INTRA MODE CODING IN HEVC STANDARD

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ABSTRACT

New High Efficiency Video Coding (HEVC) standard is designed to provide substantial coding efficiency improvement compared to H.264/AVC. Latest subjective testing shows 50% improvement has been achieved. Many new technologies contribute to the overall improvement. Intra prediction with 35 modes is one of the key improvements. Associated with that, there is a new intra mode coding method to efficiently signal the selected modes. This paper presents this new intra mode coding method that has been adopted by HEVC. In this method, the 35 intra modes are divided into two categories. One category includes 3 most probable modes (MPMs) and another category includes 32 remaining modes. In doing so, shorter codeword is used for coding MPMs and fixed length coding is used to code the remaining modes. Experimental results show the 3MPMs based method improve the coding efficiency compared to the prior art method used in H.264/AVC.

Index Terms— H.264/AVC, HEVC, Intra mode, MPM

1. INTRODUCTION

The Advanced Video Coding standard H.264/AVC [1] has significantly improved coding efficiency compared to prior video coding standards. Since the standard was published, HDTV has replaced standard-definition analog TV as the entertainment center of the living room. Internet video has emerged from special purpose video conference to main stream entertainment options such as YouTube and etc. The ever increasing customer demand for high resolution high quality video and higher bandwidth internet make it clear that a new video coding standard with higher coding efficiency is desirable. In the mean time, the developments of new video coding technologies make it possible to establish a new standard with substantial coding efficiency improvement compared to H.264/AVC. After the investigation, The ITU-T Video Coding Experts Group (VCEG) and the ISO/IEC Moving Picture Experts Group (MPEG) worked together to establish a Joint Collaborative Team on Video Coding (JCT-VC) and to issue a joint Call for Proposals in January 2010. The new standard is named as High Efficiency Video Coding (HEVC) standard.

In H.264/AVC, the block-based hybrid video coding framework has been adopted. The HEVC standard advanced this framework by providing a highly flexible hierarchy of quadtree coding structure which consists of three kinds of block units: coding units (CU), prediction units (PU) and transform units (TU). Among them, CU is a macroblock-like square unit with size from the smallest CU (SCU), which is selected to be 8x8 luma pixels in the common test condition (CTC), to the largest coding unit (LCU), which is set to 64x64 pixels in CTC. When the CU is the leaf node in quadtree structure, PU is used as basis unit to conduct predictions. Currently, only square PU is supported by Intra prediction. As the result, the intra PU size can be 4x4, 8x8, 16x16, 32x32 and 64x64. Since the maximum size of TU cannot exceed 32x32, the intra TU can only have size 4x4, 8x8, 16x16 and 32x32.

Directional prediction has been successfully utilized in H.264/AVC to improve the prediction accuracy. It exploits the directional properties of the texture and use reconstructed pixels directly above and to the left of the block to generate the prediction pixel values. Up to nine prediction modes are defined in H.264/AVC for 4x4 and 8x8 blocks, which includes DC mode and eight directional modes as shown in Figure 1. For 16x16 luma Intra prediction and chroma Intra predictions, four prediction modes including Vertical, Horizontal, DC and Plane modes are allowed.

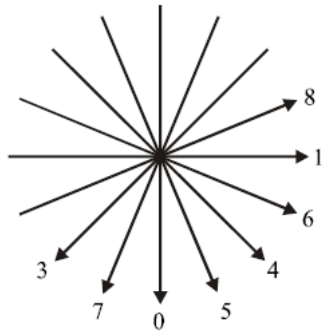

Fig. 1. AVC Intra prediction angle illustration

The eight directions cannot represent the texture directional properties accurately, especially for big blocks. In order to significantly improve the intra prediction accuracy, the directional intra prediction with fine angularity is proposed and adopted by HEVC. Up to 33 directions can be used by each PU. The set of available prediction directions is selected in a way the angle between the directions is roughly constant as shown in Figure 2. Besides that, DC mode and Planar mode are also adopted in HEVC. The effective representation of the 35 intra modes is critical for high efficiency video coding.

This paper introduces the new intra mode coding method in HEVC. This method is based on the principle of the entropy coding which uses shorter code words for the modes with high probabilities, and longer code words for the modes with low probabilities. In general, the 35 modes are divided into most probable modes (MPM) and remaining modes. The MPMs are estimated based on the statistics and the correlations between the current PU and the PUs directly above and to the left of it. One to two bits are used to code the MPMs and fixed length coding (FLC) is used to code the remaining modes. This method has been adopted in the initial committee draft for HEVC [5] in the 8th meeting.

The rest of this paper is organized as follows. Section 2 reviews the prior art of the intra mode coding in HEVC. The details of the proposed intra mode coding method are described in Section 3. Section 4 presents the experiment results of the proposed intra mode coding method. Section 5 concludes the paper.

2. PRIOR ARTS OF INTRA MODE CODING

After the 33 directional modes are adopted by HEVC, the intra mode coding technologies have been evolved from AVC like single MPM based methods with interleaved numbering to the final 3MPM based methods with logical numbering through several stages.

2.1. Single MPM and interleaved mode numbering

In the early stage of HEVC, the luma intra prediction had had total 34 modes including DC mode and 33 directional modes [2]. The 34 modes are labeled by an interleaved numbering scheme that is based on the probabilities of each mode as shown in Figure 2. For 4x4 PU, total 17 modes from mode 0 to mode 16 are used. For 8x8, 16x16 and 32x32 PU, total 34 modes from mode 0 to mode 33 are used. For 64x64 PU, total 3 modes from 0 to 2 are used.

Until the 4th JCT-VC meeting, a single MPM had been selected as the mode with smaller number from the left PU and the upper PU. One PU level flag, MostProbableMode, was transmitted to indicate whether the current mode was equal to the most probable mode or not. If not, the current mode was then coded as remaining mode with longer code words. Contextual model was required.

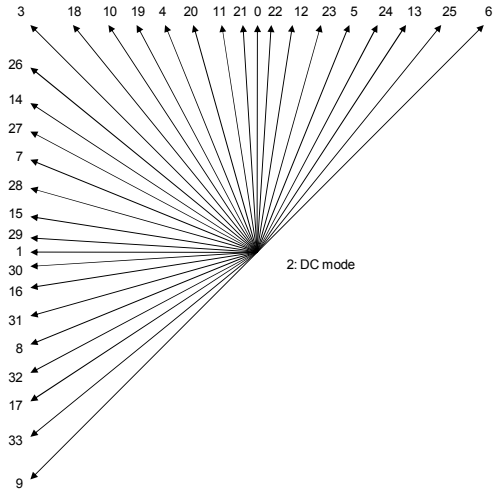

Fig. 2. Intra mode with interleaved numbering.

2.2. Adaptive MPM

In order to fully utilize the correlations among neighboring PUs, the adaptive MPM selection methods were proposed in the 4th meeting ([6], [7]). In the proposed methods, the mode of left neighbor PU (*ModeA*) and the mode of upper neighbor PU (*ModeB*) were used to generate the MPMs. If *ModeA* was not equal to *ModeB,* two MPMs were available, a new flag *mpm_index* was used to indicate which one of *ModeA* and *ModeB* was chosen in the bitstream. Otherwise, only one MPM was available (if *ModeA* and *ModeB* were both unavailable, DC was set as MPM). Meanwhile, the improved planar mode was also proposed and adopted for intra prediction. The Planar mode was treated as special mode and coded together with DC mode. By harmonizing with the planar mode, the adaptive MPM approach [8] was adopted in the 5th JCT-VC meeting. Comparing with the single MPM based method in HM2.0 software [14], 0.5% BD rate [18] reduction was obtained. The detailed results are shown in Table 1.

Table 1. Adaptive MPM coding BD-rate performance (%) on HM2.0

	Intra			Intra LoCo		
	Y	U	V	Y	U	V
Class A	-0.3	-0.2	-0.1	-0.3	-0.2	-0.2
Class B	-0.5	-0.4	-0.4	-0.6	-0.4	-0.5
Class C	-0.5	-0.4	-0.4	-0.5	-0.5	-0.5
Class D	-0.3	-0.3	-0.3	-0.4	-0.4	-0.4
Class E	-0.8	-0.5	-0.5	-1.0	-0.6	-0.6
All	-0.5	-0.4	-0.3	-0.5	-0.4	-0.4

2.3. Parsing Friendly 2MPM

In the content adaptive MPM selection approach, the parsing throughput was affected due to necessity of prior knowledge of intra prediction modes of left and upper PUs. Furthermore, the statistics showed that Planar mode had the highest probability to be selected. Based on proposals from different companies, a 2MPM based method was adopted [9] to avoid parsing problems in the 6th JCT-VC meeting. In this method, the number of most probable modes was always kept as 2. This method only needed changes when only one MPM was resulted in the adaptive MPM method; if the only one MPM was not equal to planar mode, the planar mode was added as the second MPM mode; otherwise, the DC mode was added as the second MPM mode. In the meeting, the signaling of the Planar mode was also separated from that of the DC mode and mode 0 was assigned to it. As the result, all the mode numbers shown in Figure 2 were incremented by one. Compared with the prior art HM3.0 software [15], 0.2~0.3% BD rate reduction was obtained with the benefit of improved parsing throughput.

2.4. 4MPM for Best Coding Efficiency

In the 7th JCT-VC meeting, several companies worked together to propose a 4MPM based solution [11]. This solution used 4 MPMs and mode ranking for coding remaining modes bins. Chroma coding was also modified by considering in the candidate sets the 4 MPMs from luma. A 19th mode was added back to the set of 4x4 block modes to get a more coherent set of modes. Although an average of 0.5% BD-rate reduction was obtained, this solution was not adopted due to its relative complex design, especially for hardware.

3. PROPOSED INTRA MODE CODING

In the 2MPM based approach, only 18 prediction modes can be selected by the 4x4 PU. The "HOR+6" mode is missing. This mode is shown as number 17 in Figure 2. As the result, the full directional coverage cannot be obtained, which is not an elegant design. For 32x32 PU, 16x16 PU and 8x8 PU, 35 prediction modes can be selected. Besides of the two MPMs, there are 33 remaining modes exist. In order to code these 33 modes, at least six bins (bits) have to be used if simple fixed length codes are used. Since five bins (bits) are enough to code 32 modes, use six bins (bits) to code 33 modes is not a desirable solution.

In order to simplify the intra mode coding design and achieve the BD rate reduction at the same time, we proposed 3MPM based methods [13] in the 8th JCT-VC meeting. In the proposed method, 19 modes including direction "HOR+6" are used for 4x4 PU and 35 modes are used for other PU sizes from 8x8 to 64x64.

To find the MPMs, three factors have been considered: neighbor PU correlation, neighbor mode correlation and overall coding statistics. Based on the study, the neighbor PU correlation always has the highest priority. That is, if one mode is selected in the neighbor PU, this mode is most probable to be selected in the current PU. If one mode is selected by the neighbor PU, the left and right neighbor mode of the selected mode also have higher probability to be selected by the current PU than the other modes. Without considering the neighbor correlations, the statistics show Intra_Planer, Intra DC and Intra_Vertical are three most frequently selected modes.

In the proposed method, the 3 MPMs are derived by the following procedures.

- For the intra prediction modes of the left PU and the upper PU, if any one of them is not available (out of boundary or inter coded), the corresponding intra prediction mode is set as DC.
- If the mode of left neighbour PU (*ModeA*) and the mode of upper neighbour PU (*ModeB*) use the same mode, the following applies:
  - If *ModeA* is either Intra_DC or Intra_Planar, the 3MPMs are derived as:
    MPM0 = Intra_Planar
    MPM1 = Intra_DC
    MPM2 = Intra_Vertical
  - Otherwise, the 3 MPMs are derived by either using *method A* or using *method B*.
    - *Method A* derives the 3 MPMs as following:
      MPM0 = *ModeA*
      MPM1 = Intra_Planar
      MPM2 = Intra_DC
    - *Method B* is based on finding the left and right neighbours of *ModeA* as:
      MPM0 = *ModeA*
      MPM1 = $\text{Mode}_{\text{left\_neighbor}}$
      MPM2 = $\text{Mode}_{\text{right\_neighbor}}$
- If *ModeA* is not equal to *ModeB*, the following applies:
  - MPM0 and MPM1 are derived as:
    MPM0 = *ModeA*
    MPM1 = *ModeB*
  - If none of MPM0 and MPM1 is equal to Intra_Planar, MPM2 is set equal to Intra_Planar,
  - Otherwise, If none of MPM0 and MPM1 is equal to Intra_DC, MPM2 is set equal to Intra_DC,
  - Otherwise, MPM2 is set equal to Intra_Vertical.

After the 3 MPMs are derived, the intra mode coding is applied by following procedure as shown in Figure 3:

- If the current PU uses the prediction mode equal to any of the 3 MPMs, flag "**prev_intra_luma_pred_flag**" is coded as one. Then, the following applies:
  - If current PU uses MPM0, "**mpm_idx**" is set as zero and "0" is coded. Otherwise, "1" is coded and next step applies,
  - If current PU uses MPM1, "**mpm_idx**" is set as one and "0" is coded. Otherwise, "**mpm_idx**" is set as two and "1" is coded.

- If the current PU uses the prediction mode not equal to any of the 3 MPMs, "**prev_intra_luma_pred_flag**" flag is coded as zero. Then, remaining mode "**rem_intra_luma_pred_mode**" is coded by fixed length coding. Since only 32 modes are left after the 3 MPMs are excluded, 5 bins are enough.

In the decoder side, let candModeList[0] = MPM0, candModeList[1] = MPM1 and candModeList[2] = MPM2, the intra prediction mode "IntraPredMode" can be derived by following procedures:

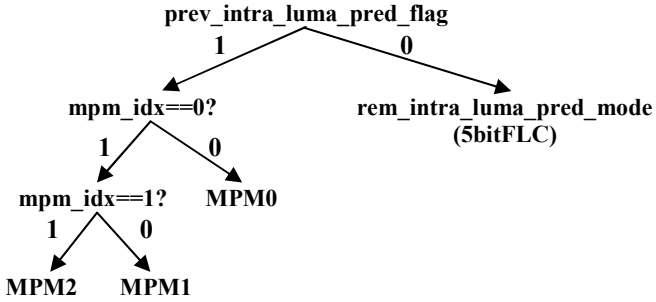

Fig. 3. Illustration of intra mode coding tree

- If "**prev_intra_luma_pred_flag**" is equal to 1, the decoder decode the "**mpm_idx**" and the intra prediction mode is set equal to candModeList[**mpm_idx**].
- Otherwise, the IntraPredMode is derived by applying the following ordered steps:
  1. The array candModeList[x], x=0..2 is modified such that candModeList[0] is less or equal to candModeList[1], and candModeList[1] is less or equal to candModeList[2],
  2. the intra prediction mode is then derived as the following ordered steps:
     i. IntraPredMode = rem_intra_luma_pred_mode
     ii. When IntraPredMode is greater than or equal to candModeList[0], the value of IntraPredMode is increased by one
     iii. When IntraPredMode is greater than or equal to candModeList[1], the value of IntraPredMode is increased by one
     iv. When IntraPredMode is greater than or equal to candModeList[2], the value of IntraPredMode is increased by one

With the current 3MPM based intra mode coding method, all the PUs use same fixed length coding. Except for flag "**prev_intra_luma_pred_flag**", contextual models are not used anymore. The intra mode coding is simplified with benefit of additional coding gain.

With the interleaved numbering as shown in Figure 2, a look-up table is needed to find the left and right neighbours of the current mode for the proposed *method B*. Moreover, additional tables are needed to map the number to the direction. To solve the problems, a logical mode numbering scheme [12] has been adopted [5]. Correspondingly, the intra prediction modes are described by Table 2.

Table 2. Specification of intra mode and associate names

Intra prediction mode	Associated names
0	Intra_Planar
1	Intra_DC
Otherwise (2..34)	Intra_Angular

With the new numbering scheme and 35 modes for all PUs, finding the the left and right neighbours of the current mode (*ModeA*) can be applied by following equations. Through the discussion of the experts, the combination of the proposed *method B* and the new numbering scheme has been adopted in the initial committee draft for HEVC [5].

$$Mode_{left\_neighbor} = 2 + ((ModeA + 29) \% 32)$$
$$Mode_{right\_neighbor} = 2 + ((ModeA - 1) \% 32)$$

4. EXPERIMENTAL RESULTS

During the development of HEVC standard, HEVC Test Model software (from TMuC software to HM5.0 software for 8th JCT-VC meeting) and corresponding common test configurations are released after each meeting. All the new proposals should be implemented and tested based on them. The proposed 3 MPM based methods are built on top of HM5.0 [16]. In the experiment, total 18 video sequences are tested, which are grouped into five classes by resolution and content characteristics. Class A contains two 4K (2560x1600) sequences, class B contains five full HD (1080p) sequences, class C contains four WVGA sequences, class D contains four WQVGA sequences and class E contains three 720p sequences with slow motions. All Intra configuration has been tested. Anchor data was generated by HM5.0 software under the common test conditions [17]. The results for the proposed scheme are compared with the anchor data and presented in average B-D rate [18] per class.

Table 3 shows the experimental results of the proposed 3MPM based *method A*. Comparing with the prior art HM5.0 software [16], 0.2% BD rate reduction is obtained with the simplified design.

Table 3. Method A BD-rate performance on HM5.0

	All Intra HE			All Intra LC		
	Y	U	V	Y	U	V
Class A (8bit)	-0.3%	0.1%	0.2%	-0.4%	-0.1%	-0.1%
Class B	-0.2%	-0.1%	0.0%	-0.3%	-0.2%	-0.1%

Class C	-0.1%	-0.1%	0.0%	-0.2%	-0.1%	-0.1%
Class D	-0.2%	0.0%	0.0%	-0.2%	-0.1%	-0.1%
Class E	-0.1%	0.1%	0.3%	-0.2%	-0.2%	0.0%
Overall	-0.2%	0.0%	0.0%	-0.2%	-0.1%	-0.1%
	-0.2%	0.0%	0.0%	-0.2%	-0.1%	-0.1%

Table 4 shows the experimental results of the proposed 3MPM based *method B*. Comparing with the prior art HM5.0 software [16], 0.2%~0.3% BD rate reduction is obtained.

Table 4. Method B BD-rate performance on HM5.0

	All Intra HE			**All Intra LC**		
	Y	U	V	Y	U	V
Class A (8bit)	-0.3%	0.0%	0.1%	-0.4%	-0.2%	-0.1%
Class B	-0.2%	-0.1%	0.0%	-0.3%	-0.1%	-0.1%
Class C	-0.2%	-0.1%	-0.1%	-0.2%	-0.1%	-0.1%
Class D	-0.2%	0.0%	-0.1%	-0.2%	-0.1%	-0.2%
Class E	-0.3%	0.0%	0.2%	-0.4%	-0.3%	-0.1%
Overall	-0.2%	0.0%	0.0%	-0.3%	-0.2%	-0.1%
	-0.2%	0.0%	0.0%	-0.3%	-0.2%	-0.1%

A simply way to compare the coding performance of the current intra mode coding method with the prior art H.264/AVC single MPM method is to calculate the summation of the adopted intra mode coding method results. For all intra high efficiency test condition, the summation value is 1.0% BD rate reduction. It should be noted all the coding gains shown above is achieved on top of the previous HEVC test model. Therefore, compared to H.264/AVC like single MPM approach, the real coding gain of the current 3 MPM based method will be higher than the simple summation of the above results.

5. CONCLUSION

In this paper, a new intra mode coding method is introduced. This method is based on the principle of the entropy coding which uses shorter code words for the modes with high probabilities, and longer code words for the modes with low probabilities. The intra prediction modes are divided into most probable modes (MPM) category and remaining modes category. The MPMs are dynamically estimated for each PU based on the statistics and the correlations between the current PU and the PUs directly above and to the left of it. One to two bits are used to code the modes belong to the MPM category and 5 bit fixed length coding is used to code the modes belong to remaining modes category. Compared to single MPM approach, at least 1.0% improvement is obtained in terms of coding efficiency. The intra mode coding scheme is also simplified with fixed length coding for remaining modes.

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