Method to Minimize Redundancy of Intra-Mode

Kibaek Kim, Dongjin Jung, and Jechang Jeong
Department of Electronics and Computer Engineering
Hanyang University
Seoul, South Korea
k2b0002@hanyang.ac.kr, dling@naver.com,
jjeong@hanyang.ac.kr

Gwanggil Jeon
Department of Electronics and Computer Engineering
University of Incheon
Incheon, South Korea
ggjeon@gmail.com

***Abstract*— In this paper, we present a method to minimize redundancy of intra-prediction mode. To minimize spatial correlation, H.264/AVC standard utilizes intra-prediction approach, which has nine modes for 4x4, 8x8 blocks, and this mode information should be signaled and four bits are needed to represent nine modes in binary. To minimize the average length of mode information, H.264/AVC estimates Most Probable Mode (MPM) and if the MPM is the same as the best intra-predicted mode, only one bit needs to be signaled. In this paper, we propose merging MPM approach to reduce the bits for signaling. By using adaptive scheme of intra-mode signaling, we could achieve 0.801% bit reduction while giving similar performance. In particular, 1.901% bit reduction was achieved in low bit rate condition.**

Keywords-H.264/AVC; Intra-prediction; Coding efficiency; most probable mode.

I. INTRODUCTION

To reduce the coded information of an image within a video sequence, Intra-prediction is an efficient tool. Intra-prediction in the spatial domain was proposed in several proposals and was involved into its current form of H.264/AVC [1-3]. Intra-prediction is to create a predictor block by extrapolation of neighboring coded block's pixels. The predictor block is subtracted from the target block and the residual components are coded by using transform, quantization and variable length coding. Since there are several directions to extrapolate for the target block, we need to determine the direction of prediction from neighboring coded block's pixels. H.264/AVC specifies a DC and 8 directional modes for 4x4 and 8x8 luminance blocks. Only DC, horizontal, vertical and planar modes are available for 16x16 luminance blocks and chrominance blocks. To save mode bit to be sent the decoder, H.264/AVC specifies MPM that estimate prediction mode by selecting direction having small mode number among modes between left and upper block. If the best mode is not equal to MPM, we send best mode to be selected among remaining modes except MPM. Then we need three bits to represent the best mode because one is selected among eight candidate modes (except MPM out of nine modes).

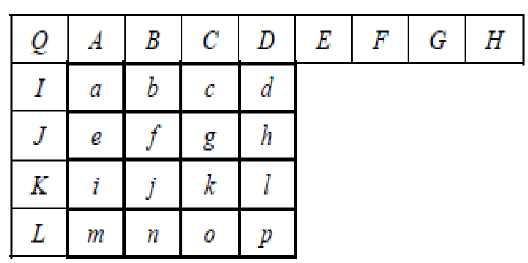
H.264/AVC provides several profiles to support various video services. Among the profiles, H.264/AVC supports baseline profile for low bit rate condition's devices. For low bit rate condition's devices, we can use high quantization parameter (QP) for coding video sequences. In low bit rate conditions, the importance of intra-prediction becomes higher, so we need to reduce the quantity of mode information. To reduce the quantity of mode information, Kim et al. [4] proposed an intra-mode skip method based on adaptive single-multiple prediction and Zhu et al. [5] proposed a clustering approach for reducing the number of intra-modes. By analysis on neighboring block's characteristics, it can reduce the intra-mode bits efficiently. Although some tool can be less complex in the encoder, analysis can be burden in the decoder complexity.

In the paper, we focus on the accuracy rate of MPM and we try to reduce mode bits efficiently. In the decoder, there is no additional analysis, so there is no complex increase. The reminder of this paper is organized as follows. In Section 2, we present the proposed algorithm. Simulation results for a variety of video sequences are provided in Section 3. Finally, conclusions are given in Section 4.

II. PROPOSED ALGORITHM

A. *Intra-prediction in H.264/AVC*

Intra-prediction is conducted in the transform domain, by referring to neighboring samples of previously coded blocks, which are to the left and above the block to be predicted. Macroblock (MB) is the basic coding unit of H.264 and its size is 16x16. According to image characteristic, various block size is applied for prediction. For luminance samples, intra-prediction may be formed for each 4x4 block or for each 8x8 block or a 16x16 block. There are a total of 9 optional prediction modes for each 4x4 and 8x8 luminance block; 4 modes a 16x16 luminance block. Similarly for chrominance 8x8 block, 4 modes are supported.



(a)

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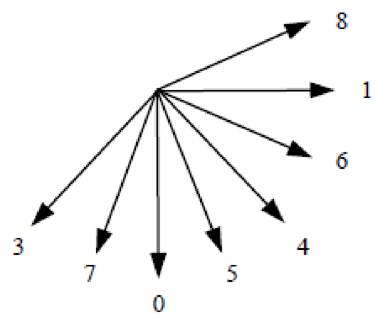


(b)

Figure 1. Labelling and direction of intra-prediction, (a) Neighboring pixels and pixels of current block (b) Eight directional prediction modes

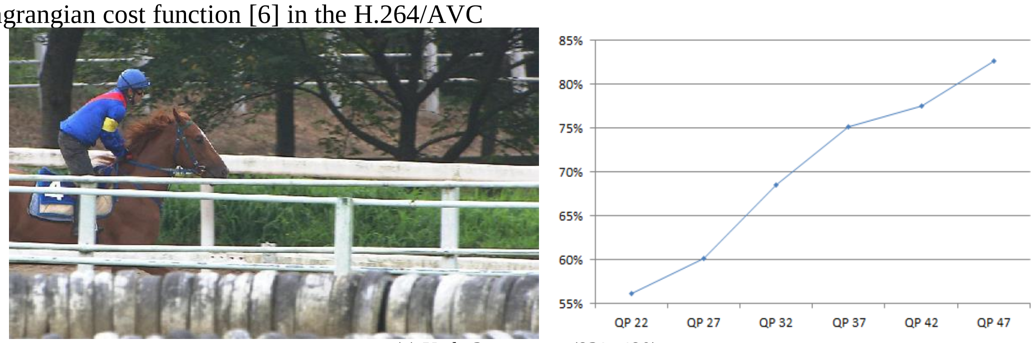
Figure 1 shows labeling and direction of intra-prediction. In Fig. 1(a), the small letter pixels (a~p) are the current 4x4 block and the capital letters (A~L, Q) are the prediction pixels, which are already decoded. Eight of the nine directional predictions are already shown in Fig. 1(b), where DC prediction (mode 2) that uses the average value of the eight boundary pixels (A~D and I~L) as the predictor is not shown. Each block is independently coded as one of the nine prediction modes. One of these nine modes is selected through the Rate-Distortion Optimization (RDO) process [6,7]. To efficiently compress the prediction mode in H.264/AVC, the prediction mode of the current block is estimated from the smaller directional prediction number between the above and left adjacent blocks of the current block. The estimated prediction mode is called the MPM. Just one bit flag is sent to the decoder if the MPM is equal to the best mode of the current block that is determined by computing a Lagrangian cost function [6] in the H.264/AVC encoder. Otherwise, an one bit flag indicating that the MPM does not match the best mode of the current block and an additional three bits are sent to the decoder to represent one of the eight directional modes.

B. *Background about statistic of intra-mode*

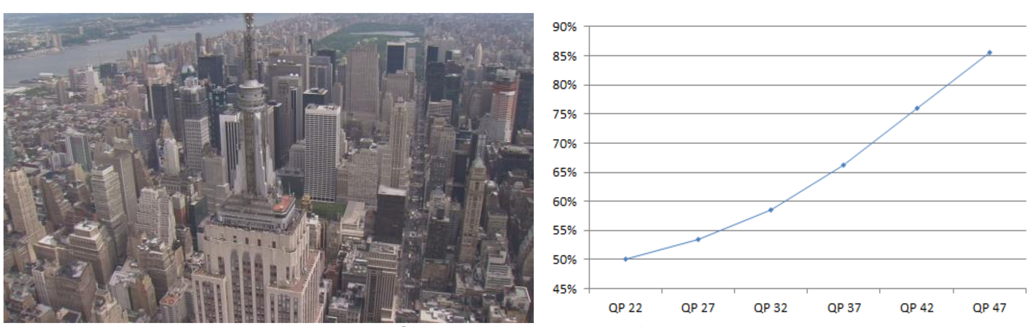
Figure 2 shows the sample of Keiba3 and City sequence and its accuracy rate of MPM, respectively. When QP becomes higher, the accuracy rate of MPM also becomes high. As shown in Fig. 3, bit rate is more important than distortion in low bit rate condition, which loss of residual data incurred by big quantization value. RDO is used to decide which mode is the most appropriate for each MB or block by minimizing the following equation:

$$J(s,c,Mode) = SSD(s,c,Mode) + \lambda \times R(s,c,Mode)$$
$$SSD = \sum_{x=i}^{m}\sum_{y=j}^{n}(s(x,y)-c(x,y))^2 \qquad (1)$$

where λ is the Lagrange multiplier for the mode decision and Mode indicates the mode chosen from the possible prediction mode candidates. SSD is the sum of squared differences between the original 4x4 block luminance signal (s) and its reconstruction signal (c) and R represents the number of bits associated with the chosen Mode. s(x,y) and c(x,y) denote the original luminance and reconstructed pixel values, respectively. When QP increases, λ also increases. Mode with short R (that is, MPM) is advantageous in low bit rate condition. High QP means an increase of quantization step size.



(a) Keiba3 sequence (832x480)



(b) City sequence (1280x720)

Figure 2. The sample of Keiba3 and City sequence and its accuracy rate of MPM

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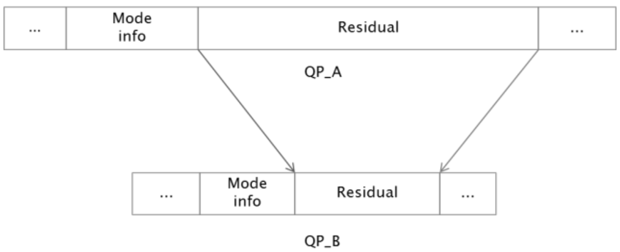

Figure 3. Change of bitstream according to QP increase (QP_A < QP_B)

Therefore, intra-prediction mode should be identical to MPM to reduce mode bits unless there is big difference in terms of distortion. The cases that block's intra-mode is equal to MPM increase according to the increase of QP as shown in Fig. 2. When QP is equal to 47, the accuracy rate of MPM in Keiba3 and City sequence reach 82% and 86%, respectively. It is obvious that the most sequence's accuracy rate of MPM increases according to the increase of QP. That the accuracy rate of MPM becomes higher, which means that entropy becomes lower. In other words, we can use this statistic to reduce the mode information.

C. *Proposed method*

Figure 4(a) shows the composition of intra-mode in H.264/AVC If MPM is selected as best mode of block, it requires one bit. Otherwise, we need four bits to represent best mode by using MPM and remaining modes. Since the accuracy rate of MPM increases according to the increase of QP as shown in Fig. 2, it is wasteful to send MPM per every block.

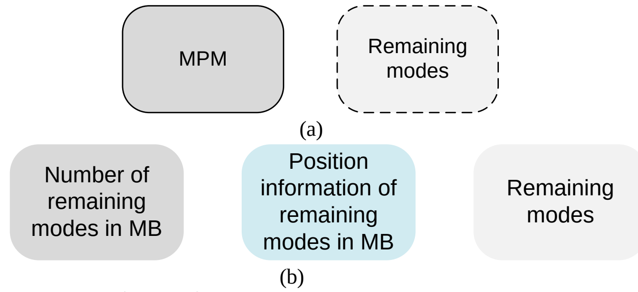

Figure 4. Bit format of the proposed algorithm, (a) conventional method, (b) proposed method

We place the MPM into other flags to represent the mode information for MBs with a high accuracy rate of MPM. The proposed flag contains the number of MPM in MB along with the position information of the remaining modes. For MBs with a low accuracy rate of MPM, we use the conventional method in H.264/AVC. For distinguishing the boundary between a high and low accuracy rate of MPM, we set a specific threshold as the boundary. If the accuracy rate of MPM in an MB is higher than the threshold, the proposed method is chosen. Otherwise, the conventional method is chosen.

We changed the bit format as shown in Fig. 4. The conventional method to be applied to MB with low accuracy rate of MPM is described in Fig. 4(a), while the proposed method to be applied to MB with high accuracy rate of MPM is described in Fig. 4(b).

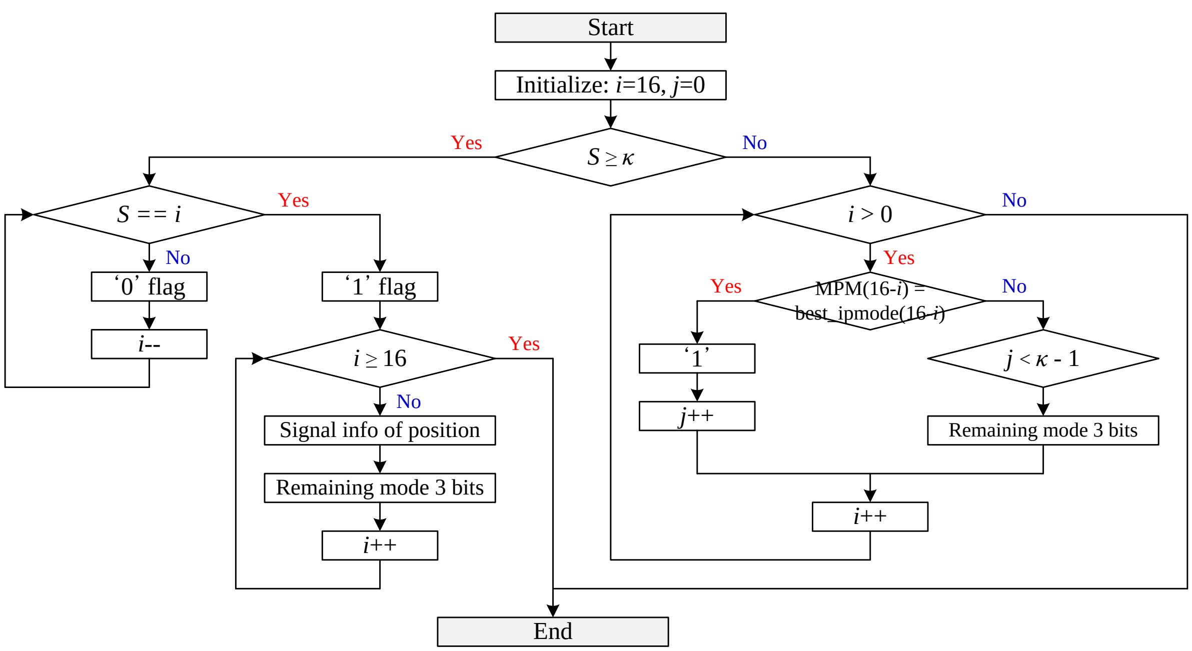

Figure 5. Flowchart of the proposed algorithm

The proposed method replaces MPM in additional flags. If the accuracy rate of MPM in an MB is higher than the threshold, then we send the number of blocks. This is because the best intra-mode in the block is different from MPM, and we denote this as MPM_{NB}, which means the best mode is not equal to MPM. If the best intra-mode is equal to MPM, we denote this as MPM_{BM}.

In the proposed method, blocks with MPM_{NB} are the target, so we should signal the position information of blocks with MPM_{NB}. Then, one mode among the remaining modes except MPM is coded. The proposed method is not effective if there are many blocks with MPM_{NB}. The threshold is determined empirically, and it should be set as a high number. If we set the threshold to thirteen, number of block with MPM_{NB} is equal to three. For number of remaining modes in MB, it requires three bits by using truncated unary binarization [8]. In order to represent the position information of block with MPM_{NB}, each block needs four bits since a MB has sixteen 4x4 blocks. There are three blocks with MPM_{NB}. We need twelve bits. And it requires additional nine bits to represent remaining mode of three blocks. If we apply this in the proposed method, it requires twenty-four bits. In conventional method, we need thirteen bits in blocks with MPM_{BM} and twelve bits in blocks with MPM_{NB}, respectively. Total twenty-five bits are required in conventional method. Through the comparison between two methods, we can know that proposed method can save one bit compared to the conventional method. However, when threshold is lower thirteen, there is no compression effect in the proposed method. This is the reason why threshold should be set as high number. We can know the range of threshold 13 to 16.

The encoder signals one bit per MB to distinguish whether or not the accuracy rate of MPM in an MB is over the threshold. Figure 5 shows the flowchart of the proposed algorithm, where S is the number of blocks to be MPM as the best mode, and κ is the threshold mentioned above. If the number of blocks with MPM_{BM} is less than κ, then conventional mode signaling is used (this is the same as the H.264/AVC case). The proposed algorithm is an adaptive scheme that is composed of the proposed intra-mode signaling combined with conventional intra-mode signaling. The method is determined by the number of blocks with MPM_{BM}. In Fig. 5, the left part shows the proposed method and the right part shows the conventional method.

III. EXPERIMENTAL RESULTS

The proposed method based on the accuracy rate of MPM was simulated in JM 16.0 reference software [9] in order to evaluate its performance. Various types of test sequences were used and a group of experiments were carried out on different QP ranges for evaluating coding efficiency in the low bit rate condition. Experimental conditions were: (a) one set of QP values were 22, 27, 32 and 37 and the other set of QP values were 32, 37, 42, 47, (b) Baseline profile was used, (c) number of frames was 100, and (d) entropy coder was CAVLC.

In this paper, we used κ=13 as the threshold value, which was determined empirically. All frames were coded as Intra. In order to evaluate the performance of the proposed method, it was compared with H.264/AVC. To calculate the efficiency, the proposed method was used to calculate the average BD-PSNR and BD-bitrate [10,11]. The RD performance comparisons are shown in Table 1.

TABLE I. CODING EFFICIENCY RESULTS WITH DIFFERENT QP RANGE

Sequence	**Resolution**	**QP range 1**		**QP range 2**	
		Bit-rate (%)	**PSNR (dB)**	**Bit-rate (%)**	**PSNR (dB)**
Foreman	CIF (352x288)	-0.099	0.006	-1.581	0.093
Container		-0.365	0.026	-1.551	0.092
Paris		-0.260	0.025	-1.219	0.087
Nuts5	WQVGA (416x240)	-1.125	0.062	-1.838	0.111
Nuts3		-1.355	0.080	-2.067	0.136
Keiba3		-0.496	0.035	-2.584	0.158
Flower4	WVGA (832x480)	-0.871	0.062	-1.331	0.074
BQmall		-0.561	0.037	-1.612	0.089
Keiba3		-0.627	0.035	-2.904	0.164
Bigships	HD (1280x720)	-0.223	0.012	-2.154	0.084
City		-0.181	0.013	-1.588	0.072
Crew		-1.486	0.060	-2.117	0.100
Jets		-2.185	0.088	-2.050	0.112
Vidyo3		-1.376	0.091	-2.023	0.138
Average		-0.801	0.045	-1.901	0.109

The average bit saving is 0.801% and the average PSNR gain is 0.045 dB for various test sequences in the Baseline profile. For additional information on the low bit rate condition, the proposed algorithm was also tested at QP range 2 (32, 37, 42, and 47). In QP range 2, the average bit saving is 1.901% and the average PSNR gain is 0.109 dB. The average bit saving increases according to the increase of QP. Especially, it is effective in some sequences. In the case of Foreman and City sequence, the bit saving of QP range 1 is 0.099% and 0.181%, respectively. It is relatively small compared to other sequences. However, the accuracy rate of MPM increases rapidly according to the increase of QP. In low bit rate condition, the bit saving of QP range 2 is 1.581% and 2.904%, respectively. Thus, we can verify that the proposed method is effective in the low bit rate condition. This means that the attempt to reduce redundancy of MPM is successful. As QP increases, the accuracy rate of MPM increases and the number of blocks with MPM_{BM} increase. Hence, mode signaling of the proposed method occurs often in the low bit rate condition.

In H.264/AVC, Intra-4x4 has an advantage regarding the PSNR because of the accuracy of its predictions. However, in the low bit rate condition, it also has a disadvantage in its bit rate because the mode information of 16 blocks is signaled. So, Intra-16x16 is selected as the best partition in the low bit rate condition. However, in the low bit rate condition in the proposed algorithm, Intra-4x4 is more often selected as the best partition compared to H.264/AVC because it can reduce the burden of bit rate. In other words, the number of bits used to represent the intra-mode information is reduced in the proposed algorithm. Table 2 shows the increase of Intra-4x4 partition compared to H.264/AVC. In the table, △I4x4 is used to calculate the number of Intra-4x4 partitions in the proposed algorithm compared to H.264/AVC. △I4x4 is calculated like following:

$$\Delta I_{4\times4} = \frac{I_{4\times4}^{prop} - I_{4\times4}^{H.264}}{I_{4\times4}^{H.264}} \times 100 \qquad (2)$$

TABLE Ⅱ. INCREASE OF INTRA-4X4 PARTITION COMPARED TO H.264/AVC

Sequence	Resolution	QP = 37	QP = 42
		ΔI_{4x4} (%)	ΔI_{4x4} (%)
Foreman	CIF (352x288)	6.680	11.425
Container		9.697	8.783
Paris		5.594	5.286
Nuts5	WQVGA (416x240)	17.53	36.922
Nuts3		27.910	49.278
Keiba3		6.681	16.130
Flower4	WVGA (832x480)	29.250	31.941
BQmall		9.050	17.125
Keiba3		10.621	25.798
Bigships	HD (1280x720)	17.999	38.404
City		5.796	23.488
Crew		36.205	57.326
Jets		25.880	27.542
Vidyo3		11.381	16.577
Average		15.734	26.145

When QP is equal to 37, the average of △I4x4 is 15.734%. It means that Intra-4x4 partition increases 15.734% compared to Intra-4x4 in H.264/AVC. In particular, when QP is equal to 42, Intra-4x4 partition increases 26.145% as shown in Table Ⅱ.

IV. CONCLUSION

In this paper, we proposed mode signaling to use the accuracy rate of MPM. An adaptive scheme is applied to the blocks according to number of block with MPM_{BM}. Two types of bit format are supported to code intra-mode information and it is selected based on the accuracy rate of MPM. Especially, the proposed algorithm can improve the coding efficiency in the low bit rate condition. According to the experimental results, the average bit reduction is 0.801% and the average PSNR gain is 0.045 dB. In particular, in the low bit rate condition, the average bit rate reduction is 1.901% and the average PSNR gain is 0.109 dB. This paper is enhancing the compression efficiency at low bit rate application such as video-conferencing and video telephony.

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