A FAST INTRA CODING ALGORITHM FOR HEVC

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ABSTRACT

High Efficiency Video Coding (HEVC) is the emerging video coding standard, which provides equivalent subjective quality with about 50% bit rate reduction compared to H.264/AVC High Profile. However, the improvement of coding efficiency is obtained at the expense of increased computational complexity. In this paper, a fast algorithm for HEVC intra coding is proposed. Firstly, a depth range prediction method by exploiting the correlation between the neighboring Coding Tree Units (CTUs) is proposed. Secondly, the rate distortion costs and Sum of Absolute Difference with Hadamard transform (HSAD) of recently encoded CUs are used to decide whether current CU will be further divided or not. Finally, only the intra prediction modes (IPMs) with lower precision are employed in the rough mode decision (RMD) and IPMs for rate distortion optimization (RDO) are reduced based on the correlation between neighboring CUs. Experimental results show that our proposed algorithm can achieve average 54% (up to 57%) encoding time saving while causing negligible RD performance loss (1.0% BD-rate increase on average) in All Intra High Efficiency test condition compared with HM 10.0.

Index Terms— Video coding, HEVC, intra mode decision, fast algorithm

1. INTRODUCTION

High Efficiency Video Coding (HEVC)[1], which is developed by the Joint Collaborative Team on Video Coding (JCT-VC), can provide the same video quality with just about 50% bit rate reduction when compared to H.264/AVC[2]. HEVC standard adopts the similar block-based hybrid video coding framework as H.264/AVC, but provides a highly flexible hierarchy of unit representation, which includes three units: coding unit (CU), prediction unit (PU) and transform unit (TU). CU is the basic coding unit, which can be recursively divided into four equal size sub-CU. CU may take a size from 8x8 luma samples up to the size of 64x64. For intra coding, there are two PU types, which are PART_2Nx2N and PART_NxN. PART_2Nx2N is available for all CUs whereas PART_NxN is only available for the smallest CU. TU is used for transform and quantization processes. TUs are also arranged by quad-tree partitioning structure. Furthermore, HEVC adopts 35 intra direction modes for spatial prediction, which is nearly four times as many as that in H.264/AVC. These advanced techniques bring better compression performance as well as higher complexity of the encoder. Therefore, how to relieve the encoder computational burden is becoming a critical problem in power-constrained and real-time applications.

In recent years, some algorithms have been proposed to reduce the complexity of HEVC intra coding. To reduce the complexity of intra mode decision, Y. Piao et al. proposed a rough mode decision (RMD) method to reduce the complexity of mode decision [3]. Furthermore, L. Zhao et al. improve the RMD by always including the most probable mode (MPM) as the candidates to compete for the optimal mode of current PU [4]. Predominant direction achieved by calculating gradient histogram of current PU is used to reduce prediction modes [5][6][7]. The intra modes of neighboring CUs and parent CUs are employed to reduce the searching space of the intra modes of current PU [8][9][10]. To avoid the checking of unnecessary CU sizes, the CU depth of spatial neighboring CUs and temporal co-located CUs are utilized to skip the mode decision of certain CU depth due to the strong correlation among them. Shi Y et al. utilized spatial and temporal neighboring LCUs to shrink the depth range of current CU [11]. But CU depth information of previous encoded frames is used in both methods, which can be not applied to the case of intra coding. Depths rarely used in nearby CUs are skipped in current CU to reduce the complexity [12]. In [13], a fast CU splitting and pruning method based on statistical information is presented. To reduce the number of prediction unit levels, a low complexity scheme based on level preprocessing filtering is proposed in [14]. In [15], a two stage PU size decision algorithm is proposed to speed up intra coding in HEVC. Texture complexities were analyzed to filter out unnecessary PUs for both the LCU and its sub-blocks. An early termination method based on the statistics of rate-distortion costs in CU splitting process with setting a threshold related to QP was introduced in [16]. A low complexity rate-distortion (RD) estimation method based on Hadamard transform was proposed in [17]. Zhang H et al. [18] proposed a novel priority classification based fast intra mode decision. A novel fast bottom-up pruning technique was proposed in [19].

To further relieve the computation load of the encoder, a fast algorithm for HEVC intra coding is proposed in this paper. Firstly, a depth range prediction method by exploiting the correlation between the neighboring Coding Tree Unit (CTUs) is proposed. Secondly, the rate distortion costs and Sum of Absolute Difference with Hadamard transform coefficients of recently encoded CUs are used to decide whether current CU will be further divided or not. Finally, only the intra prediction modes (IPMs) with lower precision are employed in the rough mode decision and IPMs for rate distortion optimization (RDO) are reduced based on the correlation between neighboring CUs.

The rest of this paper is organized as followed. Section II introduces our proposed method. Experimental results and analysis are given in Section III and conclusion is given in Section IV.

2. PROPOSED METHOD

2.1. CTU depth range prediction

Pictures are divided into a sequence of coding tree units (CTUs). A CTU is an independent coding unit. In natural pictures, neighboring blocks usually hold similar textures. Therefore, we can predict depth range of current CTU by utilizing neighboring encoded CTUs. Fig. 1 shows the spatial relation between the neighboring CTUs and current CTU. In HM10.0, the depth range of a CTU is [0, 3] represented by $R0$, where depth is set to 0 for CU with size of 64x64 and depth is set to 3 for CU with size of 8x8.

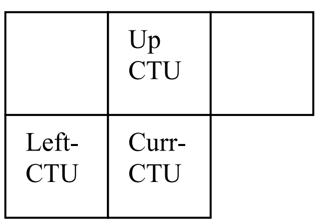

Fig. 1 neighboring CTUs and current encoding CTU

For flat and homogeneous regions, the encoder prefers to encode them with a smaller CU depth, whereas for complicated and inhomogeneous regions, the encoder prefers to encode them with a larger CU depth. Therefore, we can divide prediction depth range into two categories: $R1$= [0, 2] and $R2$= [1, 3]. The depth range $R1$ and $R2$ are used for homogenous regions and inhomogeneous regions respectively.

Formally, we define

$$DR_{curr} = \begin{cases} R1, & D_{\max}^{left} \le 1 \,\&\, D_{\max}^{up} \le 1 \\ R2, & D_{\max}^{left} > 1 \,\&\, D_{\max}^{up} > 1 \\ R0, & other \end{cases} \tag{1}$$

DR_{curr} denotes the depth range of current encoding CTU. $D_{\max}^{up}$ and $D_{\max}^{left}$ denote the max depth of upper CTU and left CTU respectively.

For each CTU, if both the max depth of the upper CTU and above CTU are less than or equal to 1, the depth range of current CTU will be categorized in $R1$. If both the max depth of the upper CTU and above CTU are more than 1, the depth range of current CTU will be categorized in $R2$. Else, the depth range of current CTU is still [0, 3] as the common test condition [20].

TABLE I: the percentages of the depth range of current CTU belonging to R1 and R2

Classification	Picture size	$p1$	$p2$
Class A	2560x1600	73.2%	98.0%
Class B	1920x1080	88.8%	95.5%
Class C	832x480	-	99.6%
Class D	416x240	-	98.9%
Class E	1280x720	93.4%	97.7%

This can be proved by Table I, where eighteen sequences in different resolutions from class A to class E with quantization parameter (QP) of 32 are employed. $p1$ and $p2$ denotes the percentages of the depth range of current CTU belonging to $R1$ and $R2$ respectively when the depth of the above CTU and left CTU satisfy the condition in (1). Since there is almost no CU with max depth less than or equal to 1 in Class C and Class D, the values are represented by "-" in the table. As is shown in Table I, the percentages are over 90% on average.

2.2. CU size decision

To determine the optimal CU partition of a CTU, the encoder traverses all the nodes of a CU partition tree using depth first search and computes the RD cost of all nodes. The whole process considerably increases the computational complexity of the encoder. Therefore in our proposed method, in order to speed up the determination of the optimal CU partition, unnecessary nodes are skipped by checking whether sum of Sum of Absolute Difference with Hadamard transform (HSAD) is higher than the given threshold (Th) and the RD cost is lower than another given threshold (Th').

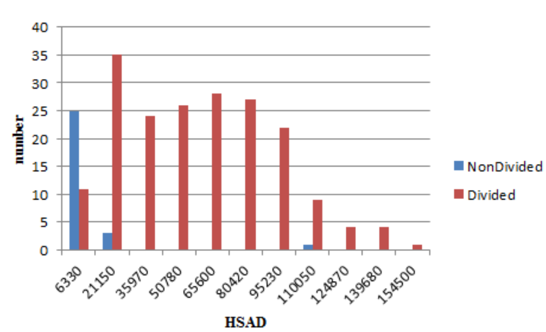

Fig. 2 distribution of HSAD of 64x64 CUs

If the HSAD of current CU is larger than the threshold *Th*, the current CU will have a high probability to be further divided. This can be proved by Figure 2. It illustrates the distribution of HSAD of 64x64 CUs for sequence *FourPeople with QP of 37*. As shown in Figure 2, when the HSAD is larger than 16710, most CUs will be further divided. Therefore, in our proposed method, if a CU's HSAD is larger than the threshold *Th*, the RDO process of current CU will be skipped. The threshold *Th* varies with the CU size. In addition, the threshold *Th* may be different for different sequences and it should be updated based on the sequence content.

In our method, we divide the frames into two groups: the first group is used for training the threshold and the second group is used for fast CU size decision. During the training, each CU's HSAD and the split flag denoting whether the CU is divided or not are stored. Because the larger the HSAD of current CU is, the higher probability current CU will be divided. The HSADs are sorted in a HSAD list in descending order to calculate the error ratio *r*. Formally we define

$$r = E_{num} / (E_{num} + D_{num}) \tag{2}$$

Where E_{num} represents the number of CUs which are not divided and their HSADs are above the threshold *Th*. Similarly, D_{num} represents the number of CUs which are divided and their HSADs are above the threshold *Th*. *r* represents the error ratio. According to (2), we count D_{num} and E_{num} from index of 0 to index of the length of HSAD list, and then we compute *r* in the HSAD list until *r* is more than 0.2, which is obtained by the experiments. Then the index and its corresponding HSAD is obtained, which is referred as the threshold *Th*.

During the fast CU size decision, if HSAD of current CU is larger than *Th*, the RDO process of current CU will be skipped and current CU will be divided into four sub CUs directly. If HSAD of current CU is smaller than *Th*, common RDO process will be done as same as HM10.0. Meanwhile, we use one frame to train the threshold and then update it after *X* frames. In our experiment, we define *X* as frame rate.

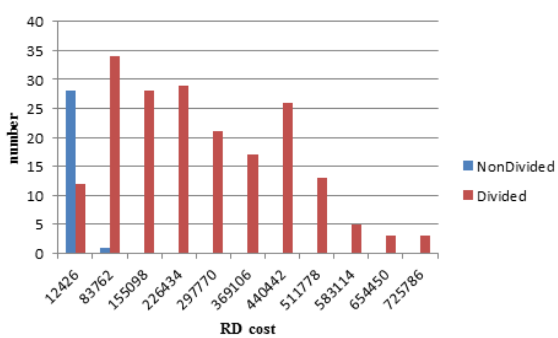

Fig. 3 distribution of RD cost of 64x64 CUs

If the RDO process of current CU is not skipped, a similar method will be applied to early terminate CU size decision of current CTU. If the RD cost is smaller than the threshold *Th*', the current CU will have a high probability to be not further divided. Figure 3 shows the statistical result of RD cost with CU size 64x64. The CU size decision of current CTU can be early terminated. Similar way of obtaining threshold is applied to this. Formally we define

$$r' = E'_{num} / (E'_{num} + D'_{num}) \tag{3}$$

Where E'_{num} represents the number of CUs which are divided and their RD costs are above the threshold. Similarly, D'_{num} represents the number of CUs which are not divided and their RD costs are above the threshold. *r'* represents the error ratio.

Then the threshold *Th*' is obtained. During the fast CU size decision, if the RD cost of current CU is smaller than *Th'*, the CU size decision of current CTU can be early terminated.

2.3. Two-step mode decision

In this proposed intra direction mode decision, only the intra prediction modes (IPMs) with lower precision are employed in the rough mode decision (RMD) and IPMs for rate distortion optimization (RDO) are reduced based on the correlation between neighboring CUs.

In modified RMD, only the intra prediction modes (IPMs) with lower precision are employed. To be specific, only 19 modes are employed rather than 35 modes. The 19 modes are defined as set *A* described in (4):

$$\begin{cases} A = B \bigcup C \\ B = \{0, 1\} \\ C = \{2i \mid i = 1 \cdots 17\} \end{cases} \tag{4}$$

Where *B* is the set of DC mode and planar mode and *C* is the set of down-sampled intra prediction modes.

During the process of RMD, 3,3,2,2,1 modes instead of 8,8,3,3,3 for PU with size of 4x4, 8x8, 16x16, 32x32, 64x64 are selected to form a candidate mode list. After RMD, the neighboring modes of the selected modes are employed to calculate the HSAD. The candidate mode list will be updated by comparing the HSAD of the neighboring modes and the modes in the candidate mode list.

In the second step, we utilize neighboring PUs' prediction modes and HSAD to skip some unnecessary modes. The candidate mode list of RDO is denoted as *S*0. *M*1 and *M*2 are defined to denote the first and the second mode in the candidate mode list respectively. *C*1 and *C*2 denote the corresponding HSAD of *M*1 and *M*2. *M*' denotes the best mode of parent PU. *S*1 denotes the set of most probable modes (MPM). *S*2 denotes the set of the modes of left, top-left, top and top-right PUs. The detailed algorithm is as follows:

```
if 1.5*C1 < C2 && M1 ∈ S1
    then S0 = {M1}
else if (M1 ∈ S2||M2 ∈ S2)&&(M1==M'||M2==M')
    then S0 = {M1, M2}
end if
if |S0| > 2
     for each mode M ∈ S0
         if HSAD(M) > 1.5C1
             then S0 = S0 – {M}
     end for
end if
```

Fig. 4 second step algorithm of mode decision

2.4. Integrated fast intra coding algorithm

In this section, we integrate the above fast intra coding methods into a full intra prediction algorithm, as shown in Figure 5.

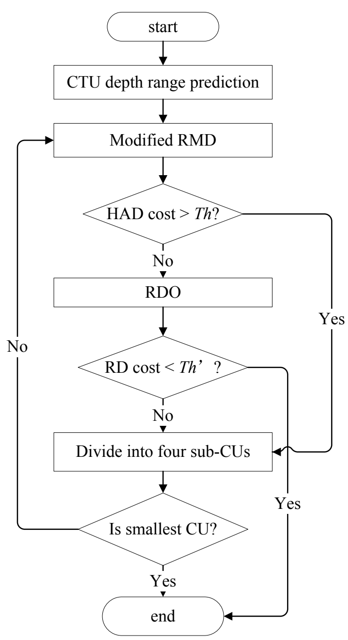

Fig. 5 the integrated algorithm

3. EXPERIMENTAL RESULT

In this section, experiments are carried out to verify the performance of the proposed fast algorithm. Our proposed fast intra algorithm is compared with the default algorithm in HM10.0, following the common conditions defined in [20]. All intra encoder setting is simulated to demonstrate the performance. Class A (4Kx2K), B (1080p), C (WVGA), D (QWVGA) and E (720p) sequences are all used for performance verification. ΔT denotes the time savings which is defined as follows.

$$\Delta T = (T_{HM} - T_{pro}) / T_{HM} \tag{5}$$

Where T_{HM} denotes the encoding time of HM 10.0 and T_{pro} denotes the encoding time of the proposed algorithm.

On average, our proposed solution achieves 54% encoding time reduction for all intra coding with 1.0% BD-Rate of luma increase, which is illustrated in Table II. Meanwhile, we compare our proposed algorithm with some existing algorithms. As shown in Table III, our proposed method saves more 8% and 39% time than [18] and [21] respectively with negligible BD-rate loss.

TABLE II: BD-rate of and time reduction compared with HM10.0

Class	**Y**	**U**	**V**	**ΔT**
A	0.8%	0.5%	0.5%	48.96%
B	0.8%	1.0%	0.9%	52.17%
C	1.1%	1.1%	1.0%	54.66%
D	1.2%	1.0%	1.0%	57.40%
E	1.2%	1.9%	1.7%	55.05%
Avg.	1.0%	0.9%	0.9%	53.65%

TABLE III: BD-rate of luma and time reduction compared with existing algorithms

Class	[21]		[18]		Proposed	
	Y	**ΔT**	**Y**	**ΔT**	**Y**	**ΔT**
A	0.6%	15%	0.7%	44%	0.8%	49%
B	0.5%	15%	0.9%	45%	0.8%	52%
C	0.5%	14%	0.9%	48%	1.1%	55%
D	0.8%	15%	0.9%	47%	1.2%	57%
E	0.9%	15%	0.9%	44%	1.2%	55%
Avg.	0.6%	15%	0.9%	46%	1.0%	54%

4. CONCLUSION

The paper proposes a fast algorithm for HEVC intra coding. It integrates depth range prediction of CTU, fast CU size decision and lower precision mode decision methods. Experimental results show that our proposed algorithm can achieve average 54% (up to 57%) encoding time saving while causing negligible RD performance loss (1.0% BD-rate increase on average) in All Intra High Efficiency test condition compared with HM 10.0.

5. ACKNOWLEDGEMENT

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