DCT) can also be coupled with an embedded zerotree quantizer. We then present such an image coder that outperforms any other DCT-based coder published in the literature, including that of the Joint Photographers Expert Group (JPEG). Moreover, our DCT-based embedded image coder gives higher peak signal-to-noise ratios (PSNR's) than the quoted results of Shapiro's EZW coder.**

I. INTRODUCTION

TRANSFORM coding has been widely used in many practical image/video compression systems. The basic idea behind using a linear transformation is to make the task of compressing an image in the transform domain after quantization easier than direct coding in the spatial domain. Although the Karhunen–Loeve transform can be found to be optimal under certain conditions, in practice, signal-independent suboptimal approximations like the discrete cosine transform (DCT) are used for computational efficiency.

In recent years, however, most of the research activities in image coding have shifted from the DCT to wavelet transforms, especially after Shapiro introduced his now famous embedded zerotree wavelet (EZW) coder [1].[1] Although wavelets appear to be capable of providing more flexible space-frequency resolution tradeoffs than the DCT, we want to point out that the wavelet transform, like the DCT, is just an element in a set of linear transformations. While the good results obtained by Shapiro's EZW coder are partly attributable to the wavelet transformation, we realize that the DCT can also be coupled with an embedded zerotree quantizer. In fact, in the sections below, we take such an approach and present a DCT-based embedded image coder. Using the customized DCT subroutine in the Joint Photographers Expert Group (JPEG) [2] and the embedded zerotree quantizer described in [3], we build a new image coder that generates an embedded bitstream, from which the decoded images give better peak signal-to-noise ratios (PSNR's) over those from both JPEG and Shapiro's EZW coder. In fact, to the best of our knowledge, our simple coder achieves better performance than any other DCT-based coders published to date in the literature [4]. Finally, an embedded DCT approach was also taken by Li *et al.* [5] for image compression using the quantizer in [6].



0	1	4	5	16	17	20	21
2	3	6	7	18	19	22	23
8	9	12	13	24	25	28	29
10	11	14	15	26	27	30	31
32	33	36	37	48	49	52	53
34	35	38	39	50	51	54	55
40	41	44	45	56	57	60	61
42	43	46	47	58	59	62	63

Fig. 1. An 8 × 8 DCT block can be treated as a depth-3 tree of coefficients.

II. A DCT-BASED EMBEDDED IMAGE CODER

An input image to our new image coder is first divided into 8 × 8 blocks, and each block transformed to the DCT domain. We can treat each 8 × 8 DCT block as a depth-3 tree of coefficients. After labeling the 64 DCT coefficients in each block as in Fig. 1, we identify the parent-children relationships between DCT coefficients as follows: The parent of coefficient i is $\lfloor i/4 \rfloor$ for $1 \leq i \leq 63$, while the set of four children associated with coefficient j is $\{4j, 4j+1, 4j+2, 4j+3\}$ for $1 \leq j \leq 15$. The DC coefficient 0 is the root of the DCT coefficient tree, which has only three children: coefficients 1, 2, and 3.

An embedded zerotree quantizer is then applied to quantize the tree-structured DCT coefficients as was done to the wavelet coefficients in [1]. During zerotree quantization, coefficients with the same index from all DCT blocks are grouped together and scanned, starting from the DC coefficients. That is, we quantize the DC coefficient of all blocks before moving on to the AC coefficients.

Zerotree quantization works by efficiently predicting the children nodes based on the significance/insignificance of their parent. An embedded zerotree quantizer refines each input coefficient sequentially using a bitmap type of coding scheme, and it stops when the size of the encoded bitstream reaches the exact target bit rate. For more details of the embedded zerotree quantizer, the reader is referred to [1].

The tree structure for DCT coefficients defined in Fig. 1 is motivated by the recognition that an 8 × 8 DCT image representation can be viewed as a 64-subband decomposition.

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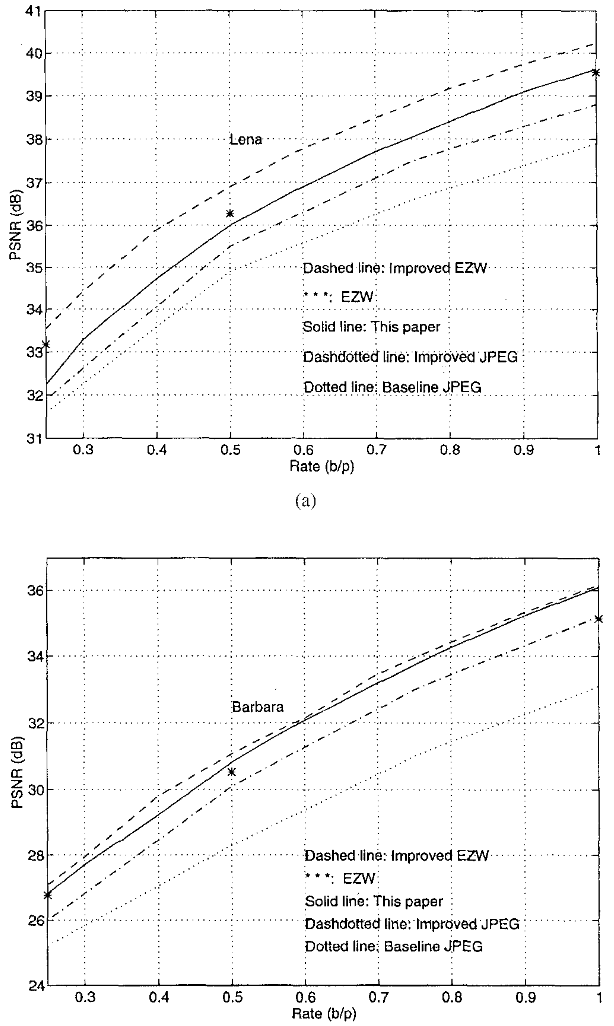
[1] Quadrature mirror filters, instead of wavelet filters, are actually used in Shapiro's work.

TABLE I
PERFORMANCE COMPARISONS OF THE DCT-BASED EMBEDDED IMAGE CODER WITH JPEG AND EZW CODERS

Rate	PSNR (dB)									
	Baseline JPEG		Improved JPEG		EZW		Improved EZW		This paper	
(b/p)	Lena	Barbara	Lena	Barbara	Lena	Barbara	Lena	Barbara	Lena	Barbara
0.25	31.6	25.2	31.9	26.0	33.17	26.77	33.53	27.09	32.25	26.83
0.50	34.9	28.3	35.5	30.1	36.28	30.53	36.90	31.07	36.00	30.82
0.75	36.6	31.0	37.5	33.0			38.86	34.00	38.06	33.70
1.00	37.9	33.1	38.8	35.2	39.55	35.14	40.23	36.17	39.62	36.10



(a)

(b)

Fig. 2. Comparison of operational rate-distortion performance between the new coder and other coders. (a) Lena. (b) Barbara.

The parent-children relationship for the DCT (or 64-subband) decomposition is an extension of that in [1] for wavelet decompositions. We note that other tree structures are also possible. In fact, we have implemented another DCT-based embedded coder using a JPEG-style zigzag scan, in which embedding is achieved by replacing the zerotree root symbol in [1] by the end of block (EOB) symbol. Such a coder gives similar performance as the one presented here. We focus on the current coder because of the availability of the EZW coder [3].

III. EXPERIMENTAL RESULTS

We test our DCT-based embedded image coder on the standard 512 × 512 Lena and Barbara images. In our implementation, we use the customized transform subroutine in JPEG [2] to perform DCT, and the embedded zerotree quantizer in [3] to quantize the DCT coefficients. The quantizer we use is an improved version of the one in [1], which additionally enables the prediction of grandchildren nodes from their grandparent on a DCT coefficient tree.

Coding results for both Lena and Barbara at different rates are listed in Table I. For comparison purposes, we also include in Table I results from baseline JPEG [2], improved JPEG [7], EZW [1], and improved EZW (with a 3-scale wavelet transform) [3]. From Table I we see that our DCT-based embedded coder consistently outperforms the baseline JPEG by a large margin for both images (0.65–3.0 dB). It is also 0.35–0.9 dB better than the improved JPEG in [7], which optimizes JPEG's quantization table. Although our DCT-based coder falls short when compared to the wavelet-based coder in [3], it is capable of giving better performance than Shapiro's EZW coder for Lena at 1 b/pixel, and for Barbara at a wide range of bit rates. Operational rate-distortion performances of different coders are plotted in Fig. 2.

Finally, our proposed DCT-based image coder is also very competitive in terms of computational complexity. For the Lena image at 0.25 b/pixel, our coder finishes encoding in 3.18 s on a SPARC 5 compared with 2.38 s for baseline JPEG.

IV. CONCLUSIONS

This letter presents a low complexity DCT-based embedded image coder that is better than both JPEG and Shapiro's EZW coder. More importantly, we show that, by clever quantizer design, DCT is capable of delivering much better performance than JPEG, just as it is for the wavelet transform.

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