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Improved Intra Prediction of H.264/AVC

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1. Introduction

H.264/AVC is the latest international video coding standard developed by ITU-T Video Coding Expert Group and the ISO/IEC Moving Picture Expert Group, which provides gains in compression efficiency of about 40% compared to previous standards (ISO/IEC 14496-10, 2004, Weigand et al., 2003). New and advanced techniques are introduced in this new standard, such as intra prediction for I-frame encoding, multi-frame inter prediction, small block-size transform coding, context-adaptive binary arithmetic coding (CABAC), de-blocking filtering, etc. These advanced techniques offer approximately 40% bit rate saving for comparable perceptual quality relative to the performance of prior standards (Weigand ct al., 2003). H.264 intra prediction offers nine prediction modes for 4x4 luma blocks, nine prediction modes for 8x8 luma blocks and four prediction modes for 16 x 16 luma blocks. However, the rate-distortion (RD) performance of the intra frame coding is still lower than that of inter frame coding. Hence intra frame coding usually requires much larger bits than inter frame coding which results in buffer control difficulties and/or dropping of several frames after the intra frames in real-time video. Thus the development of an efficient intra coding technique is an important task for overall bit rate reduction and efficient streaming. H.264/AVC uses rate-distortion optimization (RDO) technique to get the best coding mode out of nine prediction modes in terms of maximizing coding quality and minimizing bit rates. This means that the encoder has to code the video by exhaustively trying all of the nine mode combinations. The best mode is the one having the minimum rate-distortion (RD) cost. In order to compute RD cost for each mode, the same operation of forward and inverse transform/quantization and entropy coding is repetitively performed. All of these processing explains the high complexity of RD cost calculation. Therefore, computational complexity of encoder is increased drastically. Using nine prediction modes in intra 4x4 and 8x8 block unit for a 16x16 macroblock (MB) can reduce spatial redundancies, but it may needs a lot of overhead bits to represent the prediction mode of each 4x4 and 8x8 block. Fast intra mode decision algorithms were proposed to reduce the number of modes that needed calculation according to some criteria (Sarwer et al.,2008, Tsai et al., 2008, Kim, 2008, Pan et al., 2005, Yang et al., 2004). An intra mode bits skip (IBS) method based on adaptive single-multiple prediction is proposed in order to reduce not only the overhead mode bits but also computational cost of the encoder (Kim et al., 2010). If the neighbouring pixels of upper and left blocks are similar, only DC prediction is used and it does not need prediction mode bits or else nine prediction modes are computed. But the IBS method suffers with some drawbacks a) the reference pixels in up-right block are not considered for similarity

measure. If variance of reference pixels of upper and left blocks is very low, diagonal-down-left and vertical-left-modes are not similar to all other modes. But IBS considered all modes produce similar values. In this case, only DC prediction mode is not enough to maintain good PSNR and compression ratio. b) In IBS, each block is divided into two categories, either DC modes or all 9 modes. That's why; the performance improvement is not significant for very complex sequences such as Stefan because only small amount of blocks are predicted by DC mode for these types of sequences. c) also computational expensive square operations are used in variance and threshold calculation which is hardware inconvenient in both encoder and decoder side. In order to reduce the intra mode bits, methods for estimating the most probable mode (MPM) are presented in (Kim et al., 2008, Lee et al., 2009). But the performance improvements are not significant.

The rest of this chapter is organized as follows. Section 2 provides the review of intra-prediction method of H.264/AVC. In Section 3, we describe the proposed method. The experimental results are presented in Section 4. Finally, section 5 concludes the paper.
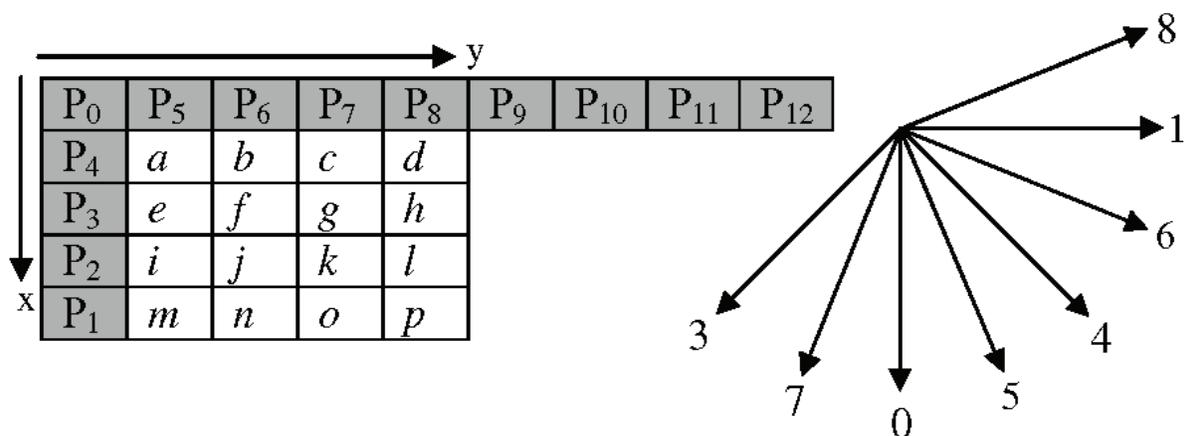

Fig. 1. Labelling and direction of intra prediction (4x4)

2. Intra prediction of H.264/AVC

In contrast to some previous standards (namely H.263+ and MPEG-4 Visual), where intra prediction has been conducted in the transform domain, intra prediction in H.264/AVC is always conducted in spatial domain, by referring to neighbouring samples of previously coded blocks which are to the left and/or above the block to be predicted. For the luma samples, intra prediction may be formed for each 4x4 block or for each 8x8 block or for a 16x16 macroblock. There are a total of 9 optional prediction modes for each 4x4 and 8x8 luma block; 4 optional modes for a 16x16 luma block. Similarly for chroma 8x8 block, another 4 prediction directions are used. The prediction block is defined using neighbouring pixels of reconstructed blocks. The prediction of a 4x4 block is computed based on the reconstructed samples labelled P_0-P_{12} as shown in Fig. 1 (a). The grey pixels (P_0-P_{12}) are reconstructed previously and considered as reference pixels of the current block. For correctness, 13 reference pixels of a 4x4 block are denoted by P_0 to P_{12} and pixels to be predicted are denoted by a to p. Mode 2 is called DC prediction in which all pixels (labelled a to p) are predicted by $(P_1+P_2+P_3+P_4+P_5+P_6+P_7+P_8)/8$. The remaining modes are defined according to the different directions as shown in Fig. 1 (b). To take the full advantages of all modes, the H.264/AVC encoder can determine the mode that meets the best RD tradeoff

using RD optimization mode decision scheme. The best mode is the one having minimum rate-distortion cost and this cost is expressed as

$$J_{RD} = SSD + \lambda \cdot R \tag{1}$$

Where the SSD is the sum of squared difference between the original blocks **S** and the reconstructed block **C**, and it is expressed by

$$SSD = \sum_{i=1}^{4} \sum_{j=1}^{4} (s_{ij} - c_{ij})^2 \tag{2}$$

where s_{ij} and c_{ij} are the (i, j)th elements of the current original block **S** and the reconstructed block **C**. In equation (1), the R is the true bits needed to encode the block and λ is an exponential function of the quantization parameter (QP). A strong connection between the local Lagrangian multiplier and the QP was found experimentally as (Sullivan & Weigand, 1998)

$$\lambda = 0.85 \times 2^{(QP-12)/3} \tag{3}$$
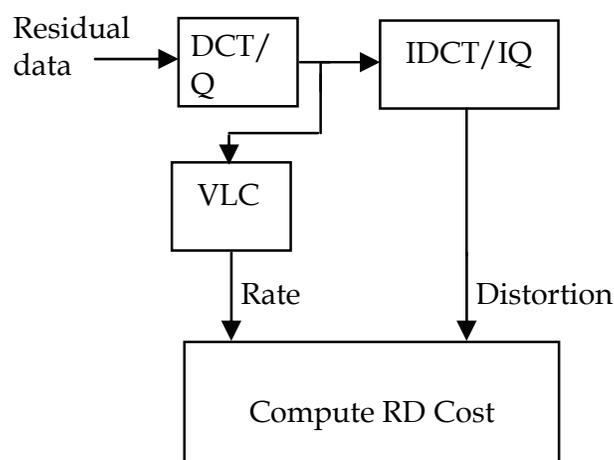
Fig. 2. Computation of RD cost

Fig. 2 shows the computational process of RD cost for 4x4 intra modes. As indicated in Fig. 2, in order to compute RD cost for each mode, same operation of forward and inverse transform/quantization and variable length coding is repetitively performed. All of these processing explains the high complexity of RD cost calculation.

After the best mode is acquired, it will be encoded into the compressed bit stream. The choice of intra prediction mode for each block must be signalled to the decoder and this could potentially require a large number of bits especially for 4x4 blocks due to the large number of modes. Hence the best mode is not directly encoded into the compressed bit stream. Intra modes for neighbouring blocks are highly correlated and for example if a previously-encoded block was predicted using mode 2, it is likely that the best mode for current block is also mode 2. To take advantage of this correlation, predictive coding is used to signal 4x4 intra modes.

For current 4x4 block, a mode is predicted based on the modes of upper and left blocks and this mode is defined as the most probable mode (MPM). In the standard of H.264/AVC, the

MPM is inferred according to the following rules; if the left neighbouring block or the up neighbouring block is unavailable, the MPM is set to 2(DC) or else the MPM is set to the minimum of the prediction mode of left neighbouring block and the up neighbouring block. For intra prediction according to each prediction mode, the encoder uses the condition of the MPM with a flag to signal the prediction mode. If the MPM is the same as the prediction mode, the flag is set to "1" and only one bit is needed to signal the prediction mode. When the MPM and prediction mode is different, the flag is set to "0" and additional 3 bits are required to signal the intra prediction mode. Encoder has to spend either 1or 4 bits to represent the intra mode.

N	N	N	N	N	N	N	N	N
N	a	b	c	D				
N	e	f	g	H				
N	i	j	k	L				
N	m	n	o	P				

Fig. 3. Case 1: All of the reference pixels have same value

3. Proposed improved 4x4 Intra prediction method

3.1 Adaptive number of modes

Although H.264/AVC intra coding method provides good compression ratio, owing to the use of nine prediction modes of 4x4 luma blocks, its computational complexity increases drastically. Using nine prediction modes in intra 4x4 block unit for a 16x16 MB can reduce the spatial redundancies, but it may needs a lot of overhead bits to represent the prediction mode of each 4x4 block. Based on the variation of neighboring pixels, the proposed method classifies a block as one of three different cases.
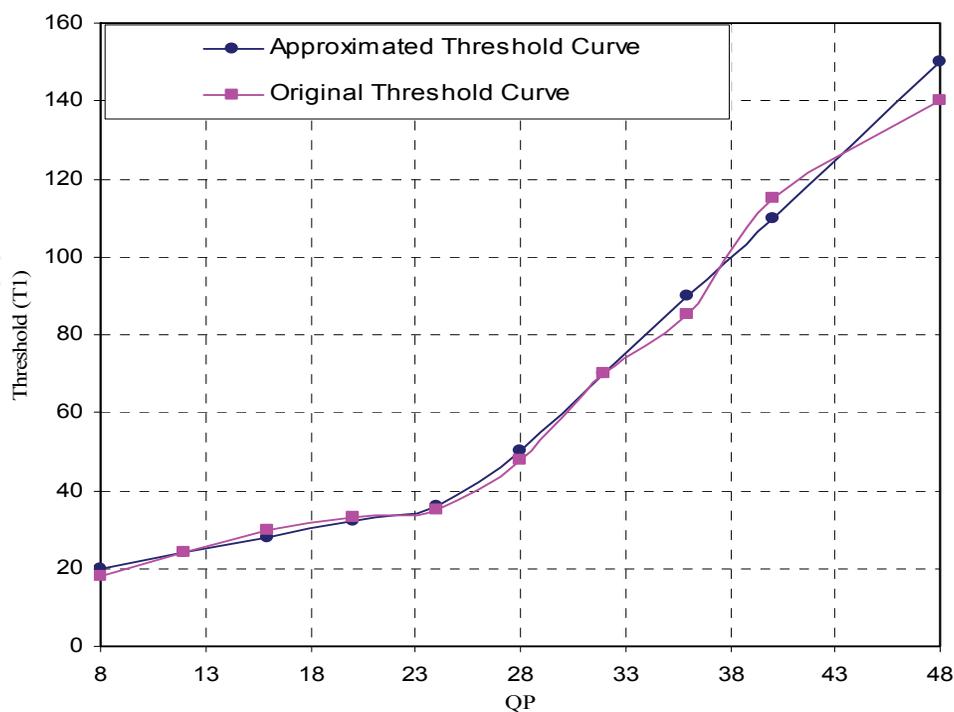

Fig. 4. Variation of threshold T_1 with QP

a. Case 1:

As shown in Fig. 3, if all of the reference pixels are same, the prediction values of nine directional predictions are same. In this case, it does not need to calculate the entire prediction modes. Only DC mode can be used, so that the prediction mode bit can be skipped. If variance σ_1 of all of the neighboring pixels is less than the threshold T_1, only DC prediction mode is used. The variance σ_1 and mean μ_1 is defined as,

$$\sigma_1 = \sum_{i=1}^{12} |P_i - \mu_1| \text{ , and } \mu_1 = \left\lfloor (\sum_{i=1}^{12} P_i)/12 \right\rfloor \qquad (4)$$

where P_i is the i-th reference pixel of Fig. 1(a) and μ_1 is the mean value of block boundary pixels. In order to set the threshold T_1, we have done several experiments for four different types of video sequences (*Mother & Daughter, Foreman, Bus* and *Stefan*) with CIF format at different QP values. *Mother & Daughter* represents simple and low motion video sequence. *Foreman* and *Bus* contain medium detail and represent medium motion video sequences. *Stefan* represents high detail and complex motion video sequence. By changing the threshold, we observed the RD performance and found that threshold T_1 is independent on the type of video sequence but depends on the QP values. Fig. 4 shows the variation of selected threshold T_1 with QP values. The original threshold curve is generated by averaging the threshold values of all four sequences for each QP. By using the polynomial fitting technique, the generalized threshold value T_1 is approximated as follows:

$$T_1 = \begin{cases} QP + 12 & \text{if } QP \le 24 \\ 5QP - 90 & \text{Otherwise} \end{cases} \qquad (5)$$

b. Case 2:

As shown in Fig. 5, if all of the reference pixels of up and up-right blocks are same, vertical, diagonal-down-left, vertical-left, vertical-right and horizontal-down modes produce the same prediction value. That's why, in the proposed method we have chosen only vertical prediction mode from this group. If variance σ_2 of the neighboring pixels of up and up-right blocks is less than the threshold T_2, four prediction modes (vertical, horizontal, diagonal-down-right and horizontal-up) are used. Instead of using 3 bits of original encoder, each of four prediction modes is represented by 2 bits that is shown in Table 1. Threshold T_2 is selected as same way of T_1. T_2 also depends on the QP and better results were found at $T_2 = \lfloor (2T_1/3) \rfloor$. The variance σ_2 and mean μ_2 are defined as,

$$\sigma_2 = \sum_{i=5}^{12} |P_i - \mu_2|, \text{ and } \mu_2 = \left\lfloor (\sum_{i=5}^{12} P_i)/8 \right\rfloor \qquad (6)$$

where μ_2 is the mean value of block boundary pixels of top and top-right blocks.

The flow diagram of the proposed method is presented in Fig. 6. The variance σ_1 and threshold T_1 are calculated at the start of the mode decision process and if the variance is less than the threshold ($\sigma_1 < T_1$) only DC prediction mode is used. In this case computational expensive RDO process is skipped and a lot of computations are saved. In

Mode	Binary representation
Vertical	00
Horizontal	01
Diagonal-down-right	10
Horizontal-up	11

Table 1. Binary representation of modes of case 2

P_0	N	N	N	N	N	N	N	N
P_4	a	b	c	d				
P_3	e	f	g	h				
P_2	i	j	k	l				
P_1	m	n	o	p				

Fig. 5. Case 2: The reference pixels of up and up-right blocks have same value
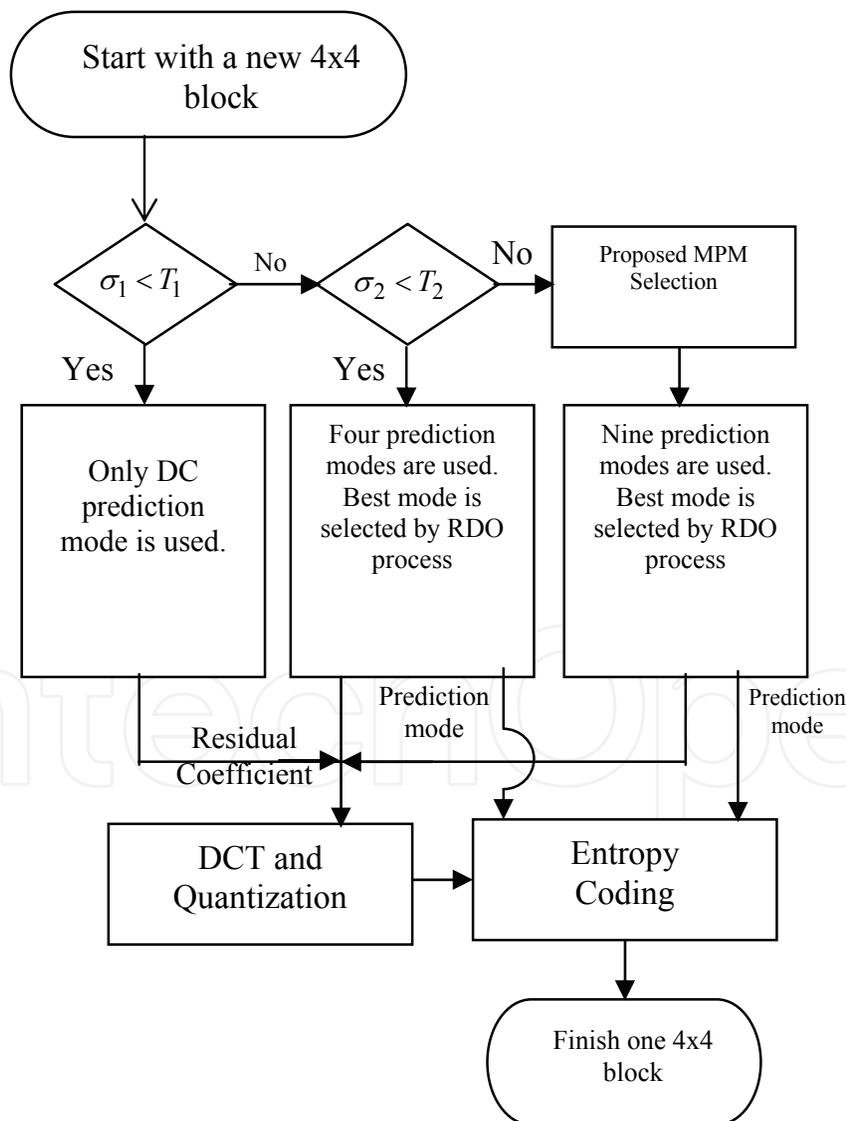
Fig. 6. Flow diagram of proposed method

addition, no bit is necessary to represent intra prediction mode because only one mode is used. In the decoder side, if $\sigma_1 < T_1$, decoder understands that DC prediction mode is the best prediction mode. On the other hand, if $\sigma_1 < T_1$ is not satisfied, encoder calculates the variance σ_2 and threshold T_2. If $\sigma_2 < T_2$, vertical, horizontal, diagonal-down-right and horizontal-up modes are used as candidate modes in RDO process. A substantial saving in computations is achieved using 4 prediction modes instead of 9 modes of the original RDO process. The best mode is the mode which has the smallest rate-distortion cost. In order to represent the best mode, 2 bits are sent to the decoder and Table 1 shows the four prediction modes with corresponding binary representations. As shown in Table 1, if the diagonal-down-right mode is selected as the best mode, the encoder sends "10" to the decoder. In this category, only 2 bits are used to represent the intra prediction mode whereas 3 bits are used in the original encoder. Consequently a large number of intra prediction mode bits are saved.

If $\sigma_2 < T_2$ is not satisfied, nine prediction modes are used as the candidate mode and one of them is selected through the RDO process, as in H.264/AVC. In this case, based on the MPM either 1 or 4 bits are allocated to represent the intra prediction mode. The new prediction mode numbers are recorded and compared against H.264/AVC in Table 2. Since diagonal-down-left, vertical-right, horizontal-down and vertical-left predictions modes are not utilized in the previous cases, the probability of these modes are high in this case and thus these modes are defined as small numbers. Similarly mode numbers for other modes are higher value.

From some simulations, we have found that a significant number of blocks still calculate 9 prediction modes. If the MPM is the best mode, only 1 bit is used; otherwise 4 bits are required to represent the prediction mode. Therefore, if we can develop a more accurate method to estimate the MPM, a significant percentage of blocks will use only 1 bit for mode information.

Mode	Mode number H.264/AVC	Mode number Proposed
Diagonal-down-left	3	0
Vertical-right	5	1
Horizontal-down	6	2
Vertical-left	7	3
Vertical	0	4
Horizontal	1	5
DC	2	6
Diagonal-down-right	4	7
Horizontal-up	8	8

Table 2. Prediction modes recording of the proposed method

3.2 Selection of Most Probable Mode (MPM)

Natural video sequences contain a lot of edges and these edges are usually continuous thus indicating that the prediction direction of neighboring blocks and that of current block is also continuous. Let us consider that X is the current block as shown in Fig. 7 and four neighboring blocks are denoted as A, B, C and D. So if the upper block (B) is encoded with

vertical mode, the mode of current block is more likely to be vertical mode. Similarly, if mode of up-left block (C) is diagonal-down-left mode (mode 4 in Fig. 1(b)), then the mode of the current block is more likely to be diagonal-down-left mode. If the direction from the neighboring block to the current block is identical to the prediction mode direction of the neighboring block, there is a high possibility that the best prediction mode of the current block is also identical to the prediction mode direction. Based on this idea, the weight of the proposed MPM method is proportional to the absolute difference between block direction and mode directions. The mode direction (θ_m) is calculated based on the direction of Fig. 1 (b) and tabulated in Table 3.

C	B	D
A	X	
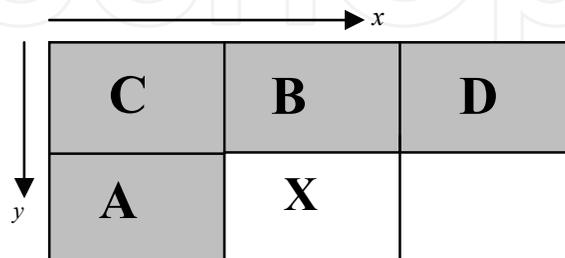
Fig. 7. Current and neighbouring blocks

Mode	Direction
Vertical	$\pi / 2$
Horizontal	0
Diagonal-down-left	$3\pi / 4$
Diagonal-down-right	$\pi / 4$
Vertical- right	$3\pi / 8$
Horizontal-down	$\pi / 8$
Vertical-left	$5\pi / 8$
Horizontal-up	$-\pi / 8$

Table 3. Mode directions (θ_m)

The block direction (θ_B) and block distance (D_B) are calculated by the following set of equations.

$$\theta_B = \tan^{-1} \frac{y_c - y_n}{x_c - x_n} \tag{7}$$

$$D_B = \left| y_c - y_n \right| + \left| x_c - x_n \right| \tag{8}$$

Where, (x_c, y_c) and (x_n, y_n) are the position of current and neighboring block, respectively. The mode of the neighboring block is denoted as M_n. Weight is also dependent on the distance between the current block and neighboring block. If the distance between the current and neighboring block is higher, the correlation between the blocks is lower and weight is also low. Based on these observations weight of neighboring mode M_n is calculated as

$$W(M_n) \;=\; \min[0, \; \frac{\alpha}{D_B} - \beta|\theta_B - \theta_m|] \tag{9}$$

where α and β are the proportionally constant and min(P,Q) means minimum value between P and Q. Based on simulation, α and β are selected as 6 and $\frac{8}{\pi}$.

Instead of using two neighboring blocks A and B in the original H.264/AVC encoder, the proposed method utilizes the prediction mode used in the four neighboring blocks (A, B, C and D). The weight of the prediction mode of each neighboring block is calculated and updated by adding the weight of same mode. Since, DC has no unified direction, if the neighboring mode is DC, the weight corresponding to this block is set to 0. The weight of each prediction mode is counted up and find out the mode with highest weight $W_{\max}$. If the maximum weight $W_{\max}$ is very low, it seems that there is no continuation of edges. In this case, possibility of DC prediction mode to be the best mode is higher. If maximum weight $W_{\max}$ is less than a threshold T_{MPM}, the MPM is the DC mode; otherwise the MPM is the mode with maximum weight $W_{\max}$. Following is the step by step algorithm of the proposed method.

<u>Step 1:</u> Initialize weight (W) of each mode to zero.

<u>Step 2:</u>

For each of the four neighboring blocks (A, B, C and D),

   If neighboring mode $M_n = DC$, $W(M_n) \; += \; 0$.

    Otherwise

a.   Calculate block direction, θ_B and D_B

b.   Find mode direction of the neighboring mode M_n from Table 3.

c.   Calculate weight of neighboring mode:

$$W(M_n) \; += \; \min[0, \; \frac{\alpha}{D_B} - \beta|\theta_B - \theta_m|]$$

End of block

<u>Step 3:</u> Find the maximum weight $W_{\max}$ and the mode that has maximum weight.

<u>Step 4:</u> If maximum weight $W_{\max}$ is less than T_{MPM}, the most probable mode is the DC mode; otherwise MPM is the mode with maximum weight $W_{\max}$.

In order to find the threshold T_{MPM}, we have done some simulations. Four different types of video sequences (*Mother & Daughter, Foreman, Bus* and *Stefan*) were encoded by changing the value of T_{MPM} from 1 to 10 and RD performances were observed. Better results were found at $T_{MPM} = 5$. In order to reduce the computation of (9), α / D_B and θ_B of neighboring blocks A, B, C and D are pre-calculated and stored in a Table. For example, α / D_B is 6 for block A and B, and equal to 3 for block C and D. θ_B is equal to 0, $\pi/2$, $\pi/4$, and $-\pi/4$ for block A, B, C and D, respectively.

4. Simulation results

To evaluate the performance of the proposed method, JM 12.4 (JM reference software) reference software is used in simulation. Different types of video sequences with different resolutions are used as test materials. A group of experiments were carried out on the test

sequences with different quantization parameters (QPs). All simulations are conducted under Windows Vista operating system, with Pentium 4 2.2 G CPU and 1 G RAM. Simulation conditions are (a) QPs are 28, 36, 40, 44 (b) entropy coding: CABAC (c) RDO on (d) frame rate: 30 fps, (e) only 4x4 mode is used and (f) number of frames: 100. The comparison results are produced and tabulated based on the average difference in the total encoding ($\Delta T_1\%$), the average PSNR differences ($\Delta PSNR$), and the average bit rate difference ($\Delta R\%$). PSNR and bit rate differences are calculated according to the numerical averages between RD curves derived from original and proposed algorithm, respectively. The detail procedure to calculate these differences can be found in (Bjontegaard, 2001). The encoding ($\Delta T\%$) complexity is measured as follows

$$\Delta T\% = \frac{T_{original} - T_{proposed}}{T_{original}} \times 100 \tag{10}$$

where, $T_{original}$ denotes the total encoding time of the JM 12.4 encoder and $T_{proposed}$ is total encoding time of the encoder with proposed method.

Sequence	IBS (Kim et al., 2010)		Proposed	
	Δ PSNR	Δ Rate%	Δ PSNR	Δ Rate%
Grand Mother (QCIF)	0.37	-15.4	0.42	-17.0
Salesman (QCIF)	0.32	-12.9	0.40	-14.6
Stefan (QCIF)	0.10	-2.7	0.20	-6.0
Container (QCIF)	0.09	-3.1	0.18	-6.7
Car phone (QCIF)	0.66	-18.4	0.83	-23.8
Silent (CIF)	0.35	-15.4	0.42	-18.0
Bus (CIF)	0.11	-3.8	0.15	-4.1
Hall (CIF)	0.32	-8.6	0.42	-11.3
Mobile Calendar (HD-1280x720)	0.19	-6.8	0.27	-9.8
Average	0.28	-9.7	0.37	-12.4

Table 4. PSNR and bit rate comparison

	IBS (Kim et al., 2010) ΔT %	Proposed ΔT %
Grand Mother (QCIF)	39.7	49.1
Salesman (QCIF)	31.2	35.7
Stefan (QCIF)	17.9	22.6
Container (QCIF)	31.3	37.9
Car phone (QCIF)	33.8	42.0
Silent (CIF)	35.8	43.0
Bus (CIF)	16.4	28.8
Hall (CIF)	38.8	45.0
Mobile Calendar (HD-1280x720)	27.6	33.0
Average	30.3	37.5

Table 5. Complexity comparison of proposed method

The RD performance comparisons are presented in Table 4. In case of the IBS method, the average PSNR improvement is about 0.28 dB and average bit rate reduction is about 9.7%. Whereas in our proposed method, the average PSNR improvement is about 0.37 db and average bit rate reduction is about 12.4%. Out of all video sequences listed in Table 4, the best performance improvement was accomplished for *Car Phone* video sequence; bit rate reduction is about 23.8% and PSNR improvement is 0.83 dB. This is understandable because most of the blocks of this sequence are classified as either case 1 or case 2. The PSNR improvement and bit rate reduction of worst case (*Bus*) is 0.15 dB and 4.14%, respectively.
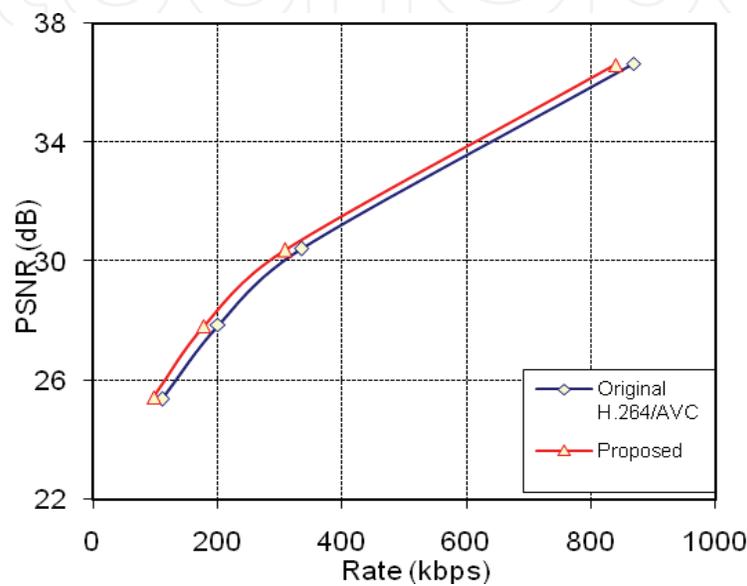
Fig. 8 (a). RD curves of original and proposed method (Salesman QCIF)
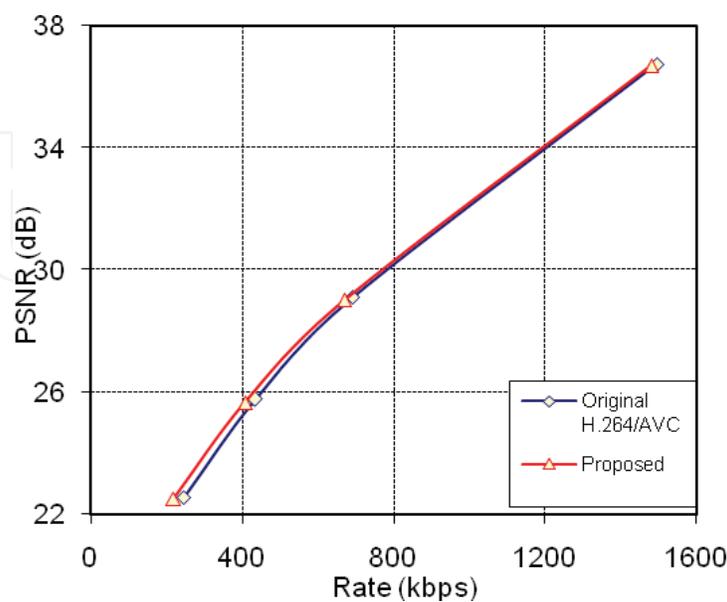
Fig. 8 (b). RD curves of original and proposed method (Stefan QCIF)
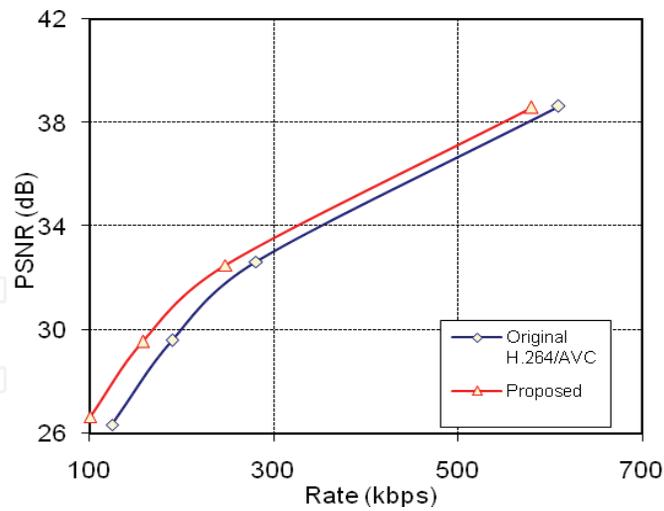
Fig. 8 (c). RD curves of original and proposed method (Car phone QCIF)
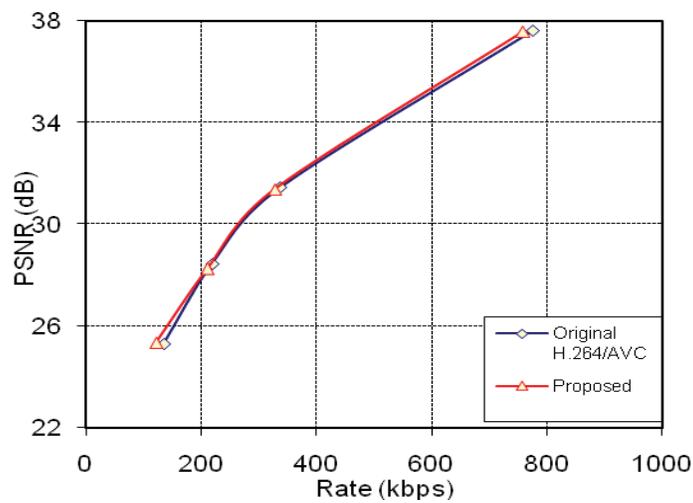
Fig. 8 (d). RD curves of original and proposed method (Container QCIF)
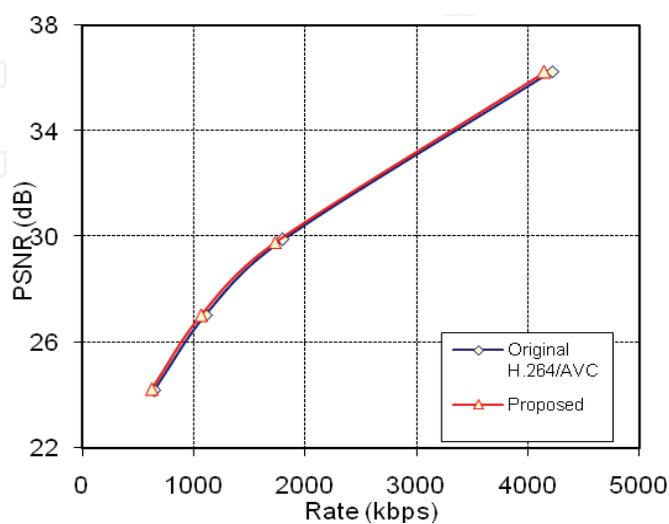
Fig. 8 (e). RD curves of original and proposed method (Bus CIF)
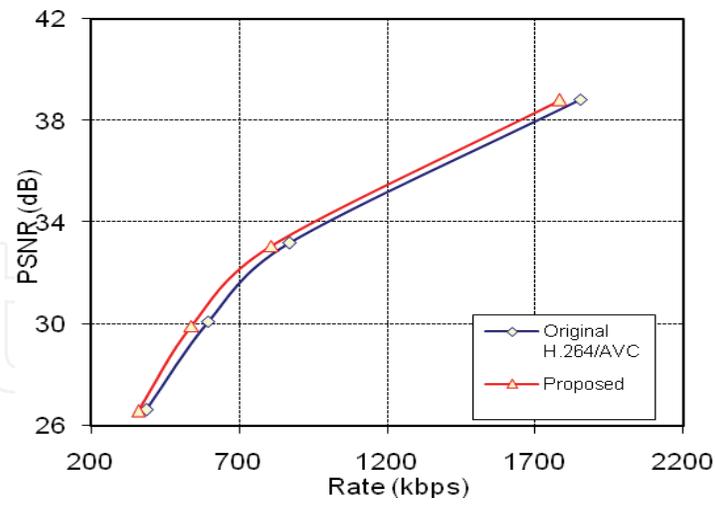
Fig. 8 (f). RD curves of original and proposed method (Hall CIF)
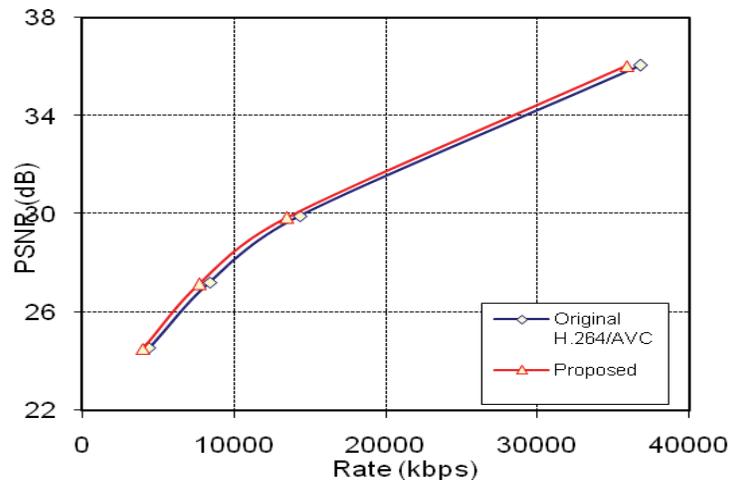

Fig. 8 (g). RD curves of original and proposed method (Mobile Calendar HD)
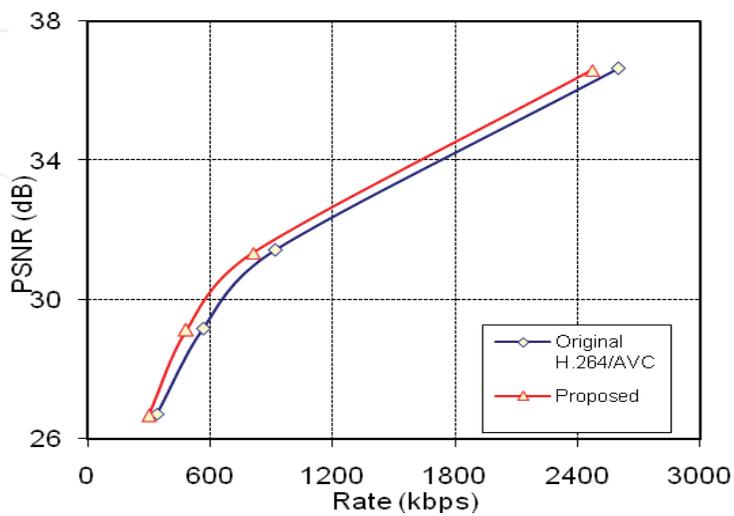
Fig. 8 (h). RD curves of original and proposed method (Silent CIF)
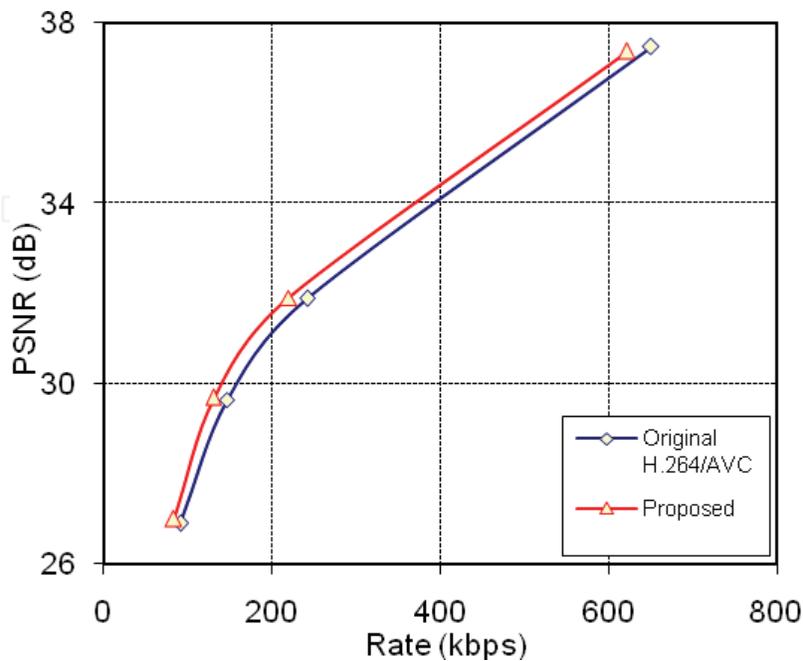
Fig. 8 (i). RD curves of original and proposed method (Grand Mother QCIF)

The computational reduction realized with our proposed method is tabulated in Table 5. Although the proposed method introduces some overhead calculation to select the MPM, the overall computation reductions is still significant and about 7% faster than the method in [6]. The proposed method saves about 37.5% computation of original H.264/AVC intra coder. . The rate-distortion (RD) curves of six different types of video sequences are plotted in Fig. 8. It is shown that RD curve of our proposed method is always superior to that of the original H.264/AVC encoder.

5. Conclusion

In this paper, an intra mode bit rate reduction scheme for representing the intra prediction mode is described. H.264/AVC intra encoder uses nine prediction modes in 4x4 block unit to reduce the spatial redundancies. Too many intra modes not only increase the encoder complexity but also increase the number of overhead bits. In the proposed method, the numbers of prediction modes for each 4x4 block are selected adaptively. Based on the similarities of the reference pixels, each block is classified as one of three categories. This paper also estimates the most probable mode (MPM) from the prediction mode direction of neighbouring blocks which have different weights according to their positions. Experimental results confirm that the proposed method saves 12.4% bit rate, improves the video quality by 0.37 dB on average, and requires 37% less computations than H.264/AVC intra coder. The proposed method not only improves the RD performance but also reduces the computational complexity of H.264/AVC intra coder.

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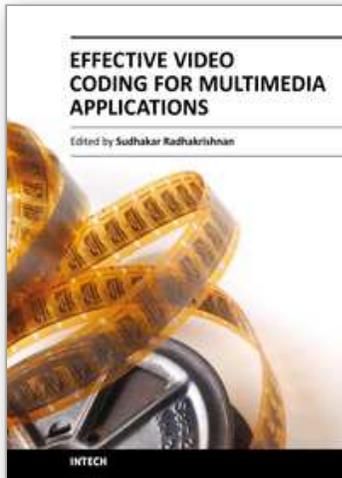
Effective Video Coding for Multimedia Applications

Edited by Dr Sudhakar Radhakrishnan

Information has become one of the most valuable assets in the modern era. Within the last 5-10 years, the demand for multimedia applications has increased enormously. Like many other recent developments, the materialization of image and video encoding is due to the contribution from major areas like good network access, good amount of fast processors e.t.c. Many standardization procedures were carrried out for the development of image and video coding. The advancement of computer storage technology continues at a rapid pace as a means of reducing storage requirements of an image and video as most situation warrants. Thus, the science of digital video compression/coding has emerged. This storage capacity seems to be more impressive when it is realized that the intent is to deliver very high quality video to the end user with as few visible artifacts as possible. Current methods of video compression such as Moving Pictures Experts Group (MPEG) standard provide good performance in terms of retaining video quality while reducing the storage requirements. Many books are available for video coding fundamentals.This book is the research outcome of various Researchers and Professors who have contributed a might in this field. This book suits researchers doing their research in the area of video coding.The understanding of fundamentals of video coding is essential for the reader before reading this book. The book revolves around three different challenges namely (i) Coding strategies (coding efficiency and computational complexity), (ii) Video compression and (iii) Error resilience. The complete efficient video system depends upon source coding, proper inter and intra frame coding, emerging newer transform, quantization techniques and proper error concealment.The book gives the solution of all the challenges and is available in different sections.

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