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Study of EBCOT in Group-of-Column Skipping in Two Scans

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Abstract

In Motion JPEG2000, embedded block coding with optimal (EBCOT) consists of Tier 1 and Tier 2 coding. In Tier 1, every bit-plane is scanned three times and coded in three channels. This means a long operation time, which may account for over 50% of total time of EBCOT. To reduce the time of compression and coding of JPEG2000, it is necessary to study the mechanism of Tier 1 coding, especially in the three-channel scanning mode. It has been found that validity flag $\sigma_i[\mathbf{j}]$ *is the first to be determined in the first and the second scan. If the validity flag is 1, then magnitude refinement (MR) coding is done; if it is 0, we need to determine whether the coding in validity channel is to be done. However, we propose the feasibility of combining the two codings together and perform scanning once. Then we only have to determine whether the coding is to be done for the pixels in the validity channel or in the MR channel. During the first scan, the value of validity flag* $\sigma_i[j]$ *will be determined only once, thus reducing the number of judgments. Therefore, the proposed process of EBCOT consists of 2 scans and coding in 3 channels. This reduces the number of judgment and scans and saves the time.*

Keywords*: Motion JPEG2000, embedded block coding with optimal (EBCOT), region of interest, rate-distortion optimal coding*

1. Introduction

EBCOT (embedded block coding with optimal) is the core algorithm and the major module for the coding of JPEG2000, consisting of Tier 1 and Tier 2 coding. Tier 1 coding comprises 3 scans of bit-plane and coding in three channels, namely, validity channel, MR channel and clearing channel. Tier 2 coding is intended for optimized truncation and organization and packing of bit-stream so as to conform to the format of JPEG2000. Generally the run time of EBCOT accounts for about one half of total coding time of JPEG2000, and the Tier 1 scanning in three channels consumes the most time. To reduce the time of scalable compression and coding for JPEG2000, we study the mechanism of Tier 1 coding in three channels in EBCOT.

2. Coding Algorithm of EBCOT

Tier 1 coding in EBCOT algorithm is to perform embedded coding for each code block so as to obtain the embedded bit-stream. This consists of two steps, which are context formation (CF) and arithmetic encoded (AE). The schematic of Tier 1 coding is shown in Figure 1.

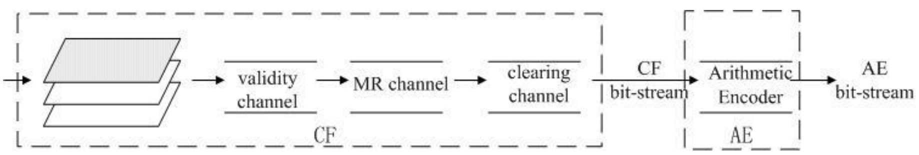

Figure 1. Schematic of Embedded Coding

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The source image is subjected to wavelet transform and quantization and decomposed into subblocks (64×64 or 32×32). In Tier 1 coding for each subblock, quantile plane coding is performed in the sequence from the most significant bit (MSB) plane containing at least 1 non-zero element to the least significant bit (LSB) plane.

1) Quantile plane coding

Suppose k is the bit value of any quantization indexing, *i.e.*, $v^{(k)}[\mathbf{j}]=0,\forall\mathbf{j}$. Each code block has different k value, and these k values are correlated with each other. To eliminate the correlation, coding is performed by using tag-tree coding. Coding starts from the MSB plane $v^{k-1}[\mathbf{j}]$, and all sample values are classified according to certain rule for coding in three channels. This is called quantile plane coding. The binary signs obtained from each sample value are submitted to the AE along with certain context information. After the first bit-plane is coded, the second bit-plane $v^{k-2}[\mathbf{j}]$ is coded in the same way. This process is repeated until that last bit-plane is coded, thus forming the bit-stream for this code block.

(2) Coding modes

The coding channel has four operations: zero-path coding (ZC), run-length coding (RLC), sign coding (SC) and magnitude refinement (MR) coding. They constitute the basis of EBCOT. Here the validity flag $\sigma_i[\mathbf{j}]$ of sample value is introduced, which can be calculated on the bit-plane p:

$$\sigma_i[\mathbf{j}]=\begin{cases}1 & if\ \ v_i[\mathbf{j}]\geq 2^{p+1}\\ 0 & if\ \ v_i[\mathbf{j}]<2^{p+1}\end{cases}$$

If the sample value is still invalid, *i.e.*, $\sigma_i[\mathbf{j}]=0$, then this sample value is coded by ZC and RLC at the same time. The validity of this sample value on the current plane is evaluated again. If it is valid, then SC is used to code the sign bit $s_i[\mathbf{j}]$. If the sample value is already valid, MR is used to code the sample value $v^{(p)}[\mathbf{j}]$.

AE incorporates 18 different context models: 9 models for ZC, 1 for RLC, 5 for SC and 3 for MR.

a. ZC

ZC is to code the bit value $v^{(p)}[\mathbf{j}]$ on the bit-plane p for sample value with magnitude $v_i[\mathbf{j}]<2^{p+1}$. The sample value displays Markov property in statistical term, which means that the validity of the sample value only depends on the validity of 8 adjacent sample values. The validity features of the 8 adjacent sample values fall into the following 3 categories:

In horizontal direction: $h_i[\mathbf{j}]=\sum_{z\in\{-1,1\}}\sigma_i[j_1+z,j_2]$, obviously $0\leq h_i[\mathbf{j}]\leq 2$;

In vertical direction: $v_i[\mathbf{j}]=\sum_{z\in\{-1,1\}}\sigma_i[j_1,j_2+z]$, similarly $0\leq v_i[\mathbf{j}]\leq 2$;

In diagonal direction $d_i[\mathbf{j}]=\sum_{z_1,z_2\in\{-1,1\}}\sigma_i[j_1+z_1,j_2+z_2]$, similarly $0\leq d_i[\mathbf{j}]\leq 4$.

Adjacent values falling outside the code block are considered invalid, and thus the code blocks are truly independent from each other. To reduce the cost and the realization complexity of self-adaptivity of the model, 256 possible features of adjacent blocks are classified into 9 contexts, as shown in Table 5.1. Before coding, the code blocks in HL subbands are transposed, so the same context distribution also applies to HL and LH subbands.

Table 1. Distribution of 9 Zero-Code Contexts

LL,LH and HL bands				HH band		
$h_i[\mathbf{j}]$	$v_i[\mathbf{j}]$	$d_i[\mathbf{j}]$	Label	$h_i[\mathbf{j}]+v_i[\mathbf{j}]$	$d_i[\mathbf{j}]$	Label
0	0	0	0	0	0	0
0	0	1	1	1	0	1
0	0	>1	2	>1	0	2
0	1	x	3	0	1	3
0	2	x	4	1	1	4
1	0	0	5	>1	1	5
1	0	>0	6	0	2	6
1	>0	x	7	>0	2	7
2	x	x	8	x	>2	8

In the table, x represents any value within the value range.

b. RLC

As many sample values are invalid most of the time, RLC is introduced to eliminate the redundancy. Multiple valid sample values are coded using a binary sign. But this will not improve the compression performance significantly; rather it only reduces the number of signs to be processed by AE so as to reduce complexity.

RLC can replace ZC if the following conditions are met: ① four continuous sample values are invalid, *i.e.*, $\sigma_i[j_1+z, j_2]=0, 0\le z\le 3$; ② the adjacent values of these sample values are invalid, *i.e.*, $v_i[j_1+z, j_2]=d_i[j_1+z, j_2]=0$; ③ the four pixels must belong to the same subblock; ④ the horizontal index of the first pixel must be an even number.

At this time, a simple sign is used to denote whether any sample value in this group is valid on the current plane. The distribution of the sign is thus modeled based on context. If certain sample values turn valid, then the first valid sample value is coded using 2 bits. It is generally considered that the probability of any one of the four sample values turning valid is very small. If at least one sample value is valid, it means the conditional distribution of run length $z\in\{0,1,2,3\}$ is approximately uniform.

c. SC

SC is performed only once for each sample value after certain sample value turns valid after ZC or RLC once. The probability that the signs of the two horizontally adjacent sample values in HL subbands are contrary is quite large, and the probability that the signs of the two vertically adjacent sample values in HL subbands are the same is also large. This situation applies to other subbands as well. Such statistical correlation can be used to reduce the redundancy between data. The four adjacent values have 3 states, namely, invalid, positive and positive. Therefore, there will be 3^4=81 context statuses. But if the horizontal and vertical symmetry is considered, only 5 context models are left, as shown in Table 2.

Table 2. Distribution of Context in Coding with 5 Signs

$\bar{h}_i[\mathbf{j}]$	$\bar{v}_i[\mathbf{j}]$	$\hat{x}_i[\mathbf{j}]$	Label
1	1	1	4
1	0	1	3
1	-1	1	2
0	1	-1	1
0	0	1	0
0	-1	1	1
-1	1	-1	2
-1	0	-1	3
-1	-1	-1	4

d. MR

MR is only performed for significant sample value $v^{(p)}[\mathbf{j}]$ on bit-plane p (*i.e.*, $v_i[\mathbf{j}] \geq 2^{p+1}$). Since this value has very weak correlation with the values and their adjacent values in the previous coded bit-plane, only 3 contexts are used. Specifically, if $\sigma_i[\mathbf{j}] = h_i[\mathbf{j}] = v_i[\mathbf{j}] = 0$, then the first context is used; if $\sigma_i[\mathbf{j}] = 0$ and $h_i[\mathbf{j}] + v_i[\mathbf{j}] \neq 0$, then the second context is used; if $\sigma_i[\mathbf{j}] = 1$, then the third context is used.

(2) Quantile plane scan and coding

To obtain a better embedded bit-stream, EBCOT performs bit-plane coding in three channels: validity channel, MR channel and clearing channel. This is the quantile plane coding.

For a code block, coding is first performed for the MSB plane. This bit-plane only satisfies the conditions for doing coding in the clearing channel. Therefore, coding is only performed in the clearing channel. For the subsequent bit-planes, coding is performed in all three channels. Here we only expound on the coding of MSB plane, as shown in Figure 2.

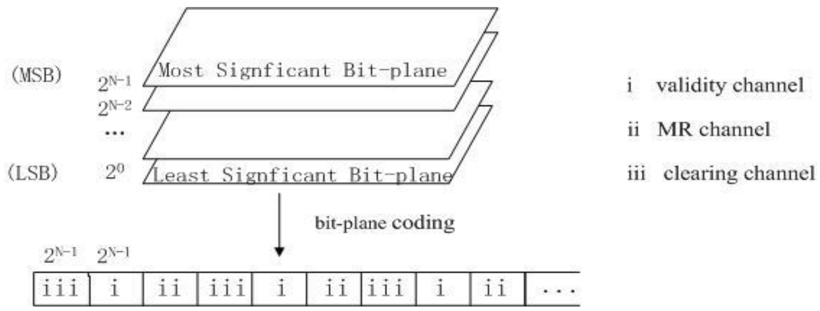


Figure 2. Channels of Quantile Plane Coding

For each bit-plane, the scan starts from the left upper corner, with 4 coefficients constituting a column, until all coefficients are scanned. The context of each coefficient is composed of 8 coefficients adjacent to it. The scan mode and context formation are illustrated in Figure 3.

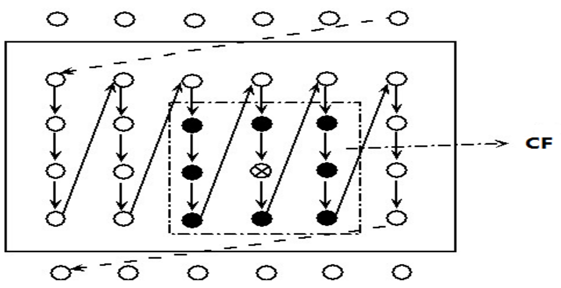


Figure 3. Scan and Coding

a. The first scan is the process of implementing validity transmission channel $\left(P_1^p\right)$.

Each pixel is scanned and coded as follows:

(1) Determine whether the validity flag $\sigma_i[\mathbf{j}]$ is 0; if yes, move to step (2); if it is 1, scan the next pixel;

(2) Determine whether $v^{(k)}[\mathbf{j}]$ is 0; if yes, move to step (3); if it is 1, move to step (4);

(3) Perform ZC and see whether the sample value turns valid on the current plane; if yes, move to step (4); if no, scan the next pixel.

(4) Set the validity flag as 1 and perform SC for the sign bit. After coding, scan the next pixel.

(5) The above process is repeated for subsequent pixels, until all pixels are scanned.

b. The second scan is the process of implementing MR channel $\left(P_2^p\right)$.

Each pixel is scanned and coded as follows:

(1) Determine whether $\sigma_i[\mathbf{j}]$ is 1. If yes, move to step (2); if it is 0, scan the nex pixel.

(2) Perform MR for this pixel. After the coding is finished, scan the next pixel.

(3) Repeat this process for subsequent pixels until all pixels are scanned.

c. The third scan is the process of implementing clearing channel $\left(P_3^p\right)$.

For the clearing channel, ZC is used to process the sample values that are not processed by the other two channels. If the conditions for RLC are met, then ZC is replaced by RLC.

The relations between the three channels are shown in Figure 4.

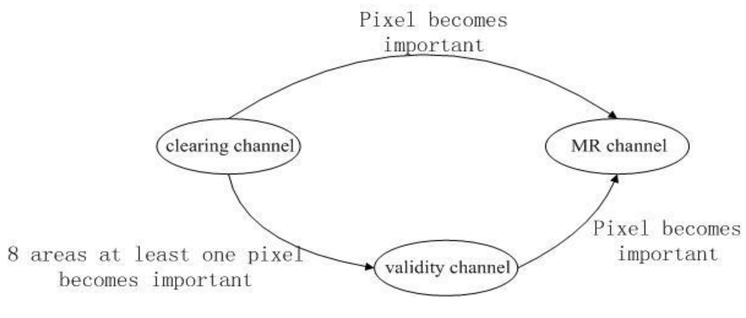


Figure 4. Relations Between the Three Channels in EBCOT

3. Question Description

As shown in the above analysis on Tier 1 coding, it is first determined whether certain conditions are met before each step of scanning and coding. Then the appropriate channels are selected for the coding. The scan has to be done three times, which is time-consuming.

Table 3 provides the time consumed for each step for the coding of bmp image of Figure 5 using JPEG2000 coding process. The size of the bmp image is 352×288, and the code block is 64×64 after 4-level 5/3 wavelet transform.

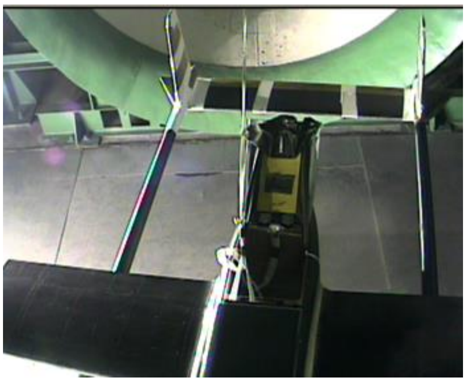


Figure 5. Raw Image for the Coding

Table 3. Run Time of Each Step of JPEG2000 Coding

		Total time	Wavelet transform	EBCOT	
				Tier1	Tier2
r=0.1 (bpp)	Time (s)	1.051	0.120	0.611	0.11
	Percentage of total time (%)		11.42	58.14	10.47
r=0.5 (bpp)	Time (s)	1.121	0.100	0.591	0.22
	Percentage of total time (%)		8.92	52.72	19.63
r＝5 (bpp)	Time (s)	1.151	0.130	0.591	0.24
	Percentage of total time (%)		11.29	51.35	20.85

It can be seen from Table 3 that the percentage of run time of EBCOT in total time is 68.61%, 72.35% and 72.20% at r=0.1bpp, 0.5bpp and 2, respectively. Thus EBCOT takes up the most time. The run time of Tier 1 coding accounts for 58.14%, 52.72% and 51.35% of total time, which acounts for 84.74%, 77.87% and 71.12% of the run time of EBCOT. Thus Tier 1 coding is the core part of EBCOT.

For each plane, three scans and coding in three channels are to be done in Tier 1, which consumes a lot of time.

In the first and the second scan, the value of validity flag $\sigma_i[\mathbf{j}]$ is judged. If it is 1, then MR coding is performed; if it is 0, then the feasibility of coding in the validity channel is evaluated. However, if the two scans are combined together, we can determine whether the pixels are to be coded in the validity channel or in the MR channel. Moreover, the value of validity flag $\sigma_i[\mathbf{j}]$ will be judged only once, which is time-saving.

Thus we propose the process of 2 scans and coding in three channels, which achieves a reduction of number of judgment and scans.

As shown by the statistics of several images scanned, the bit number exhibits the same variation trend in the three channels. Figure 6 presents the variation trend of coefficient number in the three channels of LH3 subbands after 4-level 5/3 wavelet transform on bmp image.

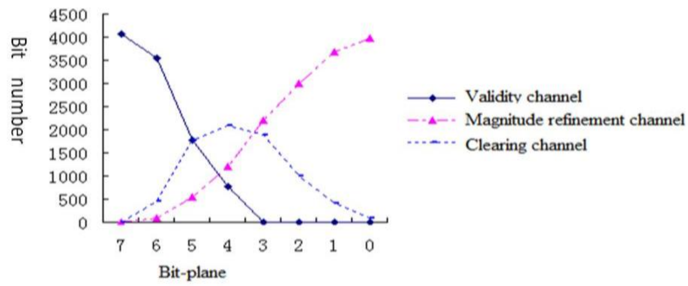


Figure 6. Variation Trend of Bit Number in the Three Channels of LH3 Subband

It can be seen from Figure 6 that all 407676 bits are coded in the clearing channel for MSB plane. As the number of bit-planes decreases, the number of bits coded in the clearing channel decreases as well. The number of bits coded in the MR channel increases from zero. The number of bits coded in the validity channel first increases and then decreases gradually. Thus, for LSB planes, most coefficients are coded in the MR channel, and only a few are coded in the validity channel. There are almost no coefficients coded in the clearing channel.

The group-of-column (GOC) flag is assigned to the coded GOC in the first scan. During the second scan, bit field of 0 indicates no bits to be coded in GOC and therefore this GOC is skipped. Bit field of 1 indicates that some bits are to be coded. The mechanism of GOC tripping can reduce the scan time.

4. GOC Coding in Two Scans of EBCOT

Some GOCs are directly skipped and not coded. But in the validity channel, the validity of the 4 uncoded fields will be predicted based on the validity flag of the previous plane, so GOC skipping does not apply. The skipping mechanism also applies to MR coding and clearing channel coding. During the prediction of validity in the validity channel, the sample values to be coded in each GOC are denoted using GOC flag of 1bit. Bit field of 0 indicates no sample values to be coded in GOC, and bit field of 1 indicates otherwise. In MR channel and clearing channel, GOC flag is first examined. GOC with bit field of 0 is directly skipped without coding, and that with bit field of 1 is scanned and coded value by value.

Here 2 scans are performed. In the first scan, the sample values are predicted using the method above, that is, GOC flag of 1 bit is assigned (Figure 7). In the second scan, bit field of GOC is first determined. If it is 0, then the GOC is skipped and the next GOC is scanned. Otherwise, the GOC is scanned value by value.

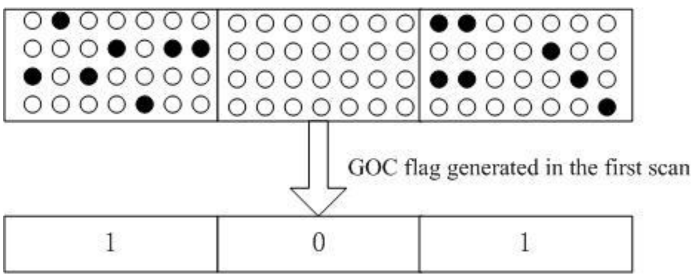


Figure 7. GOC Method

In the first scan, coding is performed in the validity transmission channel and MR channel; and coding is performed in the clearing channel for the second scan. If the first scan and the second scan are combined, the sequences of coding may be disrupted. To solve this problem, the following process is introduced.

(1) Determine the value of validity flag $\sigma[k]$ of the points to be coded. If it is 1, then coding is done in MR channel.

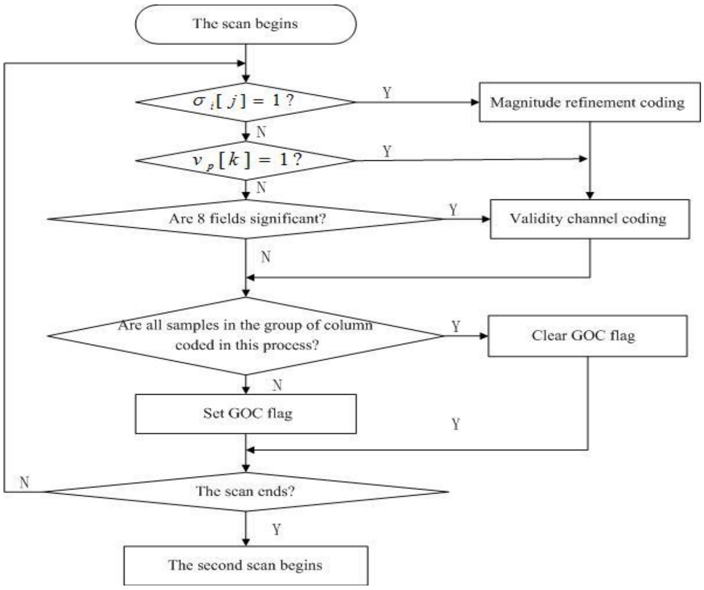
(2) If the value of validity flag is 0, then determine whether the judgment itself is valid, *i.e.*, whether Vp[k] is 1. If yes, set the validity flag $\sigma[k]=1$ and perform SC.

(3) If Vp[k]＝0, then examine the pixels in 8 fields. If the pixels are valid, then perform coding in the validity channel; if not, the next pixel is coded.

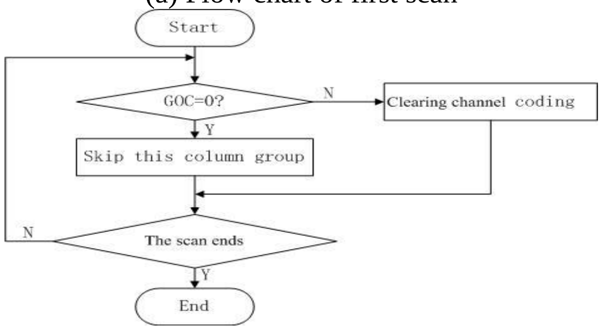
(4) Determine whether all samples in the GOC are coded in this scan. If yes, then set the bit field as 0 for this GOC. If some samples are left uncoded, then set the bit field as 1.

During the second scan, it is first determined whether the bit field of GOC is 0. If yes, this GOC is skipped and the next GOC is scanned. If it is 1, this GOC is scanned and coding is done in the clearing channel.

The flow chart of two scans is shown in Figure 8.



(a) Flow chart of first scan



(B) Flow Chart of Second Scan

Figure 8. Flow Chart of Two Scans

5. Experimental Results

Using Jasper software, we modify the JPEG2000 coding process. Table 5.4 shows the bmp image of Figure 5, with size of 352×288. After 4-level 5/3 wavelet transform, the run time is tested for GOC containing 8 columns each.

Table 5 shows the run time of the original method and the modified method for different images. Four-level wavelet transform is performed, and the testing is carried out at bit rate r＝0.1bpp for GOC containing 8 columns each.

Figure 9 shows the result of image decompression with different bit rate based on Figure 5 (352×288).

Table 4. Comparison of Run Time of Tier 1 Before and After Modification

		Before modification	After modification	Difference (former-latter)
r=0.1(bpp)	Time (s)	0.520	0.401	0.119
r=2(bpp)	Time (s)	0.591	0.480	0.111

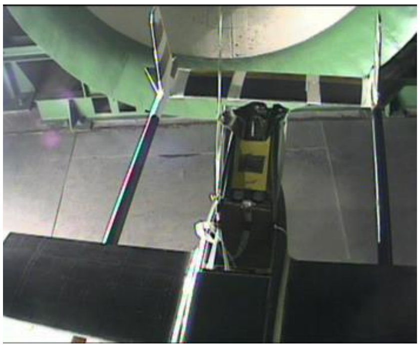
The coding time is reduced by 22.88% at r=0.1bpp and by 18.78% at r=2pp.

Table 5. Comparison of Coding Time for Different Images

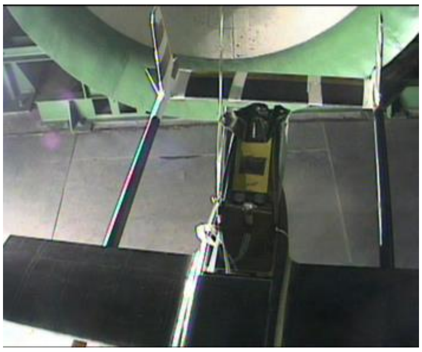
Image	Original method (unit:s)	Modified method (unit:s)	Percentage of time saved
Lena(256×256)	0.110	0.140	21.43%
Image 3.25(a)(352×288)	0.401	0.520	22.88%
Lena(512×512)	0.671	0.865	22.42%
Image 3.25(a)(704×576)	1.051	1.432	26.61%

(a_1) Original method, r＝0.1bpp, PSNR＝28.27dB

(a_2) Modified method, r＝0.1, PSNR=28.10dB



(b_1) Original method r＝0.5bpp, PSNR＝33.09dB



(b_2) Modified method r＝0.5, PSNR=32.91dB

Figure 9. Reconstructed Images Using Original Method (Left) and Modified Method (Right) at 0.1bpp and 0.5bpp

Comparing Table 4 and Table 5, it can be observed that the run time is reduced by about 20%. In Figure 9, the difference of image quality is only about 0.15dB. Thus our modification by performing 2 scans in EBCOT not only reduces the run time, but also maintains the high performance of JPEG2000 coding.

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