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A Two-Stage Fast Mode Decision Algorithm for Intra Prediction in HEVC

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ABSTRACT. *The latest video coding standard named H.265/HEVC (High Efficiency Video Coding) offers high compression. In the intra coding of HEVC, potential intra modes up to 35 should be checked to get the best mode which have optimal rate distortion cost. The process is highly time-consuming. To alleviate the encoder computation, a novel two-stage fast intra mode decision algorithm is proposed based on mode probability statistics in this paper. A hierarchical mode decision method for Rough Mode Decision (RMD) aim to reduce the number of prediction modes. Adaptive mode decision method based on rate-distortion optimized quantization (RDOQ) mainly focuses on how to reduce mode candidates. The experimental results suggest that the proposed algorithm could reduce 31.5% encoding time on average while BD-RATE may increase by up to 0.85% for HEVC reference software HM16.9 under all-intra configuration.*

KEYWORDS: *High Efficiency Video Coding (HEVC), intra prediction, fast mode decision, texture direction.*

1. Introduction

Nowadays, people tend to pursue high definition video, which requires high compression of video content under limited bandwidth. To respond to this need, video compression technology came into being. International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) and International Organization for Standardization / International Electrotechnical Commission (ISO/IEC) build Joint Collaborative Team on Video Coding (JCT-VC) release the latest generation of efficient video coding compression standards—H.265/ HEVC [1] in 2013. HEVC uses advanced processing technology to reduce the bit rate by nearly half compared to the H.264/AVC in the same video encoding quality [2]. However, HEVC is very complicated and requires a huge amount of computation, as shown in the reference software H.16.9 [3] [4].

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In recent years, many optimization schemes for intra prediction have been proposed to accelerate the speed of HEVC encoder and reduce coding complexity. In [5], gradient histogram is built to reduce modes for RMD and RDO. In [6], an adaptive mode decision algorithm based on video texture is proposed, which extract gradient direction through calculate mean of absolute along different direction. Then set constitute a new candidate list according to the gradient values, thereby reducing the prediction calculation. In [7], a method for precluding the individual angle prediction mode is proposed. The left and upper reference pixels of the PU are used to obtain the removed pixels, and the prediction mode is reduced in advance in conjunction with the literature [8] to speed up the intra coding.

The above fast algorithms based on intra prediction can effectively improve the HEVC coding efficiency and reduce the coding time. But these authors all think about methods for reducing modes before RMD. However, the time consuming of RDO processing is very large. Therefore, this paper proposes a two-stage method based on mode probability statistics.

The rest of the paper is structured as follows: The Section II mainly introduces the basic knowledge of HEVC intra prediction and related research work. The Section III details the proposed fast algorithm for intra prediction. To verify the feasibility of the algorithm, a comparative experiment will be given in Section IV. The Section V gives a final summary of this article.

2. HEVC Intra Prediction

In HEVC, a new unit called Coding Tree Unit (CTU) replaces the macroblock structure in H.264. Each CTU is divided into different size Coding Units (CUs) according to the recursive partitioning method of the quad-tree. Each CU may have one or four PUs according to the quad-tree fashion. Therefore intra prediction in HEVC supports 5 sizes of PU: 4×4, 8×8, 16×16, 32×32 and 64×64[9]. Each PU is predicted by reference samples from the adjacent reconstructed blocks according to 35 luma prediction modes (i.e., mode 0 for Planar, mode 1 for DC, and others are angular modes as shown in Fig. 1).

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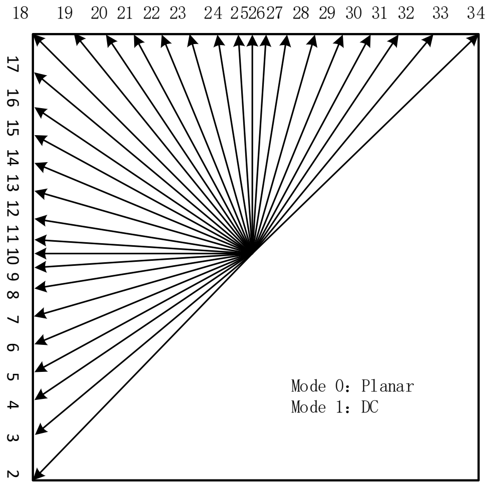

Figure. 1 Intra luma prediction modes in HEVC

In the HM16.9 encoding process, "three-step method" is designed to get the best luma prediction while minimizing the computational requirements in both the encoder and decoder. The first step is the Rough Mode Decision (RMD). This step uses Hadamard cost ranking to choose N modes as candidates as formula (1) [10]. The N modes with the lowest Hadamard cost are selected, and the N value is determined by the PU size as shown in Table 1.

$$J_{pred,satd} = SATD + \lambda_{pred} B_{pred} \tag{1}$$

Where SATD is the absolute sum of the Hadamard transform of the original pixel and the predicted pixel residual, λ_{pred} is the Lagrangian factor, and B_{pred} is the encoding code rate of the PU in this mode.

Table 1 The Number of Candidate

PU Size	4×4	8×8	16×16	32×32	64×64
N	8	8	3	3	3

Considering the high correlation of spatial neighbors, additional Most Probable Modes (MPMs) [11] [12] will be added to N candidates if they are not included yet. Moreover three MPMs are obtained based on modes of two adjacent PUs, one left and on above of the current PU.

Finally, RDOQ based RDO is then applied to obtain the best prediction mode which with the lowest RD cost mode, and the cost is calculated as shown in formula (2).

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$$J_{mode} = SSE + \lambda_{mode} B_{mode} \tag{2}$$

Where SSE represents the sum of the squares of the difference between the original pixel and the reconstructed pixel, B_{mode} represents the distortion and the number of bits, and λ_{mode} is the Lagrangian factor. This process is computationally more complex than the RMD.

The process of three-step is to guarantee the accuracy of intra prediction, but it brings huge computational complexity and encoding time shown as Fig. 2. So, the modes calculated in RMD and RDO is smaller, the time consuming is less.

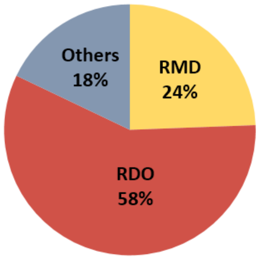

Figure. 2 Time-consuming coding

3. Proposed Fast Intra Mode Decision Algorithm

In order to reduce time consuming, the intra prediction modes are reduced in two stages: hierarchical fast algorithm is based on RMD, the other is based on RDO.

3.1 Hierarchical fast algorithm based on RMD

The optimal intra mode of final PU can be divided into three groups as shown in Fig. 3, the red modes, the purple modes and the blue modes. The red modes include Planar mode, DC mode and the modes of four main direction. The purple modes include two neighbor modes of four main direction. Therefore, the proposed hierarchical fast intra prediction algorithm mainly focuses on how to reduce the number of prediction modes based on RMD.

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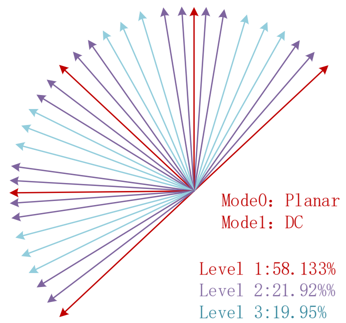

Figure. 3 Optimal mode decision

As shown in Fig. 4, instead of the full 35 modes used in RMD process, the proposed method only selects the modes through up to three layers of construction. The construction of layers method is as follows:

The first layer: all red modes, namely non-angle mode, horizontal, vertical, 45 ° and 135 ° mode. The first layer mode set is represented by Δ_1, so Δ_1 = {0, 1, 2, 10, 18, 26, and 34}. After the first layer modes are calculated in RMD, the First Minimum Mode (FMM) and the Second Minimum Mode (SMM) can be obtained.

The second layer: The second layer modes Δ_2 is set by FMM1 and SMM1. If both FMM_1 or SMM_1 is not non-angle modes, the second layer mode will be set as Δ_2, which is set according to Table 3. Moreover, $\Delta_2 = \Delta_{2\text{-}1} \cup \Delta_{2\text{-}2}$. Similarly, after RMD FMM_2 and SMM_2 can be obtained.

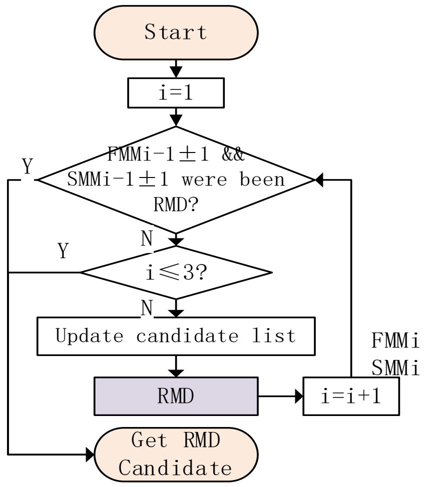

Figure. 4 Calculating based on RMD

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Table 2 Layer 1 Modes to Set

Δ_1	{0,1,2,10,18,26,34}

Table 3. Layer 2 Modes to Set

FMM_1/SMM_1	$\Delta_{2-1}/\Delta_{2-2}$
2	{3,4}
10	{8,9,11,12}
18	{16,17,19,20}
26	{24,25,27,28}
34	{32,33}

The third layer: When FMM_2 or SMM_2 is the mode next to blue modes, the modes of this layer will be set as Δ_3 according to Table 4. Also, $\Delta_3 = \Delta_{3-1} \cup \Delta_{3-2}$. After RMD all mode candidates before MPM can be obtained.

For example, if FMM_1 is mode 10 and SMM_1 is mode 26, then Δ_2= {8, 9, 11, 12, 24, 25, 27, 28}. After RMD, FMM_2 is mode 12, SMM_2 is mode 24, then Δ_3= {13, 14, and 23}. Finally, all mode candidates can be obtained after the last RMD.

Table 4 Layer 3 Modes to Set

FMM/SMM	Δ_{3-1}	SMM	Δ_{3-2}
$FMM_2=FMM_1+2/SMM_1+2$	$\{FMM_2+1, FMM_2+2\}$	$SMM_2= FMM_1+2/SMM_1+2$	$\{SMM_2+1\}$
$FMM_2=FMM_1-2/SMM_1-2$	$\{FMM_2-1, FMM_2-2\}$	$SMM_2= FMM_1-2/SMM_1-2$	$\{SMM_2-1\}$

As a consequence, the hierarchical fast algorithm could simplify reduce the RMD process modes in intra prediction

3.2 Fast algorithm based on RDO

Except that the time consumption of RMD process is very large, the RDO process can't be taken lightly. After RMD, there are 3 or 8 mode candidates and 3 MPMs will be calculate in RDO process. Furthermore, RDO process consumes more than half of the intra prediction time. The stage algorithm is to reduce modes calculated in RDO based on the probability analysis of RMD candidates and MPMs

As shown in Table 5, RMD[n] indicates the candidate mode that is sorted to n after the RMD process. For the size of 64×64, 32×32 and 16×16 PUs, RMD [0] and RMD [1] have about 70% probabilities to become the best mode. For the size of other size of PUs, the first three RMD candidates have nearly 80% probabilities to become the best mode. In addition, if the non-angle modes is included in the first

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few modes of RMD candidates, the possibility of becoming the best mode is always high.

Table 5 One of RMD Candidates is the Best Mode

Modes	64×64	32×32	16×16	8×8	4×4
RMD[0]	46.7%	51.9%	57.1%	58.3%	65.5%
RMD[1]	22.4%	19.1%	19.4%	15.7%	13.1%
RMD[2]	7.7%	10.6%	10.6%	7.5%	5.9%
RMD[3]				4.6%	3.3%
RMD[4]				3.5%	2.6%
RMD[5]	None	None	None	2.8%	2.2%
RMD[6]				2.3%	1.8%
RMD[7]				1.9%	1.6%
Total	76.8%	81.6%	87.1%	96.5%	96.0%

Furthermore, the probability of that one of MPM modes become the best mode is basically more than 80% as shown in Table 6.

Table 6 One of MPM Modes is the Best Mode

Sequence	Percentage
Traffic	80.26%
ParkScene	88.5%
Kimonol	91.18%
FourPeople	85.09%
ChinaSpeed	83.37%
BlowingBubbles	90.29%
RaceHorses	71.68%
vidyol	83.48%

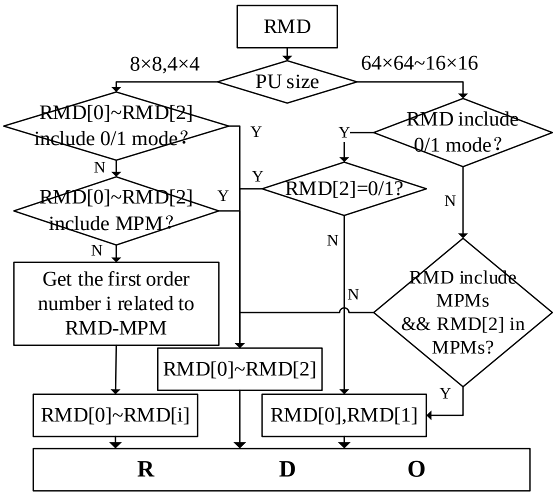

Figure. 5 The algorithm based on RDO

Therefore, the second stage algorithm proposed in this paper is shown as Fig. 5. After RMD process, if RMD [0] or RMD [1] is non-angle mode, first two RMDs into RDO calculation. Else, find out whether RMD [0] or RMD [1] is included in MPMs. If so, calculating as previous step, else, setting candidate modes based on MPMs and RMDs relationships. Moreover, candidate modes is set as RMD[0]~RMD[i] while the i is obtained by querying MPMs appears first location in RMD.

Instead of calculating 3 or 8 candidate modes and MPMs in RDO process, the proposed algorithm based on RDO selects few modes in RDO process to reduce time computation.

4. Experimental Results

In order to verify the performance of the proposed fast mode decision algorithm, this section shows the experimental results implementing in the HEVC test model HM16.9 [13]. And the experiment uses JCTVC-L1100 [14] test conditions. The simulation criteria are as follows: 20 frames; the QP are used at {22, 27, 32, and 37}; the GOP (Group of Pictures) is 8; the All Intra encoding mode (All Intra Main, AI-Main) is used. The evaluation method uses the BD-BR method proposed by Bjøntegarrd [15] in the proposed VCEG-M33. The coding save time is calculated by ΔT, and its calculation formula is:

$$\Delta T = \frac{1}{4}\sum \frac{\mathrm{Time}_{HM16.9}(QP) - Time_{prop}(QP)}{Time_{HM16.9}(QP)} \times 100\% \tag{3}$$

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$Time_{prop}$ indicates that the algorithm encoding time is time-consuming, $Time_{HM16.9}$ indicates that the reference software HM16.9 original encoding takes time, QP= {22, 27, 32, and 37}.

Table 7 shows the performances of the proposed algorithm combining hierarchical fast algorithm based on RMD and fast algorithm based on RDO. It could be confirmed from the simulation results that our algorithm can reduce 31.5% on average for the computational complexity, with BD-BR only increases 0.85%. Moreover, some relevant proposals released recently are selected to make performance comparisons. In comparison with the algorithm in [5] and [6], the proposed algorithm have more reduction in computational complexity. The algorithm in [6] just achieve little lower BD-BR compared with our algorithm. Compare with [5], our algorithm have less BD-BR.

Table 7 Performance Comparison between Proposed Scheme and Recent Fast Intra Decision Algorithm

Classes	Sequences	Jiang et al.[5]		Liu et al. [6]		Proposed algorithm	
		BD-BR/%	ΔT/%	BD-BR/%	ΔT/%	BD-BR/%	ΔT/%
A	Traffic	0.5	20.4	0.4	28.9	0.7	30.1
	PeopleOnStreet	0.6	20.4	0.7	29.3	0.9	31.7
B	BasketballDrive	1.2	19.9	0.4	30.5	0.8	32.6
	ParkScene	0.5	20.7	0.5	30.3	0.6	31.9
C	BasketballDrill	0.8	19.6	0.5	28.7	1.1	30.4
	BQMall	0.8	19.2	0.8	28.4	0.9	29.8
D	BasketballPass	1.0	19.2	0.7	29.8	0.8	31.2
	RaceHorses	1.1	20.4	1.4	28.7	0.9	30.7
E	FourPeople	1.3	22.4	0.4	28.8	0.8	30.5
	Johnny	2.1	23.0	0.8	29.3	1.0	32.6
Average		1.0	20.5	0.7	29.3	0.85	31.5

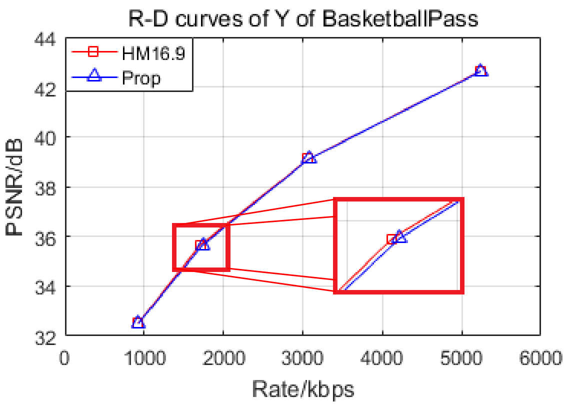

Figure. 6 RD curves proposed algorithm with the original for BasketballPass sequence

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Furthermore, in order to present the coding efficiency more intuitively, the RD curves of the proposed algorithm for BasketballPass sequence is shown in Fig. 6. From the curves we can conclude that the RD performance is very close to the original encoder.

Therefore, from Table 7 it can be concluded that the proposed algorithm in this paper almost always achieves the best compromise results between saving the coding time and maintaining RD performance.

5. Conclusion

In this paper, a two-stage fast mode decision algorithm is proposed, which first stage is hierarchical fast algorithm based on RMD and the second stage is fast algorithm based on RDO. Through the two-stage the modes calculated in RMD and RDO is reduced so that computational complexity is reduced. The simulation experiments prove that our proposed algorithm could save a lot of encoding time compared with original in HM16.9 for different sequences. Meanwhile, the bit rate and video quality are controlled well.

Acknowledgements

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