Improved All Zero Block Algorithm for MPEG-4 Encoder

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Abstract—An improved algorithm for the early detection of all-zero blocks in MPEG-4 / H.263 video encoder for video conferencing and video encoding application is proposed in this paper. Based on the theoretical analysis for the discrete cosine transform and quantization in MPEG-4 / H.263 encoder, a sufficient condition under which each quantized coefficient of Discrete Cosine Transform (DCT) block becomes zero is derived. And then, a more precise sufficient condition is proposed by modifying the calculation of AC and DC energy of coefficients, from the sum of absolute difference (SAD) obtained in the motion estimation. The simulation results show that the proposed algorithm achieves approximately an 11%–36% computational saving without video-quality degradation, compared to the conventional method. Experimental results show that the proposed algorithms outperform the previous methods in all cases and achieve major improvement in computation reduction in the range from 4.86% to 73.55% for the 8 x 8 transform. The computation reduction increases as the Quantization value (QP) increases.

Keywords-All Zero Block, DCT, MPEG-4 Encoder, ARM.

I. INTRODUCTION

The video coding technology plays a key role in servicing various multimedia applications. MPEG-4 / H.263 [1] [2] have been established as a proven standard by ISO/IEC MPEG in order to support videophone and videoconferencing applications, among others. With the emerging mobile market, providing more and more multimedia applications on low processing single core processor over DSPs adds cost advantages. Although a primary goal of the MPEG-4 encoder is to represent information as compactly as possible without compromising video fidelity, it is also very important to reduce the computational requirements of the encoder, especially on low power mobile device. Enormous number of computations required in MPEG-4 video encoding limits the applications; it can be used for, on low cost low power ARM cores. Therefore, reducing the computations of the encoder is vital for this standard. Many researchers have investigated the motion estimation of MPEG-4 encoder because it occupies about 70% of the total encoding computations. As the motion estimation is improved, the portion of the transform and quantization becomes approximately 24% of the total computations. This cannot be neglected for the realization of the encoder. Therefore, it is meaningful to develop the efficient transform and quantization for fast encoding.

It is very common that a substantial number of inter-macro blocks in the encoder are reduced to all-zero values after quantization for low bit-rate coding. Therefore, considerable computation can be saved if there is a method of early predicting those blocks, which will be quantized to zeros after implementing DCT and quantization. In this paper, the concept of detection of all-zero quantization coefficients before transformation and quantization has been extended and adapted to MPEG-4 / H.263 encoder on ARM-11 processor, which helped to achieve desired performance for video conferencing up to CIF resolution.

Xuan [3] and other researchers cited in [4], [5] and [6] had earlier proposed an early detection method for All-Zero Blocks (AZB). From a theoretical analysis, Xuan defined a condition sufficient for quantizing all DCT coefficients to zero. Each block is checked for this condition, and DCT and quantization are skipped for the AZBs. The following part of this paper is organized as follows.

Section 2 reviews the two-dimensional DCT and quantization in MPEG-4 and H.263. In Section 3, a guideline for the judgement according to the principle of DCT and quantization in MPEG-4 and H.263 is proposed. With this guideline, an approach to pre-determine the all-zero transform and quantization coefficient blocks with high efficiency is described in Section 3. Section 4 presents the experimental results, which shows that the proposed approach reduces the coding computation significantly. Finally, section 5 concludes this paper.

II. TWO-DIMENSIONAL DISCRETE COSINE TRANSFORM AND QUANTIZATION IN MPEG-4

First, let's look into the principle of two-dimensional discrete cosine transform.

Let f (x, y) represent the prediction error in an 8x8 image block, then the two-dimensional forward DCT transform F (u, v) is given by:

$$F(u,v)=\frac{1}{4}C(u)C(v)\sum_{x=0}^{7}\sum_{y=0}^{7}f(x,y)\left[\cos[\pi(2x+1)\frac{u}{16}\right]\left[\cos[\pi(2y+1)\frac{v}{16}\right] \quad (1)$$

with $u, v, x, y = 0, 1, 2, ..., 7$

where x, y = spatial co-ordinates in the pixel domain;

u, v = coordinates in the transform domain

C (u) = C (v) = $1/\sqrt{2}$ for u = 0 otherwise 1;

This implies,

$$|F(u,v)| \le \frac{1}{4}\sum_{u=0}^{7}\sum_{v=0}^{7}|f(x,y)| = \frac{1}{4} * SAE; \; u,v \ne 0 \quad ... (2)$$

$$= \frac{1}{8} * SAE \; ; u,v = 0 \quad ... (3)$$

The dc term of the DCT corresponds to the point at u = v = 0, which simplifies to

$$F(0,0)=\frac{1}{8}\sum_{x=0}^{7}\sum_{y=0}^{7}f(x,y) \quad ... (4)$$

When using the H.263 quantizer, the quantization for INTER mode blocks AC/DC coefficients can be expressed as:

$$coeff(u,v)=sign(F(u,v))*\frac{|F(u,v)|-QP/2}{2*QP} \quad ..(5)$$

For MPEG-4, the quantization for INTER mode blocks AC/DC coefficients is given as:

$$coeff(u,v)=sign(F(u,v))*\frac{(16*|F(u,v)/w[u][v]|}{2*QP} \quad ...(6)$$

where w is the non-intra quantizer matrix, QP is the quantization parameter

From above equations (5) and (6), it can be guaranteed that the DC component of an inter block would be zero if the following condition is satisfied:

For H.263 => $SAE < 20*QP$ … (7)

For MPEG-4 => $SAE < 16*QP$ …. (8)

where SAE is the Sum of Absolute Errors.

Therefore, the coefficients in the 8x8 block will quantize to zeros whenever the magnitude of F(0,0) is less than the quantization step size, i.e.,

For H.263,

$$abs(\sum_{x=0}^{7}\sum_{y=0}^{7}f(x,y)) < 20*Q \quad ... (9)$$

And for MPEG-4,

$$abs(\sum_{x=0}^{7}\sum_{y=0}^{7}f(x,y)) < 16*Q \quad ... (10)$$

holds true. This condition is not computational intensive on an RISC machine. Also it is independent of input sequence characteristics and adapts with quantization step size (2Q). A more stringent condition for more successful detection of an AZB block is put which avoids the PSNR degradation while maintaining less computational complexity.

III. Algorithm Description

The motivation for the proposed algorithm comes from the observation that, for most sequences at low bit rates, a significant portion of all macroblocks -- typically 30% to 65% -- have DCT coefficients that are all reduced to zero after quantization.

The proportion of all-zero block (AZB) macroblocks is somewhat sequence-dependent, but, for bitrates that H.263 operates around, it is not unreasonable to expect that more than 50% of all inter-macroblocks will reduce to zero after quantization. In fact, for the sequences used for simulation, at bitrates between 64 to 384kbits/sec, the number of AZB macroblocks increases to 87% or more. Also, for the low motion sequences, the numbers of AZB blocks are more. If it were possible to predict when this happens, it would be possible to eliminate a portion of the computation associated with those macroblocks. A substantial savings can be achieved in this way.

To extend this idea, two improved Sum of Absolute Errors (SAE) based sufficient conditions for AZB detection have been proposed for an 8 x 8 block. More successful prediction of AZB macroblocks can be performed by using the dc coefficient as well as ac coefficient of the DCT as an indicator. It has been observed that, in the majority of cases, the dc coefficient has a larger magnitude than all other coefficients in a transformed block. Since the coefficients in a block will quantize to zeros only if their magnitudes are less than 2Q, it follows that, when this observation holds true, a block will quantize to zeros when the dc coefficient has a magnitude less than 2Q. However this may also lead to errors in detection termed as, False Alarm and Mis-Detection cases. To make the decision making more stringent the DC as well as AC coefficient are taken into consideration. Also the complexity of calculation is kept at minimal by suitable approximation which helps to keep computation at low with no compromise on the video quality aspect. This has been confirmed by checking the PSNR of the decoded streams. The flow diagram for the prediction to save computation in the DCT and Quantizer is shown in Figure (1).

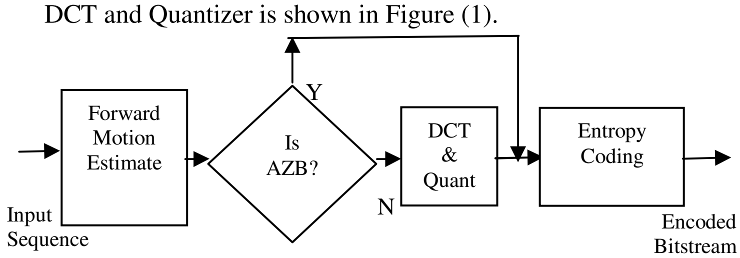

Figure 1: AZB Detection in MPEG-4 Ecnoder

A. *AZB Detection for Inter Macroblocks:*

After the motion estimation has been done and the inter-macroblock error is known, the prediction method, to determine which inter-macroblock errors should be sent to the DCT, is applied. If indeed a macro block's coefficients will quantize to zero, there is neither any need to calculate the DCT coefficients nor to quantize it. Therefore, those macroblocks whose errors pass the AZB test skip the DCT and quantization operations and go directly to the entropy coder. The coefficients for these macroblocks are set to zero. This test has been performed only on inter-macroblocks, because intra-macroblocks are less likely to satisfy the assumption that the dc DCT coefficient has the largest magnitude.

As per Parseval's theorem [7], for N x N residual block

$$\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} f^2(x,y) = \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} F^2(u,v) \quad \text{....(11)}$$

The DC coefficient is given by:

$$F(0,0) = \frac{1}{N}\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} f(x,y) \quad \text{... (12)}$$

The Energy of AC coefficient is given by:

$$\sum_{u+v\neq 0} F^2(u,v) = \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} f^2(x,y) - F^2(0,0) \quad \text{... (13)}$$

Therefore for a Block to be AZB, the necessary conditions are:

$$|F(0,0)| < 16 * QP \quad \text{.... (14)}$$

$$\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} f^2(x,y) - F^2(0,0) < (QP)^2 \quad \text{.... (15)}$$

Computation of sum of squares for each block of 8x8 is expensive, so the condition is modified for determining the sum of AC coefficients and making use of approximation, the modified equation is

$$AC = SAE - DC \quad \text{.... (16)}$$

The modified algorithm is proposed as a combination of equation (14) and equation (16). Hence to guarantee a block to be AZB, the following algorithm criteria must be satisfied

$$SAE < 16 * QP \;\; \text{... (17)} \qquad AC < QP \;\; \text{.... (18)}$$

Calculate the DC value for each 8x8 luminance block in the macroblock using equation (4). Calculate the AC value using equation (16). If the SAE obtained from the motion estimation stage of Encoder for a block has a magnitude less than 16 times of QP and AC value is less than QP then assume that the block will quantize to zero. This more stringent criterion ensures that the Hit Ratio is increased while the Errors in detection of a zero block goes down for AZB macroblocks, which leads to very less degradation in the final picture fidelity. The trade-off between the several variations for identifying AZB macroblocks comes from the two important factors, namely Hit Ratio and Errors associated with it.

Hit Ratio: It is the ratio of number of true All Zeros Blocks present in an Inter Frame to the number of correctly detected All Zeros Blocks. The more the Hit Ratio, the more are number of AZBs detected by the Algorithm, thereby avoiding DCT and Quantization stages and leading to improvement in performance.

$$\text{Hit Ratio(HR)} = \frac{\text{(AZB Detected)}}{\text{(Actual AZB)}} \quad \text{.... (19)}$$

Error: While Hit Ratio is important from performance point of view, the errors associated with his scheme are more important from picture fidelity point of view. There are two types of errors associated with the AZB classification scheme. Each time one use a feature to do the above classification, there are instances where one classify a block as zero, when it should have been coded instead (one). This error is referred as false alarm (FA).The second type of error encountered in such a classification scheme is when one classifies a block to be one when in reality it should have been zero. This error is referred as misdetection (MD). A quantitative measure of false alarm and misdetection has been formally defined:

$$FA = \frac{N_{AZB}}{N1} \;\; \text{.... (20)} \qquad MD = \frac{N_{non\text{-}AZB}}{N0} \;\; \text{.. (21)}$$

where N_{AZB} is the number of blocks classified as zero, $N_{non\text{-}AZB}$ is the number of blocks classified as one ,N0 is the number of true zero blocks, N1 is the number of true non-zero (one) blocks.

The effectiveness of the modified algorithm is compared by plotting false alarm (FA), misdetection (MD) and Hit Ratio (HR) plots against the existing AZB algorithm for various sequences at different bit rates. It is observed that the proposed algorithm has higher Hit Ratio and at the same time maintains low FA and MD thereby guaranteeing good video quality.

IV. RESULTS

The Algorithm has been tested for six video streams of QVGA size encoded at 30fps and various bit rates with MPEG-4 Encoder. The following 3 Algorithms are considered for the plots:

TABLE I. ALGORITHM SUMMARY

Algorithm	Mathematical Model	Summary
1	SAE <16* Q	Basic Conditions derived form DCT.
2	SAE<16*Q or AC Energy < (Q)2	Computationally Intensive.
3	SAE<16*Q or AC < Q	Proposed Algorithm, Computational inexpensive while maintaining picture fidelity

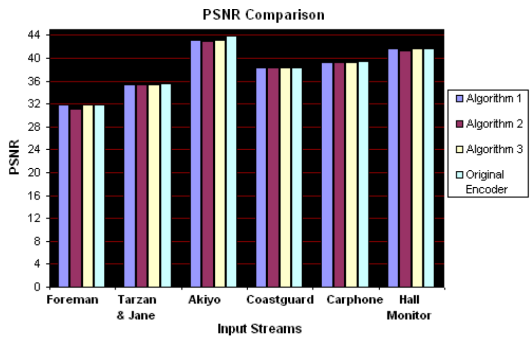

Figure 2: PSNR comparison

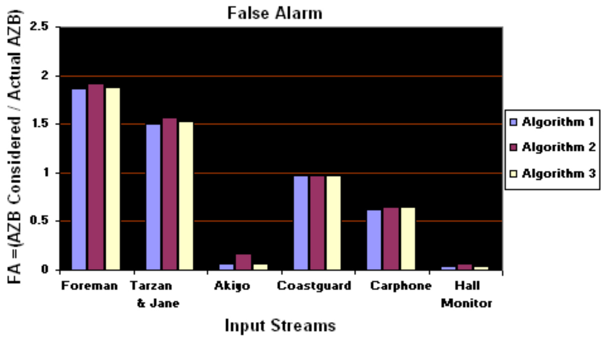

Figure 3: Plot for False Alarm

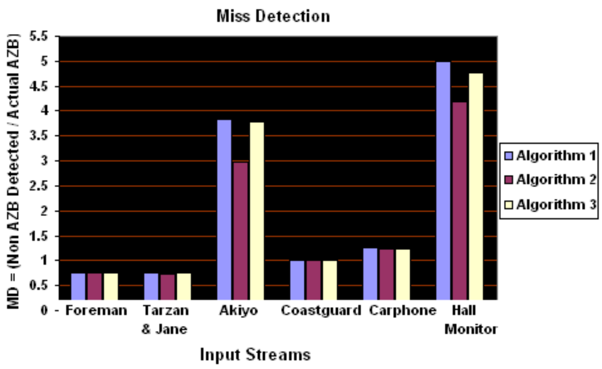

Figure 4: Plot for Mis-Detection

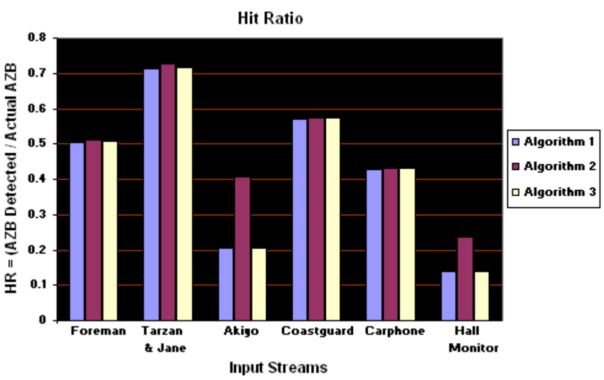

Figure 5: Plot for Hit Ratio

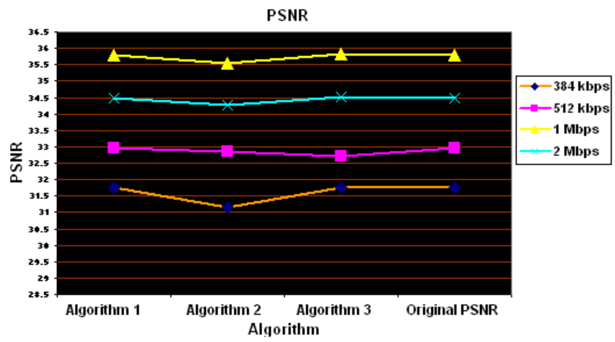

Figure 6: Plot for PSNR at various Bit Rates

V. Conclusion

Based on the theoretical and statistical analysis, a more stringent algorithm under which each quantized coefficient becomes zero have been derived for detecting AZBs early in MPEG-4/H.263 video encoding. In addition, it can be seen that the proposed condition is not computation intensive to be implemented.

The algorithm has been tested for low motion (sequence no.1, 3, and 5) as well as high motion (sequence no. 2) video streams at various bit rates till 2 Mbps.

The simulation results show that the proposed algorithm detects AZBs more precisely. It is evident from the plots of FA and MD that the proposed algorithm maintains good picture fidelity while increasing the Hit Ratio.

The proposed algorithm achieves approximately an 11%–36% computational saving. Therefore, the proposed algorithm effectively eliminates the redundant calculations for the transform and quantization without degrading video-quality.

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