EARLY INTRA BLOCK PARTITION DECISION FOR DEPTH MAPS IN 3D-HEVC

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ABSTRACT

In the three-dimensional extension of the high efficiency video coding standard (3D-HEVC), the optimal depth intra coding block partition structure with smallest rate-distortion (RD) cost is decided after recursively checking all possible partition levels (0-3). The block partition method, together with all intra modes for depth maps at each partition level, dramatically increases the computational complexity of depth intra coding. In this paper, we propose an early termination method for intra block partitioning, in which the termination decision could be decided in a simplified form associated with the current block and its first sub-block. Simulation results demonstrate that the proposed algorithm could save 45.10% of depth coding time with almost no increase in BDBR.

Index Terms— 3D-HEVC, depth map, depth intra skip mode, fast block partitioning, rate-distortion optimization

1. INTRODUCTION

Depth intra coding in 3D-HEVC basically adopts the flexible coding block quadtree structure in HEVC, where the coding block partitioning can be flexibly conducted on different block sizes from 64×64 to 8×8 (partition level is from 0 to 3). In addition to the conventional 35 HEVC intra modes (CHIM), several new depth intra coding tools such as depth intra skip mode (DIS), depth modelling mode (DMM), segment-wise DC coding (SDC) and view synthesis optimization (VSO) have been designed to code depth maps in 3D-HEVC. These new techniques improve the coding efficiency at the expense of dramatically increasing computational complexity, especially considering the recursive coding block partition process.

In order to reduce the complexity of depth intra coding, many fast approaches have appeared. They could be roughly divided into two categories: fast mode decision methods [1-4] and fast coding block partition methods [5-6]. In [1], an edge-based DMM skipping strategy was proposed in Hadamard transform domain. In [2-4], the process of DMM search or SDC decision is selectively skipped by comparing the rough rate-distortion (RD) cost of the prior checked modes. In [4], a simplified distortion calculation method in DMM search based on variance is also proposed. On the other hand, a coding block quadtree pruning algorithm was designed in [5] by considering the variance of blocks and the estimated distortion of single depth intra mode. In [6], an inter-component coding tools was developed mainly for inter frames, where the depth coding quadtree is limited to the coded texture quadtree.

However, DIS, which is the most commonly used intra mode, is seldom addressed in the current design of fast methods, especially in the fast intra block partition methods. In this paper, by analyzing the characteristic of DIS in terms of RD cost, we propose an early partition termination method, where the decision at each coding quadtree node could be decided by an inequality only related to the current block and its first sub-block.

The rest of this paper is organized as follows. In Section 2, the background of depth intra coding block partitioning in 3D-HEVC is reviewed. In Section 3, a simplified partition decision is proposed with the purpose of early terminating block partitioning. The experimental results and conclusion are given in Section 4 and Section 5 separately.

2. BACKGROUND

In 3D-HEVC, depth maps are first divided into coding tree units (CTUs, 64×64). Starting from CTU, the quadtree partitioning allows the blocks recursively splitting into four equally sized coding units (CU) until the minimum size (SCU, 8×8) is reached. Before each splitting, a CU is divided into several regions called prediction units (PU) sharing the same prediction mode, including DIS, CHIM and DMM.

During the depth coding block partition process of each CTU, all possible CU partition modes at different partition levels are successively performed in the order (1-85), as Fig.1 shows. The quadtree structure would be pruned until the minimum RD cost is achieved in the final bitstream. The partition decision of whether the quadtree node would be further split or not in the final bitstream is decided by

$$partition\_flag(d) = \begin{cases} true, & J(m_d, d) > \sum_{i=1}^{4} J_i(m_{d+1}, d+1) \\ false, & J(m_d, d) \le \sum_{i=1}^{4} J_i(m_{d+1}, d+1) \end{cases} \quad (1)$$

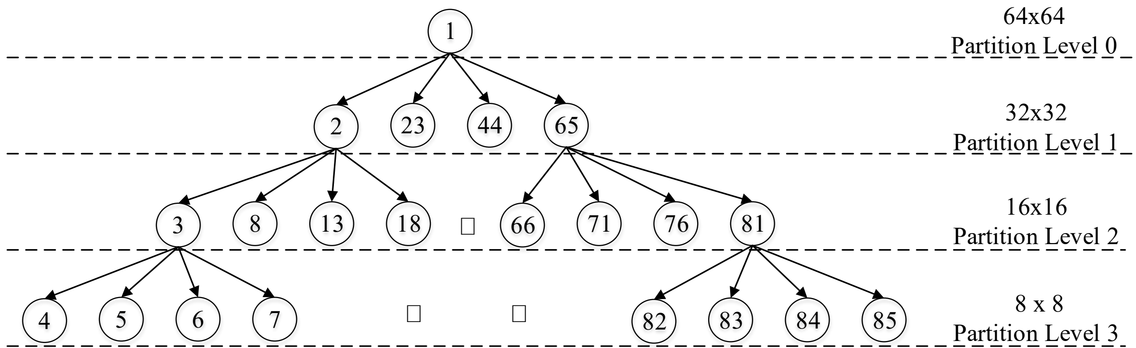

Fig. 1. An example of coding block partitioning among different partition levels, the number in the circle CU is the compressing order

Table 1. Average RD cost of CUs with different optimal modes

QP	Test sequences	32 x 32 (level 1)			16 x 16 (level 2)			8 x 8 (level 3)		
		DIS	CHIMs	DMMs	DIS	CHIMs	DMMs	DIS	CHIMs	DMMs
34	Balloons	156.2	17797.8	9365.1	102.8	4187.8	5259.9	54.8	1206.1	1419.1
	Poznan_Hall2	192.7	8567.5	7165.2	85.7	1247.2	3414.0	41.7	651.6	721.0
	Shark	746.2	18947.0	35989.3	210.2	6074.9	7271.8	59.3	1617.3	1012.9
	Average	**365.0**	**15104.1**	**17506.5**	**132.9**	**3836.6**	**5315.2**	**51.9**	**1158.3**	**1051.0**
42	Balloons	2380.9	39965.2	51310.8	1815.0	18474.5	41129.2	3531.8	11532.8	17364.3
	Poznan_Hall2	3469.4	21248.9	24589.6	1735.7	11503.1	14433.9	830.8	9489.7	8458.6
	Shark	3018.1	44988.0	59224.3	1836.4	20230.3	25086.2	882.5	14660.7	17866.9
	Average	**2956.1**	**35400.7**	**45041.6**	**1795.7**	**16735.9**	**26883.1**	**1748.4**	**11894.4**	**14563.3**

where d represents the partition depth level, *partition_flag*(d) denotes whether the current partition structure is further split or not, m_d is the best prediction mode at the depth level of d for the current CU. It is noted that m_{d+1} for each sub-CU refers to its optimal partition structure (combination from partition level $d+1$ to the maximum partition level) and its corresponding prediction modes. $J(m_d, d)$ denotes the RD cost at level d, which can be calculated by

$$J(m_d, d) = D_{VSO}(m_d, d) + \lambda \cdot B(m_d, d) \tag{2}$$

where $D_{VSO}(m_d, d)$ is the VSO distortion of blocks predicted by mode m_d, λ is the Lagrange multiplier, $B(m_d, d)$ indicates the number of bits used to encode the current CU with mode m_d.

No matter what the final coding quadtree structure is, there must be 85 times recursive dramatically computation for all possible CU partition modes of one CTU block, as shown in Fig. 1. However, not all CU partition modes are necessary to be checked. Early termination of the partition process could significantly reduce computational complexity.

3. PROPOSED ALGORITHM

As we can see, the partition decision of each quadtree node in (1) is only associated with the RD cost of the current CU and its four sub-CUs. However, it is noted that the partition decision of each quadtree node involves further partitioning to the smallest unit (SCU). For example, the partition decision of CU 2 in Fig. 1 requires the RD cost calculation of the current CU 2 and its four sub-CUs. It is noted that four sub-CUs are compressed in the order of 3, 8, 13, 18. In other words, only the current CU and its first sub-CU (left above one in Fig.2) are compressed successively. In the partition decision equation (1), if the partition flag of the CU 2 is decided as false, the smaller CUs 3, 4 … 18 would not be employed in the bitstream. However, the decision could not be made before all CUs from 3 to 18 are evaluated. In this case, a lot of redundant calculations are involved. In order to early terminate the unnecessary partition process of CU 2 in the example, we propose a method to estimate the sum of RD cost of four sub-CUs (CU 3, 8, 13, 18) in an early stage when the compression of the first sub-CU (CU 3) is finished. Based on this estimation, an early termination of block partitioning is then proposed based on the termination condition as follows, which is extracted from (1).

$$Early \quad Termination \quad Condition: \quad J(m_d, d) \le \sum_{i=1}^{4} J_i(m_{d+1}, d+1) \tag{3}$$

3.1. Derivation of Early Termination Decision

Among all intra modes, DIS is the most widely used mode in depth intra coding, where approximately 55.55%-86.00% of CUs are coded as DIS for different sequences. Besides, DIS is a special case where the residual is not transmitted [7]. Since no more bits for residual are required, the CU with DIS as its optimal mode usually has a small RD cost. In Table 1, for both low QP and high QP case, we show the average RD cost of the CUs with different optimal modes in several test sequences. As we can see, the CUs with CHIM or DMM as optimal modes have much larger corresponding

Table 2. Proportion of the first sub-CUs satisfying (9)

QP	Test sequences	level 1	level 2	level 3
34	Balloons	99.35	97.23	96.73
	Poznan_Hall2	97.04	97.89	98.18
	Shark	93.18	93.72	94.24
	Average	**96.52**	**96.28**	**96.38**
42	Balloons	96.79	97.92	99.69
	Poznan_Hall2	98.72	98.80	99.32
	Shark	94.70	97.32	97.34
	Average	**96.74**	**98.01**	**98.78**

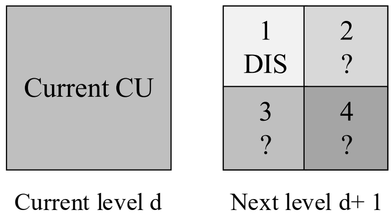

Fig. 2. Proposed case of current CU and its four sub-CUs

RD cost than those with DIS at each partition level.

Due to the special characteristic of DIS as mentioned above, in this Section, we only consider the case in Fig. 2, where the sub-CU 1 at level d+1 selects DIS as its optimal mode. Considering the optimal modes of other three sub-CUs (2-4), the case in Fig. 2 could be classified into two different sub-cases. The first sub-case is that at least one sub-CU selects CHIM or DMM as its optimal mode. And the second sub-case is that all remaining three sub-CUs select DIS as their optimal modes. These two sub-cases are then discussed separately.

***Sub-case I*:** For convenience, we assume the sub-CU r ($r \in \{2,3,4\}$) in Fig. 2 selects CHIM or DMM as its optimal mode for this sub-case. As mentioned above in Table 1, the RD cost of the CUs selecting CHIM or DMM (sub-CU r) is much larger than four times that of the CUs selecting DIS (sub-CU 1). The relation is formulated as follows.

$$4 \times J_1(DIS, d+1) << J_r(m_{d+1}, d+1) \qquad r \in \{2,3,4\} \tag{4}$$

Besides, the total cost of these four sub-CUs is obviously larger than that of one sub-CU.

$$J_r(m_{d+1}, d+1) < \sum_{i=1}^{4} J_i(m_{d+1}, d+1) \qquad r \in \{2,3,4\} \tag{5}$$

It could be easily concluded by (4) and (5) that the inequality in (6) is satisfied in this case, i.e. the total cost of sub-CUs at level d+1 is larger than four times the RD cost of first sub-CU.

$$4 \times J_1(DIS, d+1) < \sum_{i=1}^{4} J_i(m_{d+1}, d+1) \tag{6}$$

Therefore, it is valid for us to estimate the lower boundary of $\sum_{i=1}^{4} J_i(m_{d+1}, d+1)$ by $4 \times J_1(DIS, d+1)$. Obviously, if the below inequality is satisfied for the current CU and its first sub-CU,

$$J(m_d, d) \le 4 \times J_1(DIS, d+1) \tag{7}$$

the early termination condition in (3) can be modified as (7) since (8) could be deduced by combing (6) and (7).

$$J(m_d, d) \le 4 \times J_1(DIS, d+1) \le \sum_{i=1}^{4} J_i(m_{d+1}, d+1) \tag{8}$$

Sub-case II: DIS is a mode designed for smooth area [7]. Since all four sub-CUs select DIS in this sub-case, the current block area must be smooth enough, in which the RD cost of each sub-CUs should be very close.

In order to verify that the RD cost of the sub-CU 1 is close to the average cost of these four sub-CUs, we calculate the difference value of them and show the proportion of those satisfying the inequality (9) in Table 2. It is noted that the ε of (9) is a minimal value and defined in (10), where the *Average*(*J*(*DIS*, *d*+1)) refers to the corresponding value with DIS in Table 1, and α is set as 0.1 here.

$$\left| J_1(DIS, d+1) - \frac{1}{4} \times \sum_{i=1}^{4} J_i(m_{d+1}, d+1) \right| \le \varepsilon \tag{9}$$

$$\varepsilon = \alpha \times Average(J(DIS, d+1)) \tag{10}$$

As we can see from Table 2, most of the first sub-CUs among different levels, ranging from 96.28% to 98.78% in average, are satisfied with the inequality in (9). In other words, it is reasonable to estimate the value of $\sum_{i=1}^{4} J_i(m_{d+1}, d+1)$ by $4 \times J_1(DIS, d+1)$, as follows.

$$4 \times J_1(DIS, d+1) \approx \sum_{i=1}^{4} J_i(m_{d+1}, d+1) \tag{11}$$

Again, if the inequality in (7) is satisfied for the current CU and its first sub-CU, the early termination condition in (3) could be fulfilled as

$$J(m_d, d) \le 4 \times J_1(DIS, d+1) \approx \sum_{i=1}^{4} J_i(m_{d+1}, d+1) \tag{12}$$

In conclusion, in both sub-cases in Fig. 2, the termination condition in (3) could be fulfilled if the inequality in (7) is satisfied. Therefore, we here propose an early termination decision only associated with current CU at level d and its first sub-CU at level d+1, as shown in (13). When the termination decision result is true, early partition termination could be conducted for the current CU.

$$termination\_flag(d) = \begin{cases} true, & J(m_d, d) \le 4 \times J_1(DIS, d+1) \\ false, & J(m_d, d) > 4 \times J_1(DIS, d+1) \end{cases} \tag{13}$$

3.2. Proposed Early Termination of Block Partitioning

With the derived early termination decision (13), the flow chart of the proposed algorithm is shown in Fig. 3. The bold part is from the proposed scheme, while the others are original steps in 3D-HEVC. At each partition level, the RD costs of the current CU and its first sub-CU are first obtained. Then we check whether the optimal prediction mode of the sub-CU 1 is DIS. If the sub-CU 1 selects DIS as Fig. 2 shows, we calculate the RD cost of the sub-CU 1, and check the early termination decision as shown in (13). If the final termination flag result is true, the block partitioning will be suspended immediately at current partition level and all computations related with the remaining three sub-CUs and their corresponding further partitioning are skipped.

Table 3. Performance of [4], [6] and the proposed algorithms compared with HTM-16.1

Sequences	SEDV in [4] (%)		PBED in [4] (%)		Mora's [6] (%)		PRO (%)	
	ΔBDBR	ΔT	ΔBDBR	ΔT	ΔBDBR	ΔT	ΔBDBR	ΔT
Balloons	0.33	-15.05	0.33	-27.30	15.21	-45.00	-0.10	-36.21
Kendo	0.22	-14.85	0.12	-31.12	2.98	-53.97	0.23	-41.67
Newspaper	0.52	-15.60	0.64	-25.16	3.71	-44.28	0.21	-33.93
GT_Fly	0.16	-14.42	0.21	-34.87	0.12	-56.12	0.07	-59.74
Poznan_Hall2	0.31	-11.35	0.11	-43.88	2.33	-63.86	0.10	-54.46
Poznan_Street	0.08	-13.86	0.11	-31.84	1.50	-49.06	0.11	-47.47
Shark	0.04	-16.49	0.32	-23.43	0.87	-51.73	0.01	-39.11
Undo_Dancer	-0.07	-14.30	0.40	-34.41	0.79	-47.23	0.05	-48.21
Average	**0.20**	**-14.49**	**0.28**	**-31.50**	**3.44**	**-51.41**	**0.09**	**-45.10**

4. SIMULATION RESULTS

The proposed early termination of depth block partitioning has been implemented in HTM-16.1 [8]. The original depth intra mode decision in HTM-16.1 was an anchor for comparison with the algorithms in [4, 6] and the proposed algorithm. The quantization parameters(QP) were set as 25, 30, 35, 40 for texture views and 34, 39, 42, 45 for the corresponding depth views. The sequences were tested under the common test condition (CTC) specified in [9]. All frames were encoded using the all-intra structure, since our method was designed for intra coding. The experimental work was implemented on the platform with the CPU of Intel(R) Core i5-3230M CPU @ 2.60GHz and RAM 4.0GB.

To study the performances of the proposed algorithm compared with the state-of-the-art algorithms, coding results including complexity reduction and coding efficiency could be taken into account. The average of encoding time saving ΔT for four different QPs is used to evaluate the complexity reduction. And the coding efficiency is evaluated by the BDBR [10], which is calculated by the PSNR of synthesized views and the total bitrate of depth and texture videos.

The experiment results of proposed algorithms and the algorithms in [4, 6] are shown in Table 3. The SEDV and PBED are two different fast mode decision methods in [4], which could achieve 15.22% and 32.11% of time reduction with little increase in BDBR. The fast block partition algorithm in [6] is mainly designed for inter-frame coding and is applied in intra coding here. Although the time reduction of [6] is remarkable (over 50%), the BDBR increase is also beyond a normal acceptable interval, which mainly results from the mismatch between the depth map and texture image especially in intra coding. However, our proposed algorithm (PRO) could achieve 45.10% of time reduction with only 0.09% increase in BDBR, which is much superior than all other fast methods.

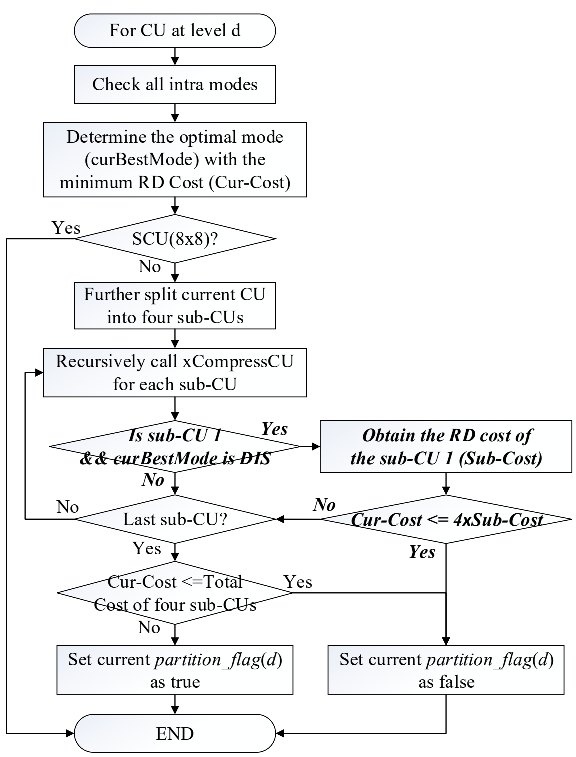

Fig. 3. Flowchart of the proposed algorithm

5. CONCLUSION

In this paper, we propose an early determination algorithm for depth intra block partitioning, in which the termination decision at each coding quadtree node could be decided by an inequality only related to the current CU and its first sub-CU. Experimental results show that the proposed algorithm can provide about 45.10% of time reduction with almost no BDBR loss.

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