RATE-DISTORTION OPTIMIZED ZEROTREE IMAGE CODING USING WAVELET TRANSFORMS

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Abstract: *In this paper, we propose a new wavelet-based image coding algorithm that is derived by rate-distortion (R-D) optimization. Since conventional coding schemes using the tree structure have reduced coding performance in terms of rate-distortion theory, we apply an R-D optimized embedding operation into the algorithm of the set partitioning in hierarchical trees (SPIHT). In this paper, we also describe modified set partitioning and R-D optimized list scan methods. Experimental results show improved rate-quality performance of the proposed algorithm over the previous wavelet-based image coding algorithms.*

Key words: *image compression, wavelet transform, rate-distortion theory.*

1. INTRODUCTION

In recent years, the discrete wavelet transforms are widely used to compress still images. While the JPEG standard for still image compression uses DCT, the recently completed JPEG 2000 standard utilizes the discrete wavelet transform [1]. In block-based still image coding methods using DCT, blocking artifacts can occur at low bit rates. However, in full image-based coding schemes using discrete wavelet transform, there are no blocking effects. In addition, scalable coding is possible and performance is comparable to DCT-based coding algorithms.

Various algorithms for still image coding using discrete wavelet transforms have been proposed. For example, Shapiro [2] proposed the embedded zero-tree wavelet (EZW) method to improve coding efficiency using parent-children relationships in each sub-band. Said and Pearlman [3] proposed the set partitioning in hierarchical trees (SPIHT) scheme that enhances the EZW method using the concept of generating and updating each list and set partitioning. Independently with these works, Li and Lei [4] proposed the rate-distortion optimized embedding (RDE) algorithm that optimizes the scan order of wavelet coefficients using estimation of the rate-distortion (R-D) slope of each wavelet coefficient.

Although RDE outperforms SPIHT, complexity has been greatly increased, because RDE scans the whole wavelet coefficients for the number of R-D slope thresholds. On the other hand, SPIHT does not provide an optimal image quality in terms of rate-distortion theory, since SPIHT raster scans the coordinates in each list. In this paper, we propose a new still image compression algorithm where we apply RDE into SPIHT and optimize the scan order of coordinates in each list.

2. THE SPIHT CODING ALGORITHM

In general, wavelet transforms are realized using the quadrature mirror filter (QMF) [5]. We can obtain the sub-band decomposition by applying wavelet transforms iteratively in rows and columns [6]. SPIHT is the representative wavelet-based image coding scheme that uses the structure of sub-band decomposition [3].

SPIHT uses three lists: the list of significant pixels (LSP), the list of insignificant pixels (LIP), and the list of insignificant sets (LIS). In LIS, we have two types of trees, A and B. While Type A considers the significance of descendents, Type B considers the significance of descendents except the children.

After the initialization process, the LIP sorting pass follows. For each coefficient in LIP, the significance of the coefficient and the sign are coded when the coefficient is significant in the current bit plane, and the insignificance of the coefficient is coded when the coefficient is insignificant until the current bit plane. In the LIS sorting pass, existence of significant descendents is coded for each tree. If any significant coefficient exists in the tree, the tree is partitioned and the same process is repeated. In the refinement pass, coefficients that are revealed as being significant until the previous bit plane are refined. Finally, threshold updating is performed. After this process, the whole process is repeated from the LIP sorting pass [3].

3. THE RDE CODING ALGORITHM

In RDE, coefficients that have the maximum R-D slope are coded first. This characteristic can be used for an embedded bit-stream that has an optimal quality at given intermediate bit rates. For this operation, we should define R-D slope threshold values and calculate R-D slopes of all wavelet coefficients. If the R-D slopes are greater than the current R-D slope threshold value, the significance identification coding or the refinement pass coding processes are performed. If the R-D slope is less than the current R-D slope threshold value, that coefficient is skipped and the next coefficient is scanned. After all coefficients with the current R-D slope threshold value are scanned in this way, the R-D slope threshold is reduced by a factor of some value. Then, the above process is repeated [4].

4. RATE-DISTORTION OPTIMIZED ZEROTREE CODING

Wavelet-based image coding algorithms, such as EZW and SPIHT, provide high compression efficiency and have embedded characteristics that are advantageous for progressive image transmission. However, those algorithms do not provide an optimal distortion performance at given bit rates in terms of rate-distortion theory. In this paper, we apply RDE to SPIHT to compensate these problems. The proposed algorithm largely consists of modified set partitioning and R-D optimized list scan.

4.1. Modified Set Partitioning

At the beginning of the LIS sorting pass for Type A entry, we output the significance of descendents. If the output is zero, we proceed to the next entry of LIS. Otherwise, we store that entry as Type B at the end of LIS and add children to LIP. After that, we calculate an expected R-D slope of children. If that value is larger than the current R-D slope threshold, the significance of child is output. Otherwise, the next child is scanned until there is no child to consider. If the child is significant, we encode the sign of that child and put the child into LSP. This algorithm is illustrated in Fig. 1

4.2. R-D Optimized List Scan

We calculate an expected R-D slope using the estimated probability of significance. The probability of significance can be obtained using Bayesian estimation. For efficient implementation of the probability estimation, we use the QM-coder state table. Using the estimated probability, we calculate expected R-D slopes for LIP and LSP [4].

In the LIP sorting pass, the probability of significance is highly affected by a significance of neighboring coefficients. On the other hand, in the refinement pass, the probability of significance is irrelevant to the significance of neighboring coefficients. Therefore, calculations of the expected R-D slopes for two passes are different. In LIP sorting pass, the expected R-D slope can be derived as Equation (2) [4],

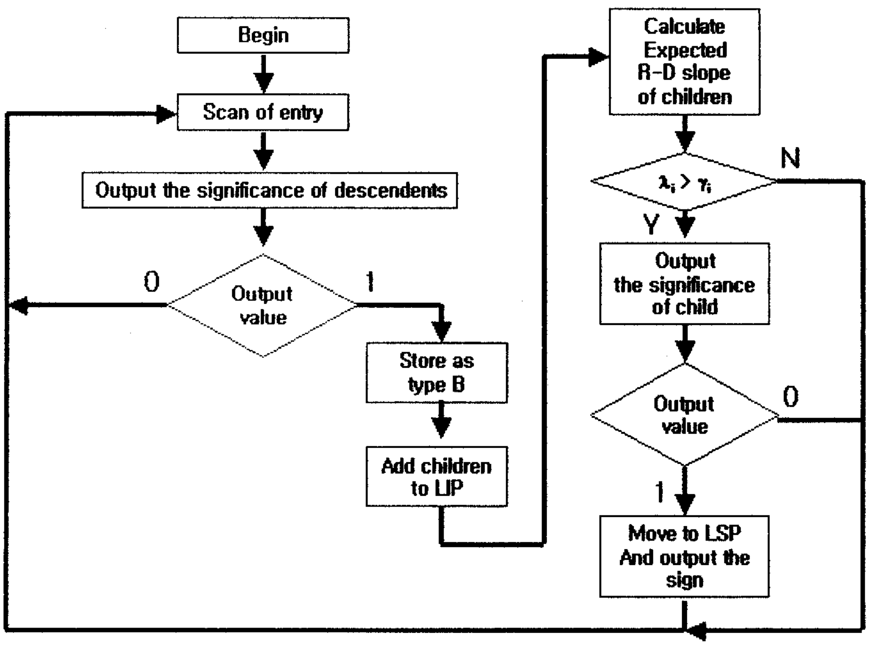

Fig. 1. Modified set partitioning algorithm for type A set

$$\lambda_{i,LIP} = \frac{E[\Delta D_i]}{E[\Delta R_i]} = \frac{2.25T_{n_i}^2}{1+\dfrac{H(p_i)}{p_i}}, \quad (2)$$

where, the entropy of binary symbol, $H(p_i)$ can be defined as Equation (3). When the probability of one is p_i,

$$H(p) = -p\log_2 p - (1-p)\log_2(1-p). \quad (3)$$

The expected R-D slope used in refinement pass can be derived as Equation (4). In contrast to the case of LIP sorting pass, the expected R-D slope used in refinement pass is irrelevant to the significance probability of coefficients [4],

$$\lambda_{i,ref} = \frac{E[\Delta D_i]}{E[\Delta R_i]} = 0.25 T_{n_i}^2 . \tag{4}$$

4.3. Overall Framework of the Proposed Algorithm

In an initialization phase, initial list states are set in the same way as the initialization process of SPIHT. The initial R-D slope threshold value is set. In the LIP sorting pass, coefficients that have larger expected R-D slope than the current R-D slope threshold are coded, while scanning the coefficients in LIP. Coefficients that have less expected R-D slope than the current R-D slope threshold are skipped in the current coding step. In the LIS sorting pass, Type A entries use the modified set-partitioning algorithm and Type B entries use the same set-partitioning algorithm as SPIHT. In the refinement pass, coefficients that have larger expected R-D slope than the current R-D slope threshold are coded. After scanning all the coordinates in three lists, the R-D slope threshold is reduced by a factor of 1.25. Then, the procedure is repeated from the LIP sorting pass.

In SPIHT, coding is based on bit-planes. However, in the R-D optimized zerotree image coding (RDOC) algorithm, the R-D slope threshold is a criterion for coding passes. Therefore, a map indicating the current bit-plane of each coefficient is necessary.

5. EXPERIMENTAL RESULTS

In this section, we provide experimental results and compare them with SPIHT. We use test images such as, Lena, Barbara, and Goldhill. All of test images are of size 512 × 512 pixels and monochrome with 8 bits/pixel.

Table 1 shows PSNR results of SPIHT and proposed algorithm. As shown in Table I, the proposed algorithm outperforms SPIHT at almost all bit rates, in all test images. Since there are infinite bit-planes in wavelet transformed coefficients, the gain still can be observed at high bit rates. Results in this table can be analyzed as follows. At first, in terms of zero-tree coding, if there are more wavelet coefficients in higher frequency sub-bands, we can expect the inefficient coding performance. In terms of probability estimation, if the distribution of coefficients is sparser, it leads to the inefficient estimation of probability. Then, this phenomenon leads to the decreased coding performance.

Table I PSNR performance comparison (dB)

Rate	Lena			Goldhill			Barbara		
	SPIHT(1)	RDOC(2)	(2)-(1)	SPIHT(1)	RDOC(2)	(2)-(1)	SPIHT(1)	RDOC(2)	(2)-(1)
0.125	30.84	31.22	0.38	28.77	29.16	0.39	24.85	25.03	0.18
0.25	33.83	34.21	0.36	30.86	31.37	0.51	27.40	27.86	0.45
0.5	36.91	37.21	0.30	34.05	34.00	-0.05	31.01	31.76	0.75
1.0	39.93	40.35	0.42	37.76	38.04	0.28	36.04	36.74	0.70

6. CONCLUSIONS

In this paper, we have proposed an R-D optimized zerotree image coding algorithm. This algorithm is based on the multi-threshold concept using the R-D slope threshold and the expected R-D slope, and the modified set partitioning algorithm. Experimental results show that performance of the proposed R-D optimized zerotree image coding algorithm is quite competitive and outperforms SPIHT at various bit rates. The R-D optimized zerotree image coding algorithm is more complex than SPIHT, but is less complex than RDE. If wavelet coefficients are densely distributed or have less energy in higher frequency sub-bands, the performance of coder would be better.

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