AN EARLY DETECTION OF ALL-ZERO DCT BLOCKS IN H.264

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ABSTRACT

In this paper, a new early detection algorithm for all-zero DCT blocks in H.264 video encoding is proposed. We have analyzed the properties of the DCT and quantization in H.264. These analyses show that a great reduction in the number of calculations can be achieved by investigating the individual conditions for the frequency components of (1,1), (1,3), (3,1), and (3,3). Based on these facts, a more precise sufficient condition is proposed by modifying the calculation order of the minimum SAD. Simulation results show that the redundant DCT and Q are efficiently removed without video-quality degradation.

1. INTRODUCTION

Video coding technology plays a key role in the service of the various multimedia applications. Currently, it is required to perform encoding with CPU or DSP in order to meet the several requirements of wide applications [1]. However, an enormous amount of computations in the video encoding causes a problem. Many researchers have studied fast motion estimation in order to accelerate video encoding. As the calculations in motion estimation are reduced, the computations required for discrete cosine transform (DCT) and quantization (Q) become more significant for fast encoding [2].

In a very low bit rate videophone application, all-zero blocks of DCT coefficients are quite common [3]. DCT and Q are not needed for the all-zero blocks if they can be detected before DCT and Q. Thus, it is important to develop the early detection for the all-zero blocks in order to reduce the computations of DCT and Q. Xuan [3] proposed an early detection method for all-zero block. From a theoretical analysis, a sufficient condition under which all DCT coefficients are simultaneously quantized into zero was suggested and checked for each block. Sousa [4] theoretically derived a precise sufficient condition and improved Xuan's algorithm.

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In this paper, the early detection for all-zero blocks in video encoding is improved. We have theoretically examined the properties of the DCT and Q in H.264 and derived the sufficient condition under which each DCT coefficient is quantized into zero. Based on this fact, a more precise sufficient condition is proposed in this paper. Simulation results show that the redundant DCT and Q are efficiently removed without video-quality degradation.

2. CONVENTIONAL EARLY DETECTION METHOD

In the H.264 standard [5], an integer DCT is used for eliminating any mismatch problems between the encoder and the decoder [6]. For a 4×4 block $e^{(i,j)}(x,y)$, its integer transform can be defined as

$$E_I(u,v)=\sum_{x=0}^{3}\sum_{y=0}^{3}e^{(i,j)}(x,y)\cdot\left\lceil 2.5\cdot\sqrt{\frac{1}{2}}k(u)\cos(\frac{2x+1}{8}u\pi)\right\rceil\left\lceil 2.5\cdot\sqrt{\frac{1}{2}}k(v)\cos(\frac{2y+1}{8}v\pi)\right\rceil,$$

$$\text{where,}\quad k(u),\,k(v)\ = 1/\sqrt{2}\quad for\quad u,v=0;\qquad = 1\quad for\quad otherwise \tag{1}$$

The $\lceil\ \rceil$ symbol in Eq. (1) denotes the rounding-off operation. Given a DCT coefficient $E_I(u,v)$ and a quantization parameter Q_P, the quantized DCT coefficient $E_q(u,v,r,Q_P)$ is described as

$$E_q(u,v,r,Q_P)=sign\{E_I(u,v)\}\frac{f+M(Q_P\%6,r)\cdot|E_I(u,v)|}{2^{15+(Q_P/6)}} \tag{2}$$

Where % and f denote the modular operator and a constant value, respectively. $M(Q_P\%6,r)$ in Eq. (2) indicates the quantization coefficient predefined for each frequency component. It is provided with a periodic table formulated as follows:

$$M(Q_P\%6,r)=\begin{bmatrix}5243 & 8066 & 13107\\ 4660 & 7490 & 11916\\ 4194 & 6554 & 10082\\ 3647 & 5825 & 9362\\ 3355 & 5243 & 8192\\ 2893 & 4559 & 7282\end{bmatrix},$$

$$\text{where}\quad r=\begin{cases}0 & for\ (u,v)\in\{(1,1),(1,3),(3,1),(3,3)\}\\ 1 & for\ (u,v)\in\{(0,1),(0,3),(1,0),(1,2),\\ & \qquad (2,1),(2,3),(3,0),(3,2)\}\\ 2 & for\ (u,v)\in\{(0,0),(0,2),(2,0),(2,2)\}\end{cases} \tag{3}$$

From Eq. (1), Eq. (2), and Eq. (3), the following inequality is easily obtained:

$$\left|E_q(u,v,r,Q_P)\right|\le\frac{f+M(Q_p\%6,0)\cdot 4\cdot\sum_{x=0}^{3}\sum_{y=0}^{3}\left|e^{(i,j)}(x,y)\right|}{2^{15+(Q_p/6)}} \tag{4}$$

If the upper bound of Eq. (4) is smaller than 1, all DCT coefficients are simultaneously quantized into zero. Thus, the sufficient condition of the conventional method is as follows:

$$\sum_{x=0}^{3}\sum_{y=0}^{3}\left|e^{(i,j)}(x,y)\right|\le\frac{2^{15+(Q_p/6)}-f}{M(Q_p\%6,0)}\cdot\frac{1}{4}=\frac{\alpha(Q_p)}{4\cdot M(Q_p\%6,0)}=Ts \tag{5}$$

Where Ts is a threshold of the conventional method.

The most left-hand-side term of Eq. (5) is easily obtained from the minimum SAD ($SAD_{\min}$) in the motion estimation. Let $R(x,y)$ be a $L\times N$ residual block and $e^{(i,j)}(x,y)$ be located at $(4i,4j)$ in the residual block. Then, the $SAD_{\min}$ can be described as follows:

$$SAD_{\min}=\sum_{x=0}^{L-1}\sum_{y=0}^{N-1}\left|R(x,y)\right|=\sum_{i=0}^{L/4-1}\sum_{j=0}^{N/4\text{-}1}\left\{\sum_{x=0}^{3}\sum_{y=0}^{3}\left|e^{(i,j)}(x,y)\right|\right\}=\sum_{i=0}^{L/4-1}\sum_{j=0}^{N/4\text{-}1}sad^{(i,j)} \tag{6}$$

From Eq. (5) and Eq. (6), it is seen that the all-zero blocks can be detected before DCT and Q stage.

3. THE PROPOSED ALGORITHM

For a particular frequency component (η,ζ), let's define $C_{\max}(\eta,\zeta)$ as the maximum value of the basis part in Eq. (1). Then, it is formulated as

$$C_{\max}(\eta,\zeta)=max\left|\left[2.5\cdot\sqrt{\frac{1}{2}}k(\eta)\cos(\frac{2x+1}{8}\eta\pi)\right]\left[2.5\cdot\sqrt{\frac{1}{2}}k(\zeta)\cos(\frac{2y+1}{8}\zeta\pi)\right]\right| \tag{7}$$

By analyzing Eq. (7) for the 4×4 block, the $C_{\max}(\eta,\zeta)$ can be rewritten as follows:

$$C_{\max}(\eta,\zeta)=C(r)=2^{2-r},\ where\ r=\begin{cases}0\ , for(\eta,\zeta)=\{(1,1),(1,3),(3,1),(3,3)\}\\ 1\ , for(\eta,\zeta)=\{(0,1),(0,3),(1,0),(1,2),\\ \qquad (2,1),(2,3),(3,0),(3,2)\}\\ 2\ , for(\eta,\zeta)=\{(0,0),(0,2),(2,0),(2,2)\}\end{cases} \tag{8}$$

Note that r has the value 0, 1, or 2 according to the position of each frequency component.

Based on Eq. (2), Eq. (3), and Eq.(8), the upper bound for each component can be formulated as follows:

$$\left|E_q(\eta,\zeta,r,Q_p)\right|\le\frac{f+C(r)\cdot M(Q_p\%6,r)\cdot sad^{(i,j)}}{2^{15+(Q/6)}} \tag{9}$$

From Eq. (9), the sufficient condition for each quantized DCT coefficient becoming zero can be easily derived as

$$sad^{(i,j)}\le\frac{2^{15+(Q_p/6)}-f}{M(Q_p\%6,r)}\cdot\frac{1}{C(r)}=\frac{\alpha(Q_p)}{C(r)\cdot M(Q_p\%6,r)}=T(r) \tag{10}$$

Where $T(r)$ is the threshold of the frequency components corresponding to the value of r. From Eq. (10), it can be seen that the individual sufficient conditions are grouped into 3 classes depending on the values of $sad^{(i,j)}$ and $T(r)$.

On the other hand, if the values of $C(r)\cdot M(Q_p\%6,r)$ in Eq. (10) are carefully examined, the following inequality is easily obtained:

$$C(2)\cdot M(Q_p\%6,2)<C(1)\cdot M(Q_p\%6,1)<C(0)\cdot M(Q_p\%6,0) \tag{11}$$

In addition, Eq. (12) is derived from Eq. (10) and Eq. (11).

$$T(0)<T(1)<T(2) \tag{12}$$

With Eq. (10) and Eq. (12), we can get the relationship of $sad^{(i,j)}$ and the thresholds $T(0)$, $T(1)$, and $T(2)$. It is summarized in Table 1.

Table 1. The relationship between $sad^{(i,j)}$ and $T(r)$.

Modes	Conditions	The corresponding zero frequency components
M0	$sad^{(i,j)} < T(0)$	$r = 0, 1, 2$
M1	$T(0) \le sad^{(i,j)} < T(1)$	$r = 1, 2$
M2	$T(1) \le sad^{(i,j)} < T(2)$	r=2
M3	$T(2) \le sad^{(i,j)}$	None

Note that we can get some information from Table 1. For example, when the condition of M0 is compared to Eq. (5), $T(0)$ is equal to the Ts which is the threshold in Sousa's method. That is, the condition of mode M0 is the same as the conventional sufficient condition. In addition, Table 1 shows that the quantized DCT coefficients corresponding to $r = 1$ and 2 are already guaranteed to be zero for mode M1. It means that in the conventional method, the all-zero blocks belonging to mode M1 are treated as non-all-zero blocks. Therefore, if we can find a special condition detecting the all-zero blocks in the mode, a computational reduction will be achieved.

For the frequency components belonging to $r=0$, we carefully examined $|E_I(u,v)|$ and obtained the following approximations :

$$\begin{aligned}&\sum_{x=0}^{3}\sum_{y=0}^{3}\left|e^{(i,j)}(x,y)\right|\cdot\left|\left\lceil 2.5\cdot\sqrt{\frac{1}{2}}k(\eta)\cos\left(\frac{2x+1}{8}\eta\pi\right)\right\rceil\left\lceil 2.5\cdot\sqrt{\frac{1}{2}}k(\zeta)\cos\left(\frac{2y+1}{8}\zeta\pi\right)\right\rceil\right|\\&\le 4\cdot sad^{(i,j)}-2\cdot hs^{(i,j)}(1,2)\quad for\ (\eta,\zeta)=(1,1),(1,3)\\&\le 4\cdot sad^{(i,j)}-2\cdot hs^{(i,j)}(0,3)\quad for\ (\eta,\zeta)=(3,1),(3,3)\\&where,\ hs^{(i,j)}(p,q)=\sum_{y=0}^{3}\left(\left|e^{(i,j)}(p,y)\right|+\left|e^{(i,j)}(q,y)\right|\right)\end{aligned} \tag{13}$$

According to Eq. (13), we can easily see that $sad^{(i,j)}$ is rewritten as Eq. (14):

$$sad^{(i,j)}=\sum_{x=0}^{3}\sum_{y=0}^{3}\left|e^{(i,j)}(x,y)\right|=hs^{(i,j)}(0,3)+hs^{(i,j)}(1,2) \tag{14}$$

Note that additional computations are not required for $hs^{(i,j)}(0,3)$ and $hs^{(i,j)}(1,2)$ if we modify the calculation order of $sad^{(i,j)}$.

Based on Eq. (13) and Eq. (14), a new upper bound can be derived for the 4 frequency components of $r=0$. The following equation is the definition of the new upper bound:

$$\begin{aligned}U_p^{(i,j)}&=4\cdot sad^{(i,j)}-2\cdot\min\{hs^{(i,j)}(0,3),\ hs^{(i,j)}(1,2)\}\\&for\ (\eta,\zeta)=(1,1),(1,3),(3,1),(3,3)\end{aligned} \tag{15}$$

From Eq. (9) and Eq. (15), the following inequality can easily be obtained:

$$\left|E_q(\eta,\zeta,0,Q_P)\right|\le\frac{f+U_p^{(i,j)}\cdot M(Q_p\%6,0)}{2^{15+(Q_p/6)}}\le\frac{f+C(0)\cdot M(Q_p\%6,0)\cdot sad^{(i,j)}}{2^{15+(Q_p/6)}} \tag{16}$$

This equation clearly shows that the new upper bound is more precise than the conventional one. Based on the derivation of Eq. (10), a new sufficient condition for $r=0$ can be described as

$$sad^{(i,j)}\le T(0)+\frac{\min\{hs^{(i,j)}(0,3),hs^{(i,j)}(1,2)\}}{2}=T(0)+(\lambda/2) \tag{17}$$

Note that the new threshold $T(0)+(\lambda/2)$ determines the frequency components of $r=0$ to be quantized into zero. Additionally, $T(1)$ guarantees that the quantized DCT coefficients for the frequency components of $r = 1$ and 2 become zero. Therefore, it is necessary to select the minimum of $T(0)+(\lambda/2)$ and $T(1)$ as the threshold (TH) of the sufficient condition for the all-zero blocks.

Based on the facts stated above, we propose an improved early detection algorithm for H.264 video encoding. For a given 4x4 block, the following steps are applied in the proposed algorithm.

Step 1. Reading $sad^{(i,j)}$ from the motion estimation stage.
Step 2. Comparing $sad^{(i,j)}$ to $T(1)$.
  If $sad^{(i,j)}$ is smaller than $T(1)$, going to Step 3.
  Else performing DCT and Q.
Step 3. Comparing $sad^{(i,j)}$ to $T(0)$.
  If $sad^{(i,j)}$ is smaller than $T(0)$, going to next block.
  Else Calculating λ and TH and going to Step 4.
Step 4. Comparing $sad^{(i,j)}$ to TH
  If $sad^{(i,j)}$ is smaller than TH, going to next block.
  Else performing DCT and Q.

4. SIMULATION RESULTS

In order to evaluate the performance of the proposed algorithm, a simulation was performed with the H.264

JM6.1 encoder. The several QCIF (176×144) sequences were tested in this simulation. The frame rate was fixed at 10fps and the Q_p was set to 28, 32, and 36. In addition, 5 reference frames were used for the motion estimation.

The proposed algorithm was compared to Sousa's algorithm in order to verify the improvement. Figure 1 shows the comparisons of the number of computations between the proposed and Sousa's algorithm.

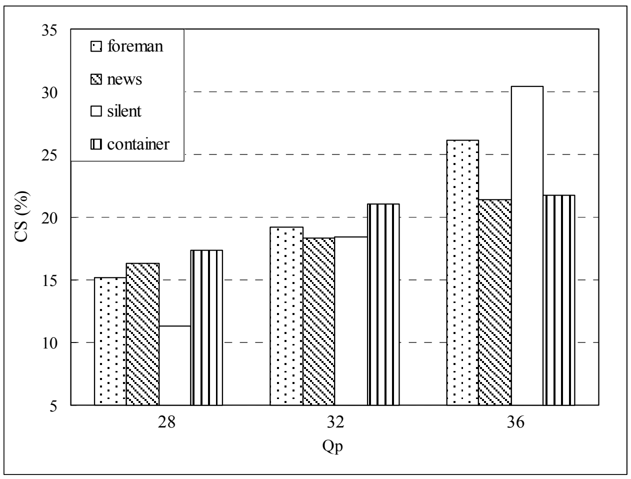

Fig. 1. Computational saving (CS) of the proposed algorithm compared to Sousa's algorithm.

The CS in Fig. 1 denotes the computational saving ratio by the proposed algorithm compared to the total calculations required for Sousa's method.

This graph demonstrates that the proposed method achieves approximately an 11-30% computational saving compared to Sousa's method. It reveals that the proposed algorithm effectively eliminates all-zero blocks which were impossible to detect in Sousa's algorithm. In addition, the proposed method does not cause any degradation of the quality.

5. CONCLUSIONS

In this paper, an improved early detection algorithm for all-zero blocks in H.264 video encoding is proposed. We have analyzed the properties of integer DCT and Q in H.264 and derived the individual sufficient condition under which each quantized DCT coefficient becomes zero. Based on these theoretical analyses, a more precise sufficient condition is proposed by modifying the calculation order for the minimum *SAD* obtained in the motion estimation.

From the simulation results, it is shown that the proposed algorithm achieves approximately a 11-30% computational saving compared to Sousa's algorithm. It means that the proposed algorithm efficiently removes all-zero blocks which are not determined by Sousa's algorithm. Therefore, the proposed algorithm effectively eliminates the redundant calculations for DCT and quantization without video-quality degradation.

6. REFERENCES

[1] S.K. Jang, S.D. Kim, J. Lee, G.Y. Choi, and J.B. Ra, "Hardware-software co-implementation of a H.263 video codec," IEEE Trans. on Consumer Electronics, vol. 46, no. 1, pp. 191-200, Feb. 2000.

[2] I. M. Pao and M.T. Sun, "Modeling DCT coefficient for fast video encoding," IEEE Trans. on Circuits and Systems for Video Technology, vol. 9, no. 4, pp. 608-616, June 1999.

[3] Z. Xuan, Y. Zhenghua, and Y. Songyu, "Method for detection all-zero DCT coefficients ahead of discrete cosine transformation and quantization," Electronics Letters, vol. 34, no. 19, pp. 1839-1840, Sep. 1998.

[4] L.A. Sousa, "General method for eliminating redundant computations in video coding," Electronics Letters, vol. 36, no. 4, pp. 306-307, Feb. 2000.

[5] T. Wiegand, "Study of final committee draft of joint video specification," Joint Video Team (JVT) of ISO/IEC MPEG and ITU-T VCEG, Doc. JVT-F100d2, Dec. 2002.

[6] H. Malvar, A. Hallapuro, M. Karczewicz, and L. Kerofsky, "Low-complexity transform and quantization with 16-bit arithmetic for H.26L," IEEE International Conference on Image Processing, vol. 2, pp. 489-492, 2002.