COMPUTATION REDUCTION TECHNIQUE FOR LOSSY JPEG2000 ENCODING THROUGH EBCOT TIER-2 FEEDBACK PROCESSING

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ABSTRACT

A novel method to reduce computation of JPEG2000 encoding is proposed. The main concept is that most of the computation in the entropy coder (EBCOT Tier-1) of JPEG2000 is a redundancy especially at lower bit-rate, and the proposed method can greatly reduce this redundancy through the feedback of EBCOT Tier-2 processing. By the information generated from Tier-2, computing time of EBCOT Tier-1 at irreversible wavelet transform mode (9-7 filter) can be reduced to about 40% and 20% at general and high compression rate, respectively. And there is even more reduction at reversible wavelet transform mode (5-3 filter).

1. INTRODUCTION

JPEG2000 is the next-generation image compression standard. It is well-known as its better compression performance compared with traditional JPEG standard especially at high compression rate [1]. However, the computational complexity of JPEG2000 is much higher than that of JPEG. The bottleneck of JPEG2000 is the entropy coding module, say, EBCOT [2], since the operations in it are bit-level processing. This kind of processing is difficult to operate optimally on general purpose processors (GPPs) and digital signal processors (DSPs) since they are byte-level computing systems. Therefore, EBCOT Tier-1 contains a larger portion of computation than other modules of JPEG2000 encoder, profiled at the rate of about 45% to 60% [3][4]. Reducing its computation can highly reduce the total processing time of the whole system.

On the other hand, almost all the lossy image compression techniques, including traditional JPEG, use quantization scheme to perform compression rate control. However, this scheme cannot ensure the best quality at a specific bit-rate and provide accurate bit-rate estimation in just one pass. Besides quantization, JPEG2000 provides a better scheme to perform rate control in EBCOT Tier-2 processing. It uses the algorithm of rate-distortion optimization to precisely control the compressed file size and guarantees the PSNR performance at this file size is nearly optimal. However, the processing of EBCOT Tier-1 at low bit-rate cannot be finished until all the transformed coefficients are coded even though many compressed elements will be discarded through Tier-2 processing. In this paper, a technique for computation reduction of JPEG2000 entropy coder is proposed. The computation in EBCOT Tier-1 is greatly reduced as the compression rate increases.

This paper is organized as follows. In Section 2, the algorithm of rate-distortion optimization is introduced. Section 3 describes the proposed computation reduction method through EBCOT Tier-2, and the simulation results are presented in Section 4. Finally, a conclusion is given in Section 5.

2. RATE-DISTORTION OPTIMIZATION ALGORITHM OVERVIEW

The framework of JPEG2000 encoder is arranged as follows, Discrete Wavelet Transform (DWT), followed by quantization, and then EBCOT block coding. In general, quantization is not used for rate control in JPEG2000 encoder. Instead, it is applied to adjust the weights of each different frequency sub-band based on the filter banks and decomposition levels of DWT, and the quantization step is set to 1, meaning no quantization, at reversible wavelet transform mode. After DWT and quantization, the coefficients are partitioned into non-overlapped code-blocks, which are the coding units for EBCOT. EBCOT, abbreviated from Embedded Block Coding with Optimized Truncation, is divided into two parts as Tier-1 and Tier-2 coding. As implied by the name, Tier-1 utilizes context-based arithmetic coding to encode each code-block into independent embedded bit-stream. Tier-2 takes the responsibilities of optimized rate control and code stream forming, which is actually an encoder issue.

In detail, the output of Tier-1 for each code-block is an independent compressed sub-bit-stream. The sub-bit-stream of a code-block is composed of several passes, which represent the bit data of each bit-plane from higher to lower in the code-block. Furthermore, every pass of a code-block is a possible truncation point. That is, at a

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given bit-rate, one can set a truncation point for each code-block, and discard all the passes behind them. The algorithm to decide the truncation point optimally is based on the rate-distortion criterion. That is, in order to minimize the total distortion at a target bit-rate, the problem is equivalent to use Lagrange operators and minimize the following equation [5],

$$\sum_i (R_i^{n_i} - \lambda D_i^{n_i}) \tag{1}$$

where $R_i^{n_i}$ and $D_i^{n_i}$ represent the number of the code bytes and distortion (denoted by Mean Squared Error, MSE) of the i-th code-block beyond the truncation point n_i, respectively. Based on the method recommended by JPEG2000 standard to solve this problem, we can calculate the rate-distortion slope values of all the passes for each code-block by the following equation,

$$S_i^k = \Delta D_i^k / \Delta R_i^k \tag{2}$$

where ΔD_i^k and ΔR_i^k mean respectively the decrease of MSE and the increase of the number of code bytes between the k-th and (k-1)-th truncation point for the ith code-block. With the increase of k, the truncation point will be from the most significant bit-plane to the least significant bit-plane. Therefore, the slope values have a natural trend to decrease monotonically since the value of the delta-distortion becomes smaller. If there are some values of these slopes that do not follow the rule, we should merge these slopes. That is, we should delete this kind of truncation points to avoid some slopes with the property of $S_i^k > S_i^{k-1}$ for $k-1 \neq 0$. Then for a given bit-rate R_T, we can iterate a few cycles to find the maximal threshold value λ^{-1} satisfying $S_i^{n_i} > \lambda^{-1}$ for all code-blocks and $\sum_i R_i^{n_i} \le R_T$. Afterwards, the optimized set of truncation points n_i is found for the best quality of the compressed image at this given bit-rate.

3. COMPUTATION REDUCTION TECHNIQUE

Examining the method introduced above, we can find that S_i^k can be calculated just after Tier-1 finishes the coding at the k-th truncation point since both ΔD_i^k and ΔR_i^k are available. However, the iteration for finding the optimized set of truncation points cannot be launched until all the code-blocks are completely encoded. When the required bit-rate is low, therefore, a large portion of Tier-1 encoding efforts will become useless after the optimized truncation. If we make some prediction for the threshold value based on the wavelet transform, the PSNR performance may significantly decrease because the model of the wavelet coefficients is not always accurate for various images. Several reports make some theoretical prediction [6]-[8], but the performance compared with the optimized rate-distortion algorithm may differ from images to images, not consistently guaranteeing the similar quality to the optimized algorithm.

We change the entire thought for finding the threshold value of slope to truncate each bit-stream of code-blocks. Actually, the proposed method need not find the threshold value in advance. Before introducing the method, we observe two properties for these slopes first. One is the monotonically decreasing property for the value of slopes in a code-block. The other is that all values of the slopes of the included passes are higher than the threshold value after the set of optimized truncation points is obtained. Based on these properties, we can apply the following processes, called "Minimal Slope Discarding" method, to perform rate-distortion optimization,

1. After a pass is coded by Tier-1, get the ΔD_i^k and ΔR_i^k of this pass to calculate S_i^k, do the monotonically decreasing processing at this pass, and accumulate the additional number of bytes. If the accumulated number of the total bytes exceeds the target bit-rate, go to step 2. Else continue the Tier-1 coding process.

2. Find the minimal value slope among the coded code-blocks. Note that we only need to check the last pass (truncation point) for each coded code-blócks because of the monotonically decreasing property. And then discard the pass with this minimal slope. That is, move the desired truncation point in that code-block one step to decrease the total accumulated bit-rate. Afterwards, There are two conditions needed to be checked,

   (1) If the accumulated bit-rate is still larger than target one, do step 2 again. Else check the condition of step (2).

   (2) If the code-block with the pass of the minimal slope is the current coding one, break out Tier-1 coding for this code-block and start for next one. Else continue Tier-1 process without breaking.

When all the code-blocks complete the Tier-1 processing with the above method, the rate-distortion optimization scheme is finished at the same time, since all the truncation points have already been determined. The computation reduction is performed by the condition of step (2) for breaking in the middle of the processing of code-blocks. Being assured to break out at that condition is because we expect that the values of slopes under the current truncation point are all smaller than included ones for the decreasing property from higher bit-planes to lower bit-planes. Although there exists some exceptions,

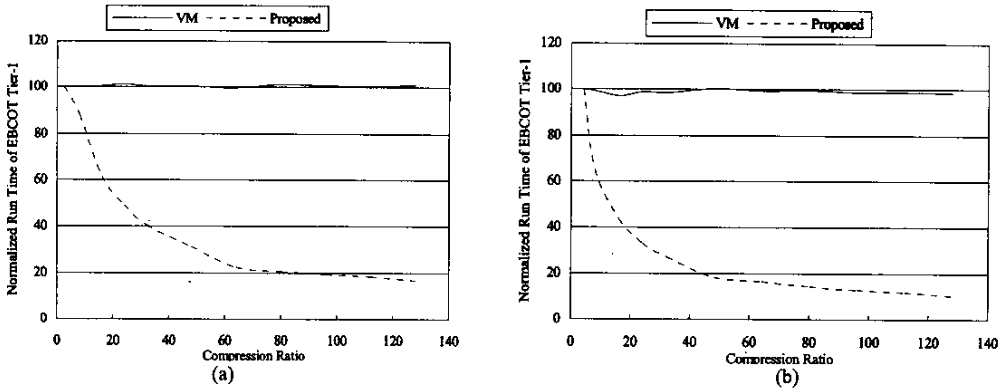


Fig. 1. Normalized run time of EBCOT Tier-1. (a) is for irreversible wavelet transform (9-7 filter), and (b) is for reversible one (5-3 filter). (Test image: Lena 512×512. 1 tile, 1 layer, 5 decomposition levels)

the influence for PSNR performance is quite small according to the simulation results that will be presented later. Hence, in this code-block, those following passes, whose values of slope are under the current minimal slope, are not possible to become the candidate when the current accumulated number of bytes is beyond the given bit-rate. The computation of Tier-1 is therefore reduced significantly especially under low bit-rate compression, and the Tier-2 process almost pays no overheads in the proposed method since Tier-2 holds little percentage of the whole compression process. Moreover, the proposed method can also reduce the computation of rate-distortion slopes because it is unnecessary to compute the slopes of those passes without coding.

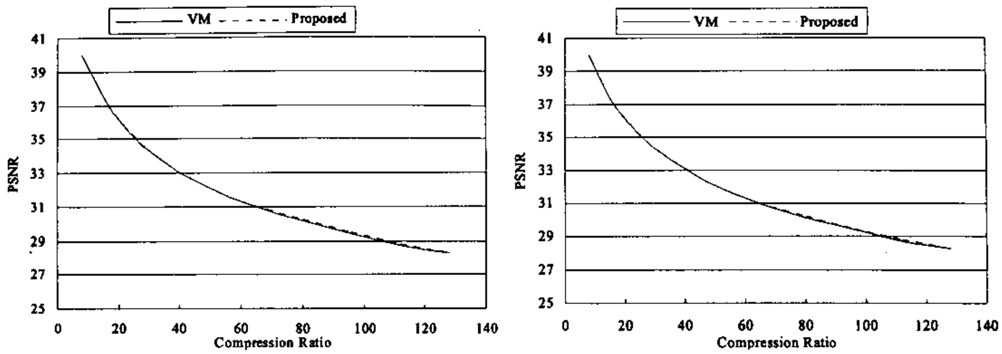
4. EXPERIMENTAL RESULTS

The "Minimal Slope Discarding" method is simulated by C program and compared with JPEG2000 Verification Model (VM) 7.2. The normalized run time of EBCOT Tier-1 is shown in Fig. 1. We can find the proposed method reduces considerable computation since a large part of unnecessary processes is skipped. Furthermore, the reduction is more efficient at reversible wavelet transform mode because the redundant passes for this mode are more than those for irreversible one at the same target bit-rate. More simulations are tabulated in Table 1 using the number of contexts processed in Tier-1 to represent computation complexity since it is more accurate to obtain and highly correlated to the run time

The PSNR performance is shown in Fig. 2 and detailed in Table 2. For these four test images, PSNR difference between the proposed method and VM is no worse than 0.06 dB at the same bit-rate. As mentioned before, the negligible decreasing is because monotonically decreasing value of slopes for a code-block is not guaranteed unless all the passes of this code-block are completely encoded. However, the influence is slight based on the simulation results because of the natural decreasing property for slopes for a code-block. On the contrary, the PSNR of our proposed method is often somewhat higher than VM. The reason is that, the VM method (standard recommended) is just able to get the passes with the value of slope greater than the threshold value. Instead, since the "Minimal Slope Discarding" method is exploited, we can contain a little more passes whose values of slope are not larger than the threshold value but fit the constraint of $\sum_i R_i^{n_i} \le R_T$.

5. CONCLUSIONS

An efficient methodology of rate-distortion optimized truncation in JPEG2000 EBCOT Tier-2 is utilized to greatly reduce the computation of EBCOT Tier-1 encoder processing. The key idea is from the fact that a large portion of the computation in Tier-1 is a redundancy at low bit-rate. It can be reduced through the feedback control from Tier-2 to eliminate unnecessary processing. Simulation shows an appreciated result for reducing computation almost without paying any overhead or PSNR cost. As for other works of Tier-2 such as layer formation for resolution scalability, the proposed method can still be exploited for rate control to all the code-blocks first, and then process the layer formation by the original method. To sum up, "Minimal Slope Discarding" method contributes to higher speed and lower power on both software and hardware issue, and the compression performance remains comparable to the JPEG2000 original method.



(a) (b)

Fig. 2. PSNR comparison at different compression ratio. (a) is for irreversible wavelet transform (9-7 filter), and (b) is for reversible one (5-3 filter). (Test image: Lena 512×512. 1 tile, 1 layer, 5 decomposition levels)

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Table 1. The number of contexts of EBCOT Tier-1 and its percentage. (a) is for irreversible wavelet transform (9-7 filter), and (b) is for reversible one (5-3 filter). (Test image: 512×512. 1 tile, 1 layer, 5 decomposition levels)

(a)

Test Image	lena		pepper		jet		baboon	
Compression Ratio	Number of Coded Contexts	Percentage (%)	Number of Coded Contexts	Percentage (%)	Number of Coded Contexts	Percentage (%)	Number of Coded Contexts	Percentage (%)
All coded	919,450	**100.00**	1,060,137	**100.00**	1,419,280	**100.00**	1,419,280	**100.00**
8	785,192	**85.40**	901,543	**85.04**	847,744	**86.51**	847,744	**59.73**
16	526,486	**57.26**	590,413	**55.69**	537,615	**59.85**	537,615	**37.88**
32	324,467	**35.29**	339,186	**31.99**	325,136	**41.26**	325,136	**22.91**
64	176,478	**19.19**	200,858	**18.95**	218,527	**25.17**	218,527	**15.40**
128	126,473	**13.76**	145,834	**13.76**	164,658	**16.96**	164,658	**11.60**

(b)

Test Image	lena		pepper		jet		baboon	
Compression Ratio	Number of Coded Contexts	Percentage (%)	Number of Coded Contexts	Percentage (%)	Number of Coded Contexts	Percentage (%)	Number of Coded Contexts	Percentage (%)
All coded	1,310,455	**100.00**	1,420,287	**100.00**	1,276,785	**100.00**	1,716,006	**100.00**
8	836,612	**63.84**	957,881	**67.44**	824,168	**64.55**	852,157	**49.66**
16	529,189	**40.38**	623,276	**43.88**	533,517	**41.79**	520,452	**30.33**
32	314,736	**24.02**	346,938	**24.43**	345,303	**27.04**	352,033	**20.51**
64	183,285	**13.99**	200,782	**14.14**	204,662	**16.03**	202,983	**11.83**
128	118,852	**9.07**	133,033	**9.37**	147,564	**11.56**	151,356	**8.82**

Table 2. PSNR comparison at different compression ratio. (Diff = $PSNR_{Proposed} - PSNR_{VM}$) (a) is for irreversible wavelet transform (9-7 filter), and (b) is for reversible one (5-3 filter). (Test image: 512×512. 1 tile, 1 layer, 5 decomposition levels)

(a)

Test Image	lena			pepper			jet			baboon		
Compression Ratio	VM	Proposed	Diff	VM	Proposed	Diff	VM	Proposed	Diff	VM	Proposed	Diff
8	41.174	41.175	0.001	38.958	38.958	0.000	42.203	42.203	0.000	29.899	29.900	0.000
16	37.957	37.990	0.033	36.574	36.574	0.000	37.501	37.536	0.035	26.329	26.349	0.020
32	34.829	34.845	0.016	34.282	34.263	**-0.019**	33.447	33.455	0.009	23.906	23.906	0.000
64	31.596	31.714	0.118	31.550	31.564	0.015	30.006	30.012	0.006	22.384	22.397	0.013
128	28.823	28.823	0.000	28.403	28.409	0.007	26.746	26.729	**-0.018**	21.394	21.411	0.017

(b)

Test Image	lena			pepper			jet			baboon		
Compression Ratio	VM	Proposed	Diff	VM	Proposed	Diff	VM	Proposed	Diff	VM	Proposed	Diff
8	40.002	40.022	0.020	38.268	38.268	0.000	40.958	40.958	0.000	29.347	29.369	0.022
16	37.112	37.114	0.002	36.015	36.027	0.012	36.819	36.781	**-0.038**	25.824	25.854	0.031
32	34.025	34.041	0.016	33.828	33.828	0.000	32.929	32.942	0.013	23.488	23.516	0.028
64	31.038	31.043	0.004	31.027	31.070	0.043	29.528	29.474	**-0.053**	22.052	22.058	0.005
128	28.292	28.304	0.012	28.090	28.095	0.005	26.517	26.496	**-0.020**	21.178	21.179	0.000