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An Efficient Method for Early Detecting All-Zero Quantized DCT Coeffcients for H.264/AVC

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***Abstract*—The residual signal gained after motion estimation needs to be transformed and quantized prior to entropy coding in H.264/AVC. In many cases, especially in low bitrate situation, the probability that obtain all zero quantized coefficients block (AZB) is high. In this paper, we study the characteristics of 4x4 integer transform first, and then we use the divide and rule strategy to inverse the formulae of integer transform and quantization. By this way, we get a new sufficient condition for AZB detection. The experiment results show that our algorithm can find out more AZBs compared with existing methods without any loss and save more computations at the same time.**

***Keywords*—video coding, H.264/AVC, integer transform, quantization**

I. INTRODUCTION

H.264/AVC[1] is the newest video coding standard released by Joint Video Team (JVT) of ISO/IEC MPEG and ITU-T VCEG in 2003. H.264/AVC introduces some new technical developments, such as intra prediction, variable block-size motion compensation with small block sizes, weighted prediction, multiple references frame motion compensation (MRF-MC) etc. These techniques enhance coding performance and compression ratio contrast with existing coding standards such as H.263 and MPEG-4; but they also raise the computation complexity inevitably at the same time[2][3], which increase the difficulty of its application.

In H.264/AVC, 4x4 image blocks should be predicted first, and then the residual signal gained through intra prediction or motion estimation should be integer transformed and quantized, after that the entire encoding process will be ended with entropy coding of quantized coefficients. Through lots of experiments, we have found that many blocks will only have zero coefficients after transform and quantization, especially when Quantization Parameter (QP) is large. We call this kind of blocks All Zero Blocks (AZB). If we have a method which can check whether a block is AZB or not before the integer transform, we could save large numbers of operations, and reduce the computation complexity.

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Xie et al. [9] proposed an AZB judge criterion based on Paseval theorem. Because DCT is a kind of orthogonal transform, so the energy of a signal block in time domain will be the same as that in frequency domain. Sousa et al. [4] derived a sufficient condition by inverse the formulae of integer transform and quantization. Moon et al. [5] and Zhang et al. [6] theoretically derived more precise conditions and improve Sousa's algorithm. Wang et al. [7][8] take use of Gaussian distribution to study integer DCT coefficients and develop a hybrid model to detect AZBs.

In this paper, we first study the process of 4x4 integer transform and quantization in H.264/AVC. Then we use the divide and rule strategy to inverse the formulae of integer transform and quantization for each group of coefficients. Then we propose a novel way for AZB early detection. The experiment results show that our algorithm could remove redundant integer transform and quantization computations without quality loss. It could also check out more AZBs compared with existing methods.

II. EXISTING METHOD

The integer transform which is based on DCT is used in H.264/AVC. The residual coefficients $e(i, j)$ obtained after motion estimation will be transformed and quantized as follows:

$$
\begin{aligned}
Y &= CXC^T \otimes PF = E_I \otimes PF \\
&= \begin{bmatrix} 1 & 1 & 1 & 1 \\ 2 & 1 & -1 & -2 \\ 1 & -1 & -1 & 1 \\ 1 & -2 & 2 & -1 \end{bmatrix} \cdot [X] \cdot \begin{bmatrix} 1 & 2 & 1 & 1 \\ 1 & 1 & -1 & -2 \\ 1 & -1 & -1 & 2 \\ 1 & -2 & 1 & -1 \end{bmatrix} \\
&\otimes \begin{bmatrix} a^2 & ab/2 & a^2 & ab/2 \\ ab/2 & b^2/4 & ab/2 & b^2/4 \\ a^2 & ab/2 & a^2 & ab/2 \\ ab/2 & b^2/4 & ab/2 & b^2/4 \end{bmatrix}
\end{aligned} \tag{1}
$$

CXC^T is a 'core' 2D transform. *PF* is a matrix of scaling factors and the symbol $\otimes$ indicates that each element of (CXC^T) is multiplied by the scaling factor in the same position in matrix *PF*. The constant a, b are 1/2 and $\sqrt{2/5}$, respectively.

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H.264 assumes a scalar quantiser. The mechanisms of the quantiser are complicated by the requirements to avoid division and/or floating point arithmetic and incorporate the post-scaling matrices *PF* described above. The basic forward quantiser operation is:

$$Z(i,j) = round\left(\frac{Y(i,j)}{Q_{step}}\right) = sign\left(E_I(i,j)\right)\cdot \left(\left|E_I(i,j)\right|\cdot M\left(q_{rem},r\right)+f\right) >> qbits \tag{2}$$

$$M(q_{rem},r) = \begin{bmatrix} 5243 & 8066 & 13107 \\ 4660 & 7490 & 11916 \\ 4194 & 6554 & 10082 \\ 3647 & 5825 & 9362 \\ 3355 & 5243 & 8192 \\ 2893 & 4559 & 7282 \end{bmatrix} \quad r=0,\ 1,\ 2$$

$$qbits = 15 + floor\left(\mathrm{QP}/6\right)$$

$$r = 2-(i\%2)-(j\%2) \qquad q_{rem} = \mathrm{QP}\%6$$

Q_{step} is a quantizer step size and $Z(i, j)$ is a quantized coefficient. If there is

$$\left|E_I(i,j)\right| < \left(2^{qbits}-f\right)/M\left[q_{rem}\right]\left[r\right] \tag{3}$$

all $Z(i, j)$ will become zero. It can be seen that the individual sufficient conditions are grouped into three classes depending on the value of r. We can get following thresholds[5]:

$$\begin{aligned} T(2) &= \left(\left(2^{qbits}-f\right)/M\left[q_{rem}\right]\left[2\right]\right) \\ T(1) &= \left(\left(2^{qbits}-f\right)/M\left[q_{rem}\right]\left[1\right]\right)/2 \\ T(0) &= \left(\left(2^{qbits}-f\right)/M\left[q_{rem}\right]\left[0\right]\right)/4 \end{aligned} \tag{4}$$

Here, we have $T(0)<T(1)<T(2)$. If $\mathrm{SAD}_{4X4}<T(0)$, it can be guaranteed all coefficients of a 4x4 block be zeros after integer transform and quantization. But this method has its limitation that it does not utility the block of its own information. It could not adjust thresholds from block to block adaptively and constant thresholds can not have a satisfying AZB detection ratio. Moon improved his method and obtained:

$$\mathrm{SAD}_{4X4} \le T(0) + \min\left\{hs(0,3), hs(1,2)\right\}/2 \tag{5}$$

$$hs(p,q) = \sum_{y=0}^{3}\left\{\left|e(p,y)\right| + \left|e(q,y)\right|\right\}$$

we could see condition (5) takes residual blocks' texture into consideration and enlarges threshold $T(0)$. If the inequality is satisfied, the transform and quantization operations could be skipped and a lot of computations can be saved.

III. Proposed Method

A. Theorem Analysis

The key of finding a sufficient condition for AZB detection is to get an upper bound of $|E_I|$. If the upper bound could be quantized to zero, E_I can be quantized to zero, too. In almost all existing algorithms, the upper bound of $|E_I|$ is estimated based on expression of SAD_{4X4}. In this way, we could take full use of existing resource and avoid introducing extra operations for computing thresholds. But the disadvantage is also obvious. The difference between these upper bounds and $|E_I|$ is large, especially when QP is small. This makes the sufficient condition so tight and the AZB detection inadequate.

We analyze the value of $E_I(i, j)$ with r=0, 1 and 2 separately. From expression (1), we could obtain the base matrices of 4x4 integer transform:

$$\underset{(1,1)}{\begin{bmatrix} 4 & 2 & -2 & -4 \\ 2 & 1 & -1 & -2 \\ -2 & -1 & 1 & 2 \\ -4 & -2 & 2 & 4 \end{bmatrix}} \underset{(1,3)}{\begin{bmatrix} 2 & -4 & 4 & -2 \\ 1 & -2 & 2 & -1 \\ -1 & 2 & -2 & 1 \\ -2 & 4 & -4 & 2 \end{bmatrix}} \underset{(3,1)}{\begin{bmatrix} 2 & 1 & -1 & -2 \\ -4 & -2 & 2 & 4 \\ 4 & 2 & -2 & -4 \\ -2 & -1 & 1 & 2 \end{bmatrix}} \underset{(3,3)}{\begin{bmatrix} 1 & -2 & 2 & -1 \\ -2 & 4 & -4 & -2 \\ 2 & -4 & 4 & -2 \\ -1 & 2 & -2 & 1 \end{bmatrix}}$$

By inspections, we find out some characteristic of these matrices. And we can group coefficients of the 4x4 base matrices into four classes:

$$\begin{aligned} S'_0 &= \left|e(0,0)+e(3,3)\right| + \left|e(0,3)+e(3,0)\right| \\ S'_1 &= \left|e(0,1)+e(3,2)\right| + \left|e(0,2)+e(3,1)\right| \\ S'_2 &= \left|e(1,0)+e(2,3)\right| + \left|e(1,3)+e(2,0)\right| \\ S'_3 &= \left|e(1,1)+e(2,2)\right| + \left|e(1,2)+e(2,1)\right| \end{aligned}$$

According to inequality theorem | X+Y |≤| X | + | Y |, the following can be obtained:

$$\begin{aligned} \left|E_I(1,1)\right| &\le 4S'_0+2S'_1+2S'_2+S'_3 \\ &= 2L+2S'_0-S'_3 \le 2\mathrm{SAD}_{4X4}+2S_0-S_3 \\ \left|E_I(1,3)\right| &\le 2L+2S'_1-S'_2 \le 2\mathrm{SAD}_{4X4}+2S_1-S_2 \\ \left|E_I(3,1)\right| &\le 2L+2S'_2-S'_1 \le 2\mathrm{SAD}_{4X4}+2S_2-S_1 \\ \left|E_I(3,3)\right| &\le 2L+2S'_3-S'_0 \le 2\mathrm{SAD}_{4X4}+2S_3-S_0 \end{aligned} \tag{6}$$

where $L = S'_0+S'_1+S'_2+S'_3$. Combining formulae (3), (4) and (6), we can get sufficient condition for quantizing r=0 components to zero.

$$L < TH'_1 = 2T(0) - \max\left\{\begin{matrix} \max\left(S'_0,S'_3\right)-\min\left(S'_0,S'_3\right)/2, \\ \max\left(S'_1,S'_2\right)-\min\left(S'_1,S'_2\right)/2 \end{matrix}\right\} \tag{7}$$

contrast with reference [6]

$$\begin{aligned} S_0 &= \left|e(0,0)\right| + \left|e(0,3)\right| + \left|e(3,0)\right| + \left|e(3,3)\right| \\ S_1 &= \left|e(0,1)\right| + \left|e(0,2)\right| + \left|e(3,1)\right| + \left|e(3,2)\right| \\ S_2 &= \left|e(1,0)\right| + \left|e(1,3)\right| + \left|e(2,0)\right| + \left|e(2,3)\right| \\ S_3 &= \left|e(1,1)\right| + \left|e(1,2)\right| + \left|e(2,1)\right| + \left|e(2,2)\right| \end{aligned}$$

due to $L \le \mathrm{SAD}_{4X4}$ and $TH'_1 \ge TH_1$[6], it is easily proved that expression (7) effectively extends the existing condition. Similarly, after studying the situation of r=2, we get the sufficient condition for quantizing r=2 components to zero:

$$L < T(2) \quad (8)$$

For the situation of r=1, we still use the condition in reference [6] to save extra computations.

$$\text{SAD}_{4X4} < TH_2 = 2T(1) - \max(S_0, S_3) - \max(S_1, S_2) \quad (9)$$

As a result, a novel sufficient condition is obtained:

$$\begin{cases} L < \min\{TH'_1, T(2)\} \\ SAD_{4X4} < TH_2 \end{cases} \quad (10)$$

All components of 4x4 residual blocks will be zero when (10) is satisfied.

B. Poposed Method

After lots of experiments on different sequences, we find that when $SAD_{4X4}<T(1)$, more than 99.9% blocks are AZBs and for some sequences the false detection that recognize non-AZB as AZB is zero. For saving extra operations for computing thresholds, we design our algorithm as follows:

Step 1) If $SAD_{4X4} \geq 2T(0)$, current block is non-AZB, skip to Step 5); else skip to Step 2).

Step 2) If $SAD_{4X4} < T(1)$, current block is AZB, skip following steps, process the next block; else compute threshold TH_2, skip to Step 3).

Step 3) If condition (9) is satisfied, compute thresholds L and TH'_1, skip to Step 4); else skip to Step 5).

Step 4) If condition (10) is satisfied, current block is AZB, skip following steps, process next block; else skip to Step 5).

Step 5) Process integer transform, quantization, inverse quantization and inverse integer transform.

IV. EXPERIMENT RESULTS

To validate our algorithm, we integrate it into H.264/AVC reference software JM11.0 and the experimental setup is as follows: five reference frames, 32x32 search window size, rate-distortion optimization (RDO) off, full search strategy for motion estimation. Our experiment is tested on four CIF (352x288) format sequences ("News", "Foreman", "Mobile" and "Akiyo") which represent different motion intensity. We encode each of these sequences 100 IPP…P frames and set QP to 18, 22, 26, 32 and 36.

The proposed algorithm was compared with Moon and Zhang's methods to verify the improvement. Table I shows the AZB detection ratio N[7] of these three algorithms. We could see that our method is much better than Moon's method and can upgrade approximately 10% of AZB detection ratio compared with Zhang's algorithm when QP is small.

$$N = \frac{N_d}{N_t} \times 100\% \quad (11)$$

where N_d is the number of the detected zero quantized DCT coefficients blocks, and N_t is the total number of encoding blocks.

TABLE I. Comparison of AZB detection ratio N (%)

Sequence	QP	Moon	Zhang	Proposed
News	18	24.3	40.4	48.2
	22	50.6	68.7	70.0
	26	66.1	78.9	79.5
	32	76.7	86.9	87.2
	36	82.4	90.5	91.2
Foreman	18	18.5	27.7	33.0
	22	26.5	44.8	46.4
	26	44.6	64.4	65.5
	32	69.1	83.9	84.5
	36	80.5	90.1	91.5
Mobile	18	30.1	43.7	49.9
	22	38.7	55.2	56.4
	26	44.2	59.3	60.1
	32	48.9	63.2	63.8
	36	52.7	67.5	69.7
Akiyo	18	34.8	54.2	62.3
	22	62.7.	79.1	80.1
	26	76.9	87.2	87.6
	32	84.7	92.3	92.4
	36	89.2	94.9	95.3

TABLE II. Operations used for each step in the proposed algorithm

Step	Condition	Processing	Operations			
			ADD	*MUL*	*SFT*	*CMP*
1	$SAD_{4X4}<2T(0)$	DCT/Q	0	0	0	0
		Overhead	0	0	0	1
	$SAD_{4X4}\geq 2T(0)$	DCT/Q	80	16	32	0
		Overhead	0	0	0	1
2	$SAD_{4X4}<T(1)$	DCT/Q	0	0	0	0
		Overhead	0	0	0	1
	$SAD_{4X4}\geq T(1)$	DCT/Q	0	0	0	0
		Overhead	2	0	0	3
3	$SAD_{4X4}<TH_2$	DCT/Q	0	0	0	0
		Overhead	18	0	2	6
	$SAD_{4X4}\geq TH_2$	DCT/Q	80	16	32	0
		Overhead	0	0	0	1
4	$L<TH'_1$	DCT/Q	0	0	0	0
		Overhead	0	0	0	1
	$L\geq TH'_1$	DCT/Q	80	16	32	0
		Overhead	0	0	0	1

Because the computations of thresholds need extra operations, only comparing the AZB detection ratio is not enough to prove our algorithm's improvement. Table II shows the number of operations needed by each step of our method, including addition (ADD), multiplication (MUL), shift (SFT) and comparison (CMP). It not only contains operations needed by integer transform and quantization (DCT/Q), but also includes overhead needed by computing L, TH'_1 and TH_2. As $T(0)$, $T(1)$ and $T(2)$ are predetermined regardless of the video sequences and can be generally applied, they do not introduce extra computations.

Table III demonstrates the computations saving ratio of three algorithms. Similarly to reference [7], we have

$$C = \frac{O_t}{O_o} \times 100\% \tag{12}$$

O_t denotes total number of computations needed by proposed algorithm, O_o is the total number of computations needed by original method. O_t and O_o both include overhead for computing thresholds.

TABLE III. Computational saving *C* (%) of the proposed algorithm compared to the existing algorithms

Sequence	QP	Moon	Zhang	Proposed
News	18	86.0	78.4	74.4
	22	64.5	54.3	53.6
	26	48.7	40.9	40.2
	32	34.3	27.3	26.9
	36	26.3	20.5	19.8
Foreman	18	94.2	91.7	90.4
	22	86.1	78.0	77.9
	26	69.4	58.3	57.7
	32	42.4	32.5	31.8
	36	28.5	21.3	20.3
Mobile	18	95.0	93.0	92.0
	22	90.0	86.4	86.3
	26	83.5	78.9	78.7
	32	72.5	65.9	65.9
	36	64.3	56.0	55.1
Akiyo	18	75.9	65.2	59.8
	22	50.8	40.7	39.6
	26	35.0	28.3	27.6
	32	23.6	18.2	17.9
	36	17.3	13.2	12.7

From experiment results, we could see our algorithm is much more effective and can save more computations contrast with existing ones without any quality loss.

V. CONCLUSION

In this paper, we propose an effective method for early detecting all-zero quantized coefficients blocks for H.264/AVC. After studying the process of integer transform and quantization intensively, we obtain a sufficient condition for AZB detection, with which we could judge whether a quantized coefficient block is AZB or not without transform and quantization actually. The experiment results show that our algorithm can find out more AZBs and save more computations contrast with existing algorithms.

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