A Survey on Early Determination of Zero Quantized Coefficients in Video Coding

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***Abstract*—In video encoding, there are a large number of discrete cosine transform (DCT) coefficients of the prediction residue which are quantized to zeros. Therefore, it is desired to design a method which can early detect zero quantized DCT coefficients before implementing DCT and quantization and thus reduce redundant computations for video coding. This paper presents an overview of some early determination of zero quantized coefficients techniques for video coding. These techniques exploit different ways in order to determine the zero quantized block before DCT and quantization.**

Keywords-component; discrete cosine transform, sum of absolute difference, zero-quantized coefficients, minimum mean absolute error, hybrid model

I. Introduction

Digital video applications are becoming more popular in our everyday lives. Currently, there are several video standards established for different purposes, such as MPEG-1 and MPEG-2 for multimedia applications and H.261 and H.263 for videophone and videoconferencing applications. H.264 [1], as newest video coding standard significantly outperforms previous standards. All these standards use the discrete cosine transform (DCT), motion compensation, quantization, and variable-length coding (VLC) as building blocks. Using these video coding standards, video encoders require large amounts of computation because motion estimation, DCT, IDCT, quantization and inverse quantization are all very computationally intensive. So there rise a significant interest and research in reducing these computations.

The efforts are put to reduce the computations of video encoders were mainly focused on the fast motion-estimation algorithms [2]-[5]. As the motion-estimation algorithm becomes more optimized, to speed up the video encoders and we also need to optimize other functions, such as DCT, IDCT, quantization and inverse quantization. Typically, a significant number of prediction error blocks will have all-zero coefficients after Q in low bit-rate video coding. Even in higher bit-rate video coding, some well-predicted blocks may have all-zero DCT coefficients after Q. If these blocks are predicted earlier computations of DCT, Q, IQ and IDCT can be completely skipped. In [5], DCT/IDCT and Q/IQ accounts approximately 40% of the total encoding time when the XVID encoder is used for evaluation with the PMVFAST ME algorithm employed. As stated in [6], average time cost in terms of DCT/IDCT and Q/IQ accounts for 34.8% of the total encoding time when a software H.263 encoder is used for testing. With this concern, several efficient methods of early determination of zero quantized blocks are examined.

II. Overview of Standard Video Encoder

Video compression is achieved by exploiting the similarities or redundancies that exists in a typical video signal. To begin, consider image compression, such as the JPEG standard, which is designed to exploit the spatial and color redundancy that exists in a single still image. Neighboring pixels in an image are often highly similar, and natural images often have most of their energies concentrated in the low frequencies. JPEG exploits these features by partitioning an image into 8x8 pixel blocks and computing the 2-D Discrete Cosine Transform (DCT) for each block. The DCT compacts most of the signal energy in the block into only a small fraction of the DCT coefficients, where this small fraction of the coefficients are sufficient to reconstruct an accurate version of the image. Each 8x8 block of DCT coefficients is then quantized and processed using a number of techniques known as zigzag scanning, run length coding, and Huffman coding to produce a compressed bit stream.

A video sequence consists of a sequence of video frames or images. Each frame may be coded as a separate image, for example by independently applying JPEG-like coding to each frame. However, since neighboring video frames are typically very similar much higher compression can be achieved by exploiting the similarity between frames. Currently, the most effective approach to exploit the similarity between frames is by coding a given frame by (1) first predicting it based on a previously coded frame, and then (2) coding the error in this prediction. Consecutive video frames typically contain the same imagery, however possibly at different spatial locations because of motion. Therefore, to improve the predictability it is important to estimate the motion between the frames and then to form an appropriate prediction that compensates for the motion. The process of estimating the motion between frames is known as motion estimation (ME), and the process of forming a prediction while compensating for the relative motion between two frames is referred to as motion-compensated prediction (MC-P). The temporal redundancy is exploited by applying MC-prediction, the spatial redundancy is exploited by applying the DCT, and the color space redundancy is exploited by a color space conversion. The resulting DCT coefficients are quantized and the nonzero quantized DCT coefficients are run length and Huffman coded to produce the compressed bit stream.

III. Early Determination of Zero Quantized Coefficients Approaches

1. *Sum of Absolute Difference:*

The DCT and other related functions like IDCT, quantization and rescaling can consume nearly 1/3 of the processing resources and so it is useful to examine methods of reducing the computational complexity of these functions. DCT is applied to compress motion compensation data in the spatial domain and a special case for the encoder occurs when all the coefficients from the DCT are quantized to zero. The computational complexity of the DCT and quantization operations may be significantly reduced by skipping the DCT and quantize operations for blocks that are likely to contain all zero coefficients after quantization. It is possible to predict quantized blocks containing all zero coefficients. For very low bit-rate coding, especially in videophone applications, this all-zero state is quite common, so early detection of this state could significantly reduce the amount of computation necessary. Zhou *et al.* [8], proposes an algorithm that uses the sum of absolute difference (SAD) of each motion compensated block as the criteria, because the SAD can be obtained after motion estimation.
The condition for all-zero DCT coefficients is

$$|F(u,v)| < 2Q \qquad (1)$$

Where u,v=0, 1, …, 7, and Q denotes the quantization level. Thus

$$\sum_{x=0}^{7}\sum_{y=0}^{7} abs\left(f(x,y)\right) < 8Q \qquad (2)$$

The above inequality gives the conditions under which the DCT has all-zero coefficient. In eq. (2), the left summation gives SAD of the motion compensation block, which can be obtained during motion estimation. Therefore no additional computation is required. The threshold can be increased according to practical requirements. With quantization level 10, ~40% of the blocks of the Miss America and Claire sequences can be determined to have all-zero coefficients.

2. *Modeling of DCT Coefficients as a Function of MMAE:*

To speed up the calculations of DCT, Pao *et al.* [9] present a fast DCT algorithm further when the quantization step size is large. The significant improvement in the processing speed can be achieved with negligible video-quality degradation. Chen *et al.* [10] propose to compare the signal energy with a threshold, and set all the DCT coefficients of one block to zeros if the signal energy is less than the threshold. In a similar manner, Yu *et al.* [11] propose to compare the sum of absolute difference available from ME with the product of the quantization parameter and a predetermined threshold. If, then the DCT and Q computations can be skipped, and the quantized DCT coefficients are all set to zeros. This method is shown to be effective in reducing the computational complexity of H.263 encoding. However, the quality of the encoded video is heavily dependent on the threshold, where to define a suitable value is not trivial. In order to reduce the degradation of video quality, Yu *et al.* [12] decrease the threshold value experimentally to detect all-zero DCT blocks.

However, the threshold was chosen empirically. If the threshold is not chosen properly, any DCT coefficients may be improperly set to zero and serve quality degradation may occur. Also, since the probability of the DCT coefficients becoming zero depends on quantization parameter, the threshold should depend on the quantization parameter. Another issue is different DCT coefficients have different variances and thus may need to be treated differently. Developed a new adaptive method with multiple thresholds derived from the statistical model to reduce the computations of DCT, IDCT, quantization and IQ. Position of EOB is investigated as a function of the quantization parameter for each different quantization parameter. EOB equals to zero means all coefficients in the block are zero after quantization; EOB equal to one means only the dc coefficient is not zero after quantization; and so on. It is clear that the EOB position decreases as the quantization parameter increases because more DCT coefficients are quantized to zero. The variance of DCT coefficients are represented as the function of minimum mean absolute error (MMAE).

If the MMAE is small, it indicates that the energy is small, and vice versa. Thus, the blocks with smaller MMAE's will have higher probabilities that the DCT coefficients will be quantized to zeros. It justifies settings the thresholds based on the MMAE. The variance of the DCT coefficients can be estimated by the variances of the pixel values at the input of DCT. It also shows that the variance of the dc coefficient is larger that than of other ac coefficients. This means, after quantization the probability of dc coefficients being quantized to zero is less than that of ac coefficients. To further reduce computations, a new DCT approximation scheme is proposed.

This method gives satisfactory performance in both high and low bit-rate situations for all video sequences with slight and intense motion activities. The Miss America sequence coded at 20 kb/s using this method only needs 11.68% of the computations compared with the original encoder in the quantization stage.

3. *Improved early detection algorithm for H.264:*

The early detection for all-zero blocks in video encoding is improved in [13]. This paper 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.

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. If $sad^{(i,j)}$ is smaller than TH, going to next block.
Else performing DCT and Q.

TABLE I. 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) <= $sad^{(i,j)}$ < T (1)	r=1,2
M2	T(1) <= $sad^{(i,j)}$ < T (2)	r=2
M3	T(2) <= $sad^{(i,j)}$	None

The proposed method achieves approximately an 11.30% computational saving compared to Sousa's method [16]. It reveals that this algorithm effectively eliminates all-zero blocks which were impossible to detect in Sousa's algorithm. In addition, this method does not cause any degradation of the quality.

4. *Prediction Algorithm of Integer DCT Coefficients:*

A theoretical analysis is performed in [14] to study the sufficient condition for DCT coefficients to be quantized to zeros. As a result, three sufficient conditions corresponding to three types of transform and quantization methods in H.264 are proposed. Compared with other algorithms, this algorithm derives more precise and efficient conditions to predict zero quantized DCT coefficients. Both the theoretical analysis and experimental results demonstrate that this algorithm is superior to other algorithms in terms of the computational complexity reduction, encoded video quality, false acceptance rate, and false rejection rate. A number of early detection algorithms of all-zero DCT blocks have been studied for the 8x8 DCT-based video encode. However, those algorithms cannot be directly applied to the H.264 encoder. The H.264 uses three transforms [15] depending on the type of residue data to be encoded: 1) an integer 4x4 DCT for all the 4 x4 blocks in the residual data (Normal4x4 type); 2) a Hadamard transform for the 4x4 array of luma dc coefficients in intra 16x16 mode (LumaDC4x4 type); and 3) a Hadamard transform for the 2x2 array of chroma dc coefficients (ChromaDC2x2 type). Unfortunately, only the Normal4x4 type is considered to detect all-zero DCT blocks, and the LumaDC4x4 type and ChromaDC2x2 type are not taken into account. Thus, the nonzero dc coefficients in both the LumaDC4x4 and ChromaDC2x2 types may be misclassified as zero-valued and the video quality will degrade as a consequence.

A comprehensive analysis of the dynamic range of DCT coefficients is performed in the Normal4x4 type and derive a more precise sufficient condition than those of Sousa's algorithm [16] and Kim's algorithm [17] to detect all-zero DCT blocks. In addition, the authors theoretically study the LumaDC4x4 and ChromaDC2x2 type and provide sufficient conditions under which the dc coefficients in these two types after Hadamard transform are quantized to zeros. As a result, this prediction algorithm can significantly reduce redundant DCT and Q computations without video quality degradation.

Prediction Algorithm for H.264 Optimization

Based on the above analysis, the following algorithm reduces redundant DCT, Q, inverse Q (IQ), and inverse DCT (IDCT) computations for H.264 encoding optimization.

Step 1) If the current macroblock is encoded in Intra16x16 mode, go to step 2. Else go to step 4.

Step 2) If $SAD_{16} < 4Th_3$, $f_{16} = 1$, else $f_{16} = 0$. Go to step 3.

Step 3) For luma blocks, if SAD < TS and $f_{16} = 1$, DCT, Q, IQ, IDCT are not performed. Else if SAD < TS and $f_{16} = 0$, DCT, Q, IQ, IDCT are only performed to dc coefficients. Else if SAD >= TS and $f_{16} = 1$, DCT, Q, IQ, IDCT are only performed to ac coefficients. Else, DCT, Q, IQ, IDCT are performed to all the DCT coefficients. Go to step 5.

Step 4) For luma blocks, if SAD < TS, DCT, Q, IQ, IDCT are skipped. Else, DCT, Q, IQ, IDCT are performed to all the DCT coefficients. Go to step 5.

Step 5) If $SAD_{4c} < 2Th_3$, $f_c = 1$, else $f_c = 0$. Go to step 6.

Step 6) For chroma blocks, if SAD < TS and $f_c = 1$, DCT, Q, IQ, IDCT are not performed. Else if SAD < TS and $f_c = 0$, DCT, Q, IQ, IDCT are only performed to dc coefficients. Else if SAD >= TS and $f_c = 1$, DCT, Q, IQ, IDCT are only performed to ac coefficients. Else, DCT, Q, IQ, IDCT are performed to all the DCT coefficients.

Generally speaking, because this algorithm is proved based on strict theoretical analysis and focused on the computational complexity reduction of DCT, Q, IQ, and IDCT functions, it can be applied with any of fast motion estimation and mode decision algorithms which use SAD as the matching criteria. The experimental results demonstrate that this prediction algorithm outperforms the other two algorithms [16] and [17] in terms of the computational complexity reduction, encoded video quality, false acceptance rate (FAR) and false rejection rate (FRR).

5. *Hybrid Model for ZQDCT:*

On the other hand, Pao *et al.* [9] propose a Laplacian distribution based model to predict ZQDCT coefficients. Based on this statistical model, multiple thresholds are derived to detect various sizes of nonzero blocks such as 1x1 nonzero block, 2x2 nonzero block, etc., and the DCT and Q computations in the other part of the 8x8 block can be skipped accordingly. Therefore, an adaptive method is developed in

[17] to reduce DCT and Q computations. As a consequence, the computation of video coding is greatly reduced with a very little degradation of video quality.

Similar to Laplacian distribution based model, a Gaussian distribution based model [24] is proposed to early detect various sizes of nonzero DCT sub-blocks with multiple thresholds. Compared with the Laplacian distribution based model, the Gaussian distribution based model provides more efficient conditions to predict ZQDCT coefficients and thus reduces more redundant computations. Later, a hybrid model is presented in [18] in order to predict ZQDCT coefficients. First the Gaussian distribution is applied to study the integer DCT coefficients in H.264 and hence an adaptive scheme with multiple thresholds is derived to realize different types of DCT and Q implementations. Then the adaptive scheme is further optimized by considering a more efficient condition to sufficiently detect all-zero DCT blocks.

Compared with other methods, the hybrid model is able to detect more ZQDCT coefficients and hence reduce more computations for H.264 encoding. It is shown by experimental results that the hybrid model can achieve the best performance in reducing computations and obtain almost the same rate-distortion (R-D) performance as the original encoder in the H.264 reference software JM9.5. A Gaussian distribution based model is firstly applied to study the integer DCT coefficients in H.264 and four thresholds are derived to determine five kinds of DCT, Q, IQ and IDCT implementations: Skip, 1x1 DCT, 2x2 DCT, 3x3 DCT and 4x4 DCT. This adaptive scheme of DCT implementation is further optimized by incorporating the sufficient condition proposed in [19] to detect all-zero blocks.

TABLE II. REQUIRED COMPUTATIONS OF DCT/Q/IQ/IDCT AND ADDITIONAL OVERHEADS.

DCT/Q/IQ/IDCT Implementation				
	ADD	***MUL***	***SFT***	***CMP***
4x4	192	32	112	64
3x3	147	18	76	50
2x2	108	8	58	40
1x1	57	2	37	34
Additional overheads				
[16]	0	0	0	1
[17]	1	0	1	3
[19]	8	0	6	9
GM	0	0	0	[1,4]
HM	8	0	6	[9,12]

To illustrate the number of computations of different types of DCT/Q/IQ/IDCT implementations occurred in the reference software JM9.5 [20], the number of addition (ADD), multiplication (MUL), shift (SFT) and comparison (CMP) operations are listed in Table II. It should be noted that additional overheads are introduced by this HM. These overheads include the computations involved and the comparison operations for determining different types of DCT/Q/IQ/IDCT implementations. However, the HM will detect more ZQDCT coefficients than the other approaches, and thus can reduce more calculations.

On average, the FRR value obtained by this HM is 37.96% which is less than GM. Because HM is the improvement of GM by introducing a more efficient sufficient condition to detect all-zero blocks, the same FAR results are obtained by HM and GM. The average PSNR loss is 0.002 dB with the maximum PSNR loss of 0.009 dB and thus negligible. Moreover, the average bit rate has been reduced by 0.05% on average, which indicates that HM can achieve better bit rate performance than the original encoder. Therefore, HM accomplishes a trade-off between the encoded video quality in terms of PSNR and the compression efficiency in terms of bit rate, and retains almost the same R-D performance as the original encoder.

6. *Through Vector Operations:*

In [21] an efficient method through the vector operations is proposed to early detect all-zero block (AZB) before the transform and quantization on H.264. Experimental results show that this method is superior to other algorithms in terms of the hit detection rate and the computational complexity reduction at the expense of insignificant degradation of video quality. The method for AZB detection is according to the significant relationship: a quantized block relative to multiplication factors (MF). Firstly, a novel model is used to form the transform signals in vector by the matrix direct product, and furthermore three criteria of AZB detection are derived by vector resultant. The detection rate and computational computations could be better than [16]-[17]. In addition, it ensures that this method could be utilized to enhance the detection ability while reducing the computations relatively.

Each component of transformed block (W) will be quantized by a quantization parameter (QP). The quantization process of H.264/AVC as follows

$$q_{nv} = \text{sign}(w_{uv}) . (|w_{uv}| . MF_{QP\_rem,idx} + c) >> QBits,$$
$$\text{sign}(q_{uv}) = \text{sign}(w_{uv}) \text{ where } 0<=u, v<=3 \quad (3)$$

where QBits = 15 + floor(QP/6), QP_rem = QP%6, the constant c = 2QBits /3 for intra blocks or c = 2QBits /6 for inter blocks, and the symbol ">>" indicates a binary shift right operator, idx = 2 – (u mod 2) – (v mod 2). To determine each transform coefficient is equal to zero after quantization. It requires the huge amount of computations to judge if quantized signal is less than TH(QP_rem,idx). The transform block (W) and the thresholds (TH) are regarded as two 4×4 matrices, which specifies the relative coordinate of the (u,v)th position. As the QP_rem is fixed, the threshold TH(*,idx) is constant on idx={0, 1, 2}. These 16 transform elements can be classified into three sets depending on the (u,v)th position. S_{idx} is the set of transform signals according to the value of idx. If all transform signals of these three sets in this transform block are less than threshold TH(QP_rem,idx) concurrently, this transform block will be an AZB. In order to reduce the computations of AZB detection, find vector resultants to represent these three sets respectively. Using the "vector addition" operation, an identical vector (e.g. vector resultant) is obtained by row vectors H_p in which of S_{idx}.

According to the above procedures, the sufficient condition of AZB detection is defined as

$$S < TH(QP\_rem, idx) \text{ for } idx = 0, 1, \text{ and } 2 \quad (4)$$

In average, PSNR drop is about 0.15 dB. It is so small that it does not influence the human being's visual quality at all. The detection of AZBs of this method is more efficient than the others two algorithms and thereby mostly all zeros block in the video sequence were detected. These blocks correspond to approximately 60% - 94% of the total AZBs detected by this vector operations method.

7. *New Rate-Quantization Models:*

To eliminate the redundant computations in AZB and consequently speed up the encoding process of H.264 video codec, a new rate-quantization model [22] is introduced. This algorithm achieves a high detection ratio up to 95.88% while maintain a very low false detection ratio. The results confirm that a more effective AZB detection for H.264 can be achieved by taking the unique feature of quantization into consideration. The criteria for the early detection of AZB are theoretically derived from two new rate-quantization models. They are different from all the existing algorithms. By exploring the unique features of their quantization processes, two models are set up for the INTRA and INTER modes in H.264. Since different criteria are applied to detect AZBs for INTRA and INTER modes, a better tradeoff between the detection ratio and false detection ratio could be obtained by using this scheme.

8. *All-Zero Block and Partial-Zero Blocks Determination:*

Ji *et al.* [23] proposes a novel approach to early determination of zero-quantized 8×8 discrete cosine transform (DCT) coefficients for fast video encoding. First, with the dynamic range analysis of DCT coefficients at different frequency positions, several sufficient conditions are derived to early determine whether a prediction error block (8×8) is an all-zero or a partial-zero block, i.e., the DCT coefficients within the block are all or partially zero-quantized. Being different from traditional methods that utilize the sum of absolute difference (SAD) of the entire prediction error block, the sufficient conditions are derived based on the SAD of each row of the prediction error block. For partial-zero blocks, fast DCT/IDCT algorithms are further developed by pruning conventional 8-point butterfly based DCT/IDCT algorithms.

All methods reviewed above are only used to early determine all-zero blocks. However, although some of the prediction error blocks cannot be determined as all-zero ones under a sufficient condition, partial coefficients in those blocks can be quantized to zeros and determined by new sufficient conditions. Fig 1. depicts the procedure for the early determination of zero-quantized coefficients for an 8x8 inter-block.

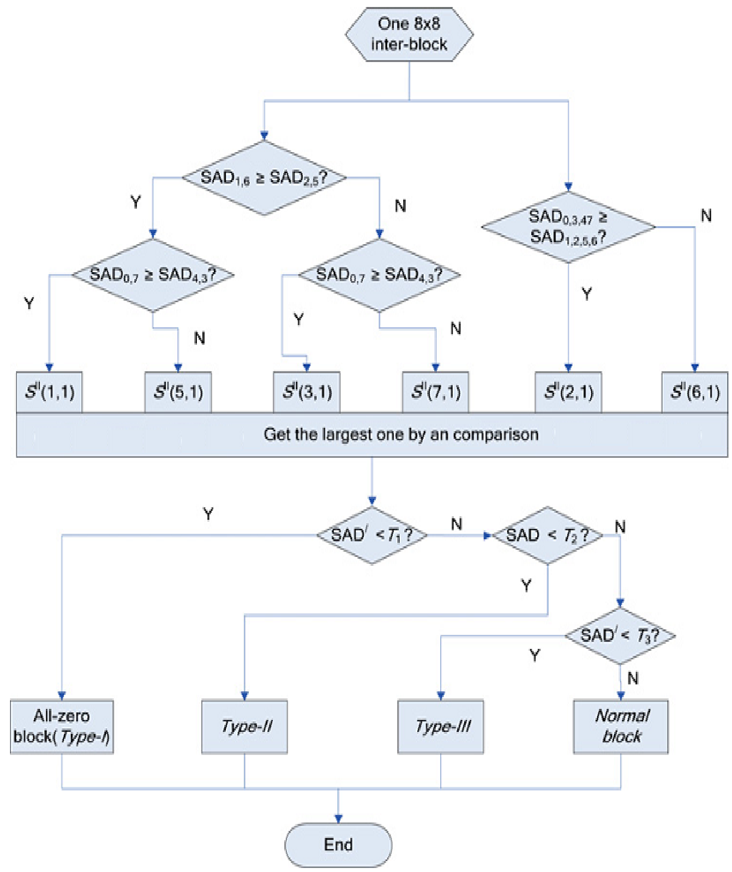

Figure 1. Early determination algorithm in [23]

Sousa's model [16] provides a sufficient condition for early determination of all-zero blocks and, Wang's model [6] use the same condition as Sousa's model for all zero blocks determination and further gives several sufficient conditions for partial-zero block determination. As compared with Sousa's model and Wang's model, our model provides a more precise sufficient condition for early determination of all-zero blocks. For sequence Table tennis at Qp = 21, only 42.04% blocks are determined as all-zero ones for Wang's mode while 53.11% for this model.

IV. Conclusion

In this paper we presented an overview of early determination of zero quantized coefficients. In the overview of these techniques, we discussed various early determination algorithms to detect zero quantized DCT coefficients before implementing DCT and quantization and thus reduce redundant computations for video coding. As a consequence, the computation of video coding is greatly reduced with a very little degradation of video quality.

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