EZW CODING WITH ZERO-TREE TRUNCATION

Cheng-Hsiung Hsieh, Chen-Wei Fu, and Shr-Hwa Chen

Department of Computer Science and Information Engineering
Chaoyang University of Technology
Wufong, Taiwan 41349, ROC
E-mail: chhsieh@cyut.edu.tw

ABSTRACT

In this paper, a simple but effective approach is proposed to improve the coding performance of EZW. It is well known that the dominant pass plays an important role in the EZW. For a given threshold, it classifies the quantized coefficients into four classes: ZTR, IZ, POS, and NEG. For correct decoding, the dominant pass tracks the locations of coefficients by the Z-scan order. Though ZTR symbols provide the location information of coefficients, they, however, contribute nothing to PSNR. Based on the observation, we propose a very simple but effective approach which is termed as the truncated EZW (TEZW). The coding process in TEZW is identical to the EZW except two modifications: (i) truncating the ZTR symbols located in the end of each bit-plane quantization and (ii) including the length of encoded symbols in the dominant pass. Since the truncated ZTR symbols contribute nothing to PSNR, thus there is no PSNR loss in TEZW when compared with the EZW. To justify the TEZW, simulations are performed. When compared with the EZW, simulation results indicate that TEZW is able to reduce bit rate from 0.05 up to 0.1 in the given examples where no lossless coding scheme is applied.

1. INTRODUCTION

In 1993, the EZW image coding scheme is proposed [1]. There are at least two advantages in EZW over the JPEG [2-3]. First, better quality is found in the reconstructed image, especially in cases of low bit rate. Second, the bit stream of coded image is in the order of significance. This property makes the progressive transmission effective between platforms. Up to present, several approaches to improve the EZW coding performance have been proposed. In [4], the approach SPIHT (set partitioning in hierarchical tree) is proposed. By the skillful manipulation of LSP (list of significant pixels), LIP (list of insignificant pixels), and LIS (list of insignificant sets), better coding performance is achieved. In [5-7], the scheme of rate-distortion optimization is put into account in the determination of zerotree and the quantization in wavelet coefficients, where the property of space and frequency localization in the wavelet domain is utilized. In [8], the parent-child relationship in EZW is modified such that one parent may have four up to nine children. Besides, symbols NEG and IZ are, respectively, taken out in the LL band and HL1, LH1, HH1 bands, for saving some more bits in the coding process. In [9], instead of four symbols as used in the EZW, eight symbols are employed in the dominant pass. And the subordinate and refine passes are replaced by a fixed residual value transmission. In [10], two symbols are used in the coding of significance map. The isolated zero coefficients are changed and considered as significant and the location of isolated zero coefficients are recorded. Since only one bit is required to represent these two symbols, better compression performance results. In [11], note that different wavelet transforms are suitable for different type of images. The approach uses two measures, smoothness measure and uniformity measure, to select the best transform among a group of candidate transforms in the coding process.

In this paper, a simple but effective approach is proposed to improve the performance of EZW. This paper is organized as follows: In Section 2, the EZW is briefly reviewed. Then the proposed approach, TEZW (Truncated EZW), is described in Section 3. In Section 4, simulations are provided to justify the proposed TEZW. Finally, conclusion is made in Section 5.

2. REVIEW OF EZW

In this section, the EZW is briefly reviewed. For details, one may consult [1]. Basically, the EZW consists of six stages: (i) wavelet decomposition, (ii) bit-plane quantization, (iii) dominant pass, (iv) subordinate pass, (v) refine pass, and (vi) lossless compression. The coding block diagram of EZW is depicted in Figure 1.

Given input image **O**, the coding process of EZW is described in the following. In Stage (i), 2-D wavelet transform are performed on image **O** to generate different subbands of quadtree structure. Figure 2 shows a three-scale wavelet decomposition where the quadtree structure of parent-child relationship is indicated as well.

In Stage (ii), the bit-plane quantization is applied. For a given threshold T_k, each coefficient $w(i, j)$ is divided into two categories: significant if $w(i, j) \ge T_k$; insignificant otherwise. In Stage (iii), the dominant pass classifies the quantized coefficients into four classes: ZTR (zero-tree root), IZ (isolated zero), POS (positive significant), and NEG (negative significant). The flowchart for the dominant pass is given in Figure 3. Besides, the dominant pass codes the quantized coefficients in the Z-scan order, as shown in Figure 4, for correct decoding. In Stage (iv) and Stage (v), the quantized significant coefficients are refined such that the reconstructed values can be closer to the original ones. Finally, the lossless compression provides further compression.

The example given in [1] is used to demonstrate the EZW coding. Assume that the 8×8 transformed image of three-scale wavelet decomposition is given in Figure 5. The coding result is shown in Table 1 where D_k, S_k, and A_k denote the sequences obtained from the dominant pass, the subordinate pass, and the refine pass, respectively. The subscript *k* denotes the *k*th bit-plane quantization. For the convenience of presentation, symbols ZTR, IZ, POS, NEG are changed to Z, I, P, N, respectively.

3. THE PROPOSED TEZW

Note that the dominant pass plays two roles: (i) to indicate the significant coefficients in the bit-plane quantization and (ii) to correctly track the location of coefficients by the Z-scan order. In the example provided in the previous section, the proposed TEZW coding scheme is motivated by the following two observations. First, as shown in Table 1 there are some contiguous ZTR symbols located in the end of D_k generally. Since ZTR symbol is insignificant and has nothing to do with S_k and A_k, it thus has no contribution to PSNR in the current bit-plane quantization. Second, the purpose of those ZTR symbols is to track the location of coefficients for correct decoding. Based on the observations, the proposed TEZW truncates the contiguous ZTR symbols at the end of D_k to reduce the bit rate. The truncated D_k is denoted as $\overline{D}_k$. Because of the truncation of ZTR symbol, it causes error in the decoding process. To avoid the problem, the length of $\overline{D}_k$, L_k, is put in the beginning of $\overline{D}_k$. The process to convert D_k into $\overline{D}_k$ is depicted in Figure 6. At the decoder, it reads L_k first and then does the decoding process as usual. Except the modifications on D_k and on the decoder, all other coding and decoding processes in the TEZW are identical to those in the EZW. Though the modification is simple, the proposed approach is able to reduce the bit rate without any PSNR loss.

In the previous example, note that, by comparing Tables 1 and 2, ZTR symbols at the end of D_k are truncated except D_4. The total number of ZTR symbols truncated is 22 which are underlined in Table 1. That is, 44 bits are saved in this case. Note that the overhead is 24 bits where 6 bits are required for each bit-plane quantization. Therefore, 20 bits are saved after all even L_4 spends 6 bits for nothing in ZTR truncation. In general, the proposed TEZW uses less bit rate to obtain same PSNR as in the EZW. This will be verified in the following section.

4. SIMULATION RESULTS

In this section, two examples are provided to justify the proposed TEZW coding approach. Moreover, the comparison between the EZW and the TEZW in terms of bit rate are made in the simulation. Two test images are 256×256 Lena and Cameraman. The three-scale Harr wavelet transform is applied to decompose these images. For the convenience of comparison, no lossless compression scheme is used in all simulations. Based on the conditions just described, the simulation results for images Lena and Cameraman are, respectively, listed in Tables 3 and 4 for $1 \le k \le 8$. In Tables 3 and 4, BR_{TEZW} and BR_{TEZW} denote bit rates used in the EZW and in the TEZW, respectively. Besides, $\Delta BR = BR_{EZW} - BR_{TEZW}$. In the calculation of BR_{TEZW}, the number of bits required for L_k has been put into account. In the simulation, it requires 16 bits for each bit-plane quantization. That is, the overhead requires $N \times 16$ bits where N is the total number of bit-plane quantization. In the simulation, $N = 8$.

The simulation results indicate that the proposed TEZW is able to reduce the bit rate, without any loss in PSNR, when compared with the EZW. The amount of bit rate reduction ranges from 0.05 to 0.10 or so. Nevertheless, some interesting observations can be found from Tables 3 and 4. For both images Lena and Cameraman, ΔBR increases slowly as k increases. For cases $k = 1$ and $k = 2$, the bit rate are saved a lot. But for cases with larger k it is not so evident. It implies that much more ZTR symbols are truncated for $k = 1$ and $k = 2$ than other cases. This is reasonable since coefficients in higher scale generally have higher energy than that in the lower scale. Therefore, for a higher threshold more ZTR symbols results at the end of D_k and vice versa.

5. CONCLUSION

In this paper, the truncated EZW (TEZW) is proposed. Note that ZTR symbols in the dominant pass have no contribution in PSNR but provide the location information of coefficients to the decoder. Thus, the ZTR symbols at the end of D_k are truncated in the TEZW and the truncated D_k is denoted as $\overline{D}_k$. For correct decoding, the length of $\overline{D}_k$, L_k, is included in the beginning of $\overline{D}_k$. By this simple modification, the coding performance of the EZW is improved. In the provided examples, the bit rate is reduced by 0.05 up to 0.1 in the TEZW when compared with the EZW.

ACKNOWLEDGMENT

This work is supported by the National Science Council of the Republic of China under grant NSC 94-2213-E-324-031.

REFERENCES

[1] J. M. Shapiro, “Embedded Image Coding Using Zerotrees of Wavelet Coefficients,” *IEEE Trans. on Signal Processing*, Vol. 41, No. 12, pp. 3445-3462, December 1993.

[2] K. R. Rao and J. J. Hwang, *Techniques and Standards for Image, Video, and Audio Coding*, Pretice Hall, 1996.

[3] G.K. Wallace, “The JPEG Still Picture Compression Standard,” Communication ACM, Vol. 34, pp. 30-44, August, 1991.

[4] A. Said and W. A. Pearlman, “A New, Fast, and Efficient Image Codec Based on Set Partitioning in Hierarchical Trees,” *IEEE Trans. on Circuits and System for Video Technology*, Vol. 6, No. 3, pp. 243-250, June 1996.

[5] Z. Xiong, K. Ramchandran, and M. T. Orchard, “Space-Frequency Quantization for Wavelet Image Coding,” *IEEE Trans. on Image Processing*, Vol. 6, No. 5, pp. 677-693, May 1997.

[6] Z. Xiong and X. Wu, “Wavelet Image Coding Using Trellis Coded Space-Frequency Quantization,” *IEEE Signal Processing Letters*, Vol. 6, No. 7, pp. 158-161, July 1999.

[7] K. Yang, H. Kudo, and T. Saito, “Wavelet Image Coding with Context-Based Zerotree Quantization Framework,” *IEICE Trans. on Information and Systems*, Vol. E83-D, No. 2, pp. 211-222, February 2000.

[8] S. Joo, H. Kikuchi, and S. Sasaki, and J. Shin, “Flexible Zerotree Coding of Wavelet Coefficients,” *IEICE Trans. on Fundamentals*, Vol. E82-A, No. 6, pp. 1117-1125, June 1999.

[9] T. Muzaffar and T.-S. Choi, “Simplified Wavelet Based Image Compression Using Fixed Length Residual Value,” *IEICE Trans. on Information and Systems*, Vol. E84-D, No. 12, pp. 1828-1831, December 2001.

[10] T. Muzaffar and T.-S. Choi, “List Based Zerotree Wavelet Image Coding with Two Symbols,” *IEICE Trans. on Information and Systems*, Vol. E87-D, No. 1, pp. 254-257, January 2004.

[11] M. D. Adams and A. Antoniou, ”Reversible EZW-Based Image Compression Using Best-Transform Selection and Selective Partial Embedding,” *IEEE Trans. on Circuit and Systems – Part II: Analog and Digital Processing*, Vol. 47, No. 10, pp. 1119-1122, October 2000.

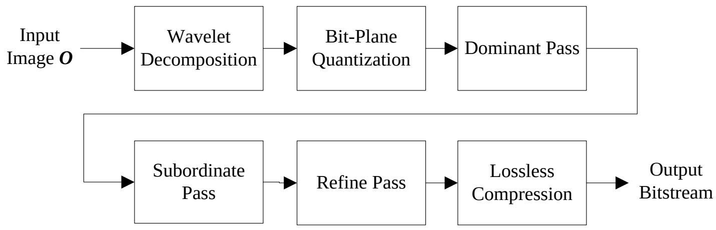

Figure 1. The coding process of EZW

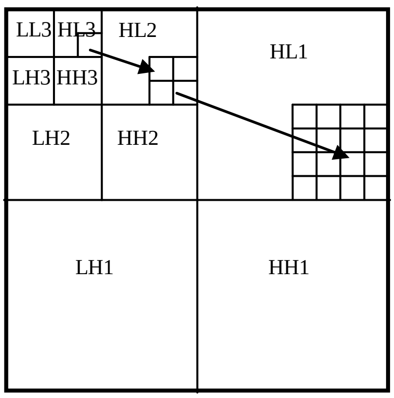

Figure 2. Three-scale wavelet decomposition with parent-child relationship

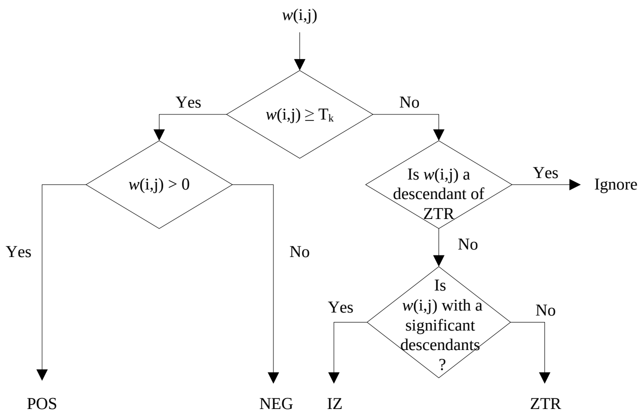

Figure 3. The flowchart of the dominant pass

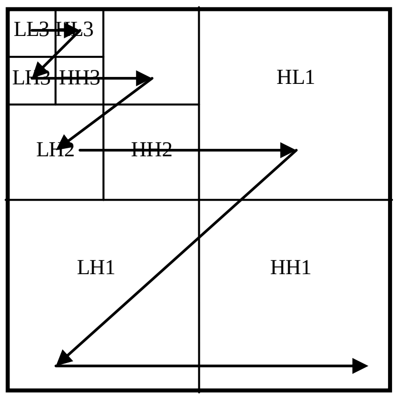

Figure 4. Z-scan order

63	-34	49	10	7	13	-12	7
-31	23	14	-13	3	4	6	-1
15	14	3	-12	5	-7	3	9
-9	-7	-14	8	4	-2	3	2
-5	9	-1	47	4	6	-2	2
3	0	-3	2	3	-2	0	4
2	-3	6	-4	3	6	3	6
5	11	5	6	0	3	-4	4

Figure 5. A three-scale wavelet decomposition example

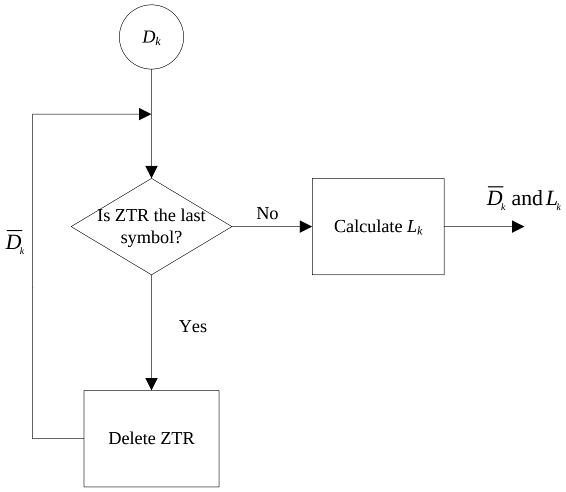

Figure 6. The process to convert D_k into $\overline{D}_k$

Table 1. The EZW coding result for $1 \le k \le 4$

D_1: PNIZPZZZZIZZZZZZZZPZZ
S_1: 1 0 1 0
A_1: ϕ (empty)
D_2: IZNPZZZZZZZZ
S_2: 1 0
A_2: 1 0 0 1
D_3: IIIIIPPNPPNZZNNPZPZZNZZZZZZZZZPZZZPZZZZZZZZZZPZZZZZZZZZZZZ
S_3: 0 1 1 1 1 0 1 1 0 1 1 0 0 0
A_3: 1 0 0 1 1 1
D_4: IIIIIIZIZINIIIIPZZPZPPZPNPZNZZZZZPZPNPPPPZZZZZPZPZZZPNP
S_4: 1 1 0 1 1 0 1 0 0 0 1 0 0 1 0 1 0 1 1 0 0
A_4: 1 1 0 1 1 1 1 1 0 1 1 0 0 1 0 0 0 0 0 1

Table 2. The $\overline{D}_k$ in TEZW for $1 \le k \le 4$

D_1: PNIZPZZZZIZZZZZZZZP
D_2: IZNP
D_3: IIIIIPPNPPNZZNNPZPZZNZZZZZZZZZPZZZPZZZZZZZZZZP
D_4: IIIIIIZIZINIIIIPZZPZPPZPNPZNZZZZZPZPNPPPPZZZZZPZPZZZPNP

Table 3. Comparison results on BR for EZW and TEZW (Lena)

k	Lena			
	BR_{EZW}	BR_{TEZW}	ΔBR	PSNR
1	0.0924	0.0388	0.0537	11.5080
2	0.1726	0.0786	0.0940	21.6212
3	0.2017	0.1073	0.0943	22.6255
4	0.2916	0.1966	0.0950	24.2413
5	0.5204	0.4248	0.0956	26.8419
6	1.0101	0.9126	0.0975	30.4745
7	1.8056	1.7060	0.0996	34.8125
8	3.0381	2.9381	0.1001	39.5352

Table 4. Comparison results on BR for EZW and TEZW (Cameraman)

k	Cameraman			
	BR_{EZW}	BR_{TEZW}	ΔBR	PSNR
1	0.0883	0.0385	0.0498	12.4306
2	0.1480	0.0780	0.0700	18.4779
3	0.2064	0.1332	0.0732	20.5800
4	0.3418	0.2629	0.0788	23.1691
5	0.6101	0.5299	0.0802	26.9474
6	1.0882	1.0078	0.0803	30.9231
7	1.8263	1.7458	0.0804	35.7681
8	2.8050	2.7246	0.0805	40.8952