Early Determination of Intra Mode and Segment-wise DC Coding for Depth Map Based on Hierarchical Coding Structure in 3D-HEVC

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Abstract— **This paper proposes a fast algorithm to reduce the high computational complexity of depth map coding in 3D-HEVC, which obstructs 3D video from the practical applications. Due to the special feature of depth maps, depth modelling modes (DMMs) were developed to keep sharp edges for depth map. Consequently, the 3D-HEVC encoder can improve the coding performance of synthesized views significantly. However, this is at the significant cost of increased complexity. Since 3D-HEVC reuses the well-known hierarchical coding structure, the mode information of the parent coding units (CU) can be reused to predict the most probable modes for their CUs. Besides, a method is also proposed for early determination of segment-wise DC coding (SDC) decision based on the hierarchical coding structure. Simulation results show that the proposed algorithm achieves a reduction of 33% encoding time while maintaining the quality of synthesized views in term of bit-rate values.**

I. INTRODUCTION

HEVC [1] is the newest international standard of video coding, which is tailor-designed for high definition (HD) or ultra-high definition (UHD) videos and provides about 40% bit-rate reduction compared with its predecessor, H.264 high profile, with the same visual quality [1]. The significant coding performance is benefit from some powerful techniques, such as hierarchical quadtree coding structure [2], uniform intra prediction [3] and so on. Fig. 1 shows the basic structure of hierarchical quadtree coding strategy, including coding unit (CU) and prediction unit (PU). Firstly, the input image is divided into some largest 64x64 CUs (LCU) as the root of coding quadtree. Then, each LCU can recursively be split into four equally CUs until the least CU (8x8) by comparing the Rate-Distortion (RD) performance. CU is the basic block for employing inter or intra prediction. In an intra CU, there are two types of partitions, SIZE_2Nx2N and SIZE_NxN, which have one and four PUs, respectively. HEVC adopts 35 intra prediction modes as shown in Fig. 2 (a), which can provide a good prediction for larger sizes of PUs with more directions.

The introduction of depth maps into the 3D video system avoids the transmission of all texture views redundantly and the required views for display can be rendered by DIBR [4]-[5] in 3D-HEVC as compared with the conventional multi-view video format specified in the early 3D-video system [6]-[9]. Besides the coding tools inheriting from HEVC, depth map coding also adopts a number of new techniques, including SDC [10], DMM [11] and view synthesized distortion [12]. They are designed for the special characteristic of depth map, the mostly smooth region delimited by sharp edges, in 3D-HEVC [13]. DMM as shown in Fig. 2 (b) and (c) is a partition-based intra prediction mode and SDC is an alternative way to encode the residual signals using a delta constant pixel value. The new DMM introduces huge amount of mode candidates as illustrated in TABLE I. The encoder decides the optimal intra mode among all mode candidates and employs SDC and non-SDC checking for residual coefficients, which brings extremely high complexity. Therefore, we should eliminate some unlikely mode candidat-

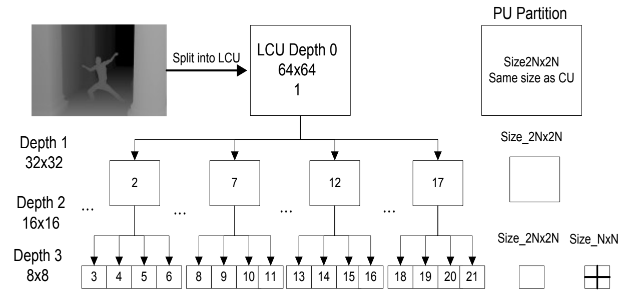


Fig. 1. Illustration of the hierarchical coding structure in HEVC

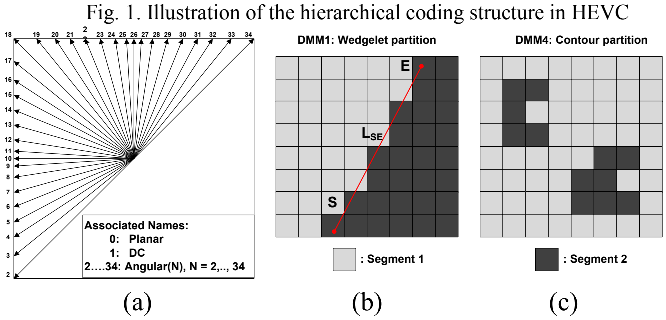


Fig. 2. Depth intra modes in 3D-HEVC, (a) 35 conventional HEVC intra modes, (b) DMM1, and (c) DMM4

TABLE I THE NUMBER OF MODE CANDIDATES IN DMM FOR DIFFERENT SIZES OF PUS

PU	Full Search	Fast algorithm [17]
4x4	86	58
8x8	766	310
16x16	510	384
32x32	510	384

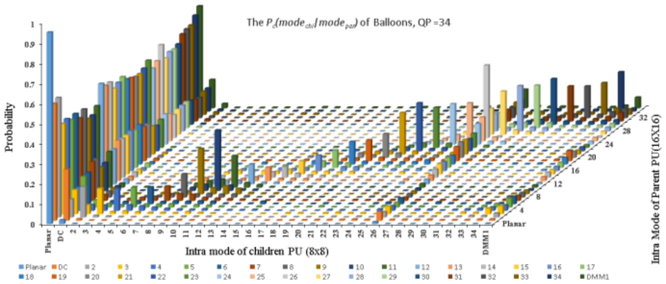
es to alleviate the burden of the encoder in the mode decision process.

The rest of this paper is organized as follows. Section II describes the related works for reducing the complexity of depth intra mode decision. In section III, the proposed hierarchical-friendly depth intra mode decision and the SDC determination method are presented based on the correlation between parent and its children PUs. Section IV provides simulation results and the corresponding discussion and analysis. Section V gives some conclusions.

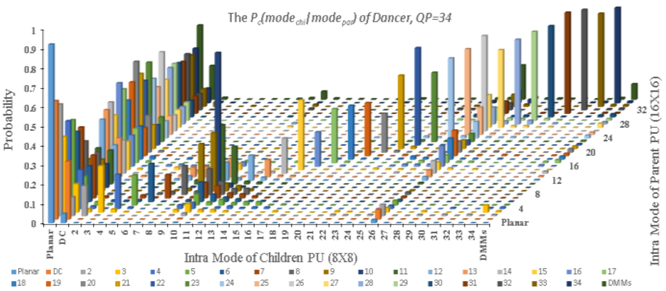
II. RELATED WORKS

Some investigations were proposed to reduce the complexity of depth intra coding, focusing on both of conventional intra modes and DMMs [14]-[23]. Tsang *et al.* achieved significant time reduction by reducing the number of intra prediction modes for smooth regions [14]. Fu *et al.* classified all wedgelet patterns into six categories according to the orientation of sharp edge and only searched the optimal DMM in a subset of the pattern candidate corresponding to the most probable orientation [15]. C. Park omitted unnecessary DMMs based on a simple edge classification in the Hadamard transform domain [16]. P. Merkle *et al.* [17] developed a two-step wedgelet pattern decision algorithm for DMMs. Gu *et al.* skipped DMMs by using the information in rough mode decision [18]. An adaptive mode selection method [19] was raised as an improved version of method [18]. A threshold method was used to early skip DMMs when the variance is bigger than that threshold [20]. In addition, Zhang *et al.* [21] skipped both of some conventional intra mode candidates and DMMs by using minimal rough cost. An adaptive fast depth intra decision was proposed to reduce the mode candidates by the reference pixels classification for smooth and complexity PUs [22]. A technique in [23] only searched the best wedgelet pattern of DMMs at the edge pixels with the largest gradient. A method in [24] was also proposed to early determinate SDC.

By adopting the state-of-the-art techniques in [17]-[18], [20] and [24], the newest test model of 3D-HEVC provides a significant time reduction. However, the complexity is still high. It is also the key bottleneck of 3D video for further applications. All the previous algorithms made use of two information to expedite the 3D-HEVC encoder, i) the prior information, such as rough cost, rough mode by rough mode decision, ii) the information of pixels, such as variance, edge detection and gradient. However, depth intra mode decision was employed in the same PU-level for all algorithms [14]-[23]. In other words, they ignore the prior information from the parent PUs. Hence, in this paper, we propose a fast depth intra mode decision by taking advantage of the hierarchical c-



(a)



(b)

Fig. 3. The distribution of $P_c(mode_{chi}|mode_{par})$. Noted that the parent PU is 16x16 and children PU is 8x8, (a) Balloons and (b) Dancer

oding structure, in which the prior information of parent PUs are reused to guide the intra mode decision in their children PUs.

III. PROPOSED DEPTH INTRA MODE DECISION

Depth map has a special characteristic, which is very different from natural image. As a result, depth maps have stronger spatial correlation than that in texture videos. Hence, we will exploit the intra mode relationship between PUs in different levels. After that, the hierarchical-friendly depth intra mode decision is suggested based on the statistical analysis.

A. Observation and Statistical Analysis

Since the parent PU is employed the mode decision before its children PUs, the optimal intra mode of the parent PU is available and may contain approximate spatial information of its children PUs. The mode or spatial information from the parent PU can be used to prune the mode process of the current PU due to the stronger spatial correlation in depth maps. If the relationship of depth intra modes between different levels of the hierarchical coding structure can be explored well, some mode candidates for the children PUs that are unlike to the parent mode should be skipped. Now, let $P_c(mode_{chi}|mode_{par})$ be the conditional probability of the children PUs selecting $mode_{chi}$ as the optimal mode when its parent PU uses $mode_{par}$ as the best mode and $P_c(sdc_{chi}|sdc_{par})$ be the conditional probability of the children PUs using SDC to encode the residual signals when its parent also adopts SDC encoding. Fig. 3(a) shows that the distribution of $P_c(mode_{chi}|mode_{par})$ generated by the sequences *Balloons* and *Undo_Dancer* when the quantization parameter (QP) equals t-

TABLE II THE PERCENTAGE OF PUS WITH SDC FOR DIFFERENT DEPTH LEVEL OF CUS

The percentage of PUs with the SDC in two differenet situation(%)								
	The percentage of PUs				$P_c(sdc_{chi}\|sdc_{par})$			
PU Depth	0	1	2	3	0	1	2	3
Kendo	34.3	73.9	89.0	94.7	-	98.0	96.4	98.3
Balloons	30.0	67.4	87.3	95.5	-	98.3	96.0	98.1
Newspaper1	15.3	45.7	62.1	67.2	-	88.8	84.3	89.3
Undo_Dancer	62.4	93.2	99.2	99.9	-	97.7	99.5	99.9
GT_Fly	70.7	94.2	98.9	99.7	-	98.8	99.4	99.8
Poznan_Street	38.3	80.0	95.1	98.9	-	94.2	97.7	99.4
Poznan_Hall2	41.2	50.9	51.6	52.1	-	81.0	85.8	90.9
Shak	49.7	83.8	95.0	98.7	-	97.0	98.5	99.7
Average	42.7	73.6	84.8	88.3	-	94.2	94.7	96.9

o 34. The y-axis denotes the mode of the parent PU and the x-axis denotes the mode of the children PUs. It is found that non-zero $P_c(mode_{chi}|mode_{par})$ mostly distributes at the planar, DC, horizontal (mode 10), vertical (mode 26) and diagonal regions (modes of the parent PUs) in Fig. 3. Generally speaking, when the parent PU with an edge is divided into four sub-PUs, only the sub-PUs that contain the edge will inherit the angular mode from its parent PUs and the remaining sub-PUs should be smoothness. It is the reason why the $P_c(planar|angular(i))$ and $P_c(DC|angular(i))$ have a high values in Fig. 3, which reflect the smooth sub-PUs. In the sub-PUs with the edge, it will reuse the angular intra mode from its parent PU to represent the possible directional information. It is also noted that $P_c(angular(i)|angular(i))$, $P_c(planar|planar)$ *and* $P_c(DC|DC)$ also have high values. In addition, the conditional probability from the parent modes to the horizontal or vertical modes are also noticeable. It is due to the fact that these two directions widely exist in natural scenario of depth maps. Based on above analysis of $P_c(mode_{chi}|mode_{par})$, some intra modes should be skipped, which has a relative low probability as the final optimal intra mode. Besides, the distribution of $P_c(sdc_{chi}|sdc_{par})$ as well as the percentage PUs of SDC for different PU levels are tabulated in TABLE II for comparison. The percentages of PUs with SDC are, on average, 42.5%, 73.6%, 84.8% and 88.3% for PUs with depth levels from 0 to 3 (64x64 to 8x8). On the contrary, the $P_c(sdc_{chi}|sdc_{par})$ is more than 94% for all sizes of PUs . In conclusion, both of intra modes and SDC between PUs in different levels have very high correlation. Therefore, some modes uncorrelated with $mode_{par}$ can be filtered out by $mode_{par}$ before the mode decision. For instance, the non-SDC for PUs is not necessary to be checked if its parent PU uses SDC. This observation can narrow the searching scope of intra mode candidates. It also inspires us to design a hierarchical-friendly depth intra mode decision method. It is noted that extensive simulations show that the other sequences and QPs have the similar distributions of $P_c(mode_{chi}|mode_{par})$ and $P_c(sdc_{chi}|sdc_{par})$ in Fig. 3 and TABLE II, respectively.

B. Hierarchical-friendly Depth Intra Mode Decision

Based on the observations of $P_c(mode_{chi}|mode_{par})$ and $P_c(sdc_{chi}|sdc_{par})$ in depth maps above, the proposed hierarchical-friendly depth intra mode decision method is de-

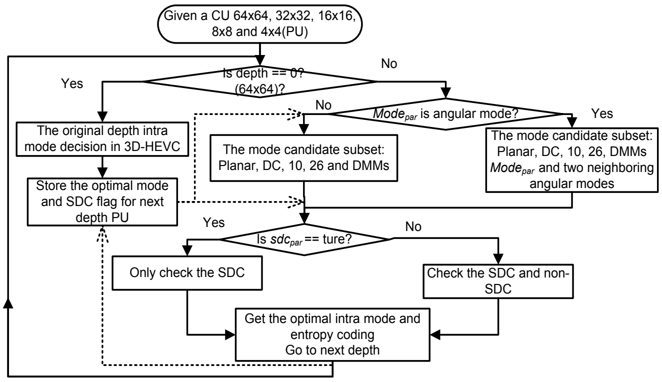


Fig. 4. The flowchart of proposed depth intra mode decision algorithm

picted in the Fig. 4. Firstly, for each LCU (64x64), the original depth intra mode decision is employed to find the optimal mode and check the SDC/non-SDC for residual block. After that, the best mode and sdc_flag (SDC flag) are stored for PUs of 32x32 size. Then the mode candidates of its four 32x32 sub-CUs will be pruned according to $mode_{par}$. If the $mode_{par}$ is the planar, DC or DMMs, the CU is likely to be smoothness, gradual change or piece-wise smoothness. Hence, the modes {Planar, DC, and DMMs} are also selected as the candidates. Besides, the horizontal and vertical modes are also included to represent the weak edges in depth images. In total, the subset of intra mode candidates {Planar, DC, DMMs, 10 (Horizontal), 26 (Vertical)} is the possible optimal intra mode, which can maintain the RD performance. However, if the $mode_{par}$ is angular mode (mode from 2 to 34) with the strong direction, the two neighboring angular modes with the similar direction are available to keep the directional information and the modes planar, DC and DMMs are also employed to represent the non-directional characteristics for some sub-PUs. In addition, if the parent PU uses the SDC to encode the residual block, the non-SDC checking can be skipped. Otherwise, the current PU needs to be encoded twice by checking SDC and non-SDC. After performing the mode decision and obtaining the optimal intra mode, the encoder should store the best mode and sdc_flag for the next depth level. The PUs of 16x16, 8x8 and 4x4 reduce the intra mode candidates and skip the non-SDC checking in the similar way.

Due to the stronger spatial correlation in depth maps, the global spatial structure in parent PUs is related to local spatial structure in their children PUs. The residual information between the different levels of PUs also has a high correlation. Based on this prior information, the proposed method can skip 31 or 28 depth intra modes. Besides, the RD calculation of non-SDC checking is also removed for the traditional HEVC modes and DMMs in some PUs.

IV. SIMULATION RESULTS

The proposed depth intra mode decision algorithm was implemented in the HTM-13.0 reference software [25]. Eight test sequences were used to evaluate the coding performance and measure the time reduction of the proposed algorithm. For each sequence, 200 to 300 frames were encoded as I-fra-

TABLE III THE CODING PERFORMANCE OF PARK'S METHOD [16] AND OUR PROPOSED ALGORITHM COMPARED WITH HTM-13.0

Sequence	Park's [16]			Proposed Mode Decision			Proposed Mode+SDC Decision		
	BDBR (%)		ΔT (%)	BDBR (%)		ΔT (%)	BDBR (%)		ΔT (%)
	BDBR(video)	BDBR(synth)		BDBR(video)	BDBR(synth)		BDBR(video)	BDBR(synth)	
Kendo	0.05	0.08	-10.2	0.16	0.65	-23.16	0.14	0.68	-32.33
Balloons	0.03	0.03	-8.42	0.15	0.65	-23.48	0.14	0.68	-31.61
Newspaper1	0.01	0.16	-4.26	0.12	0.90	-23.15	0.11	0.94	-30.21
Undo_Dancer	-0.02	0.14	-5.73	0.00	0.28	-23.82	0.00	0.29	-34.43
GT_Fly	0.03	0.02	-6.10	0.02	0.38	-30.38	0.01	0.37	-38.39
Poznan_Hall2	-0.06	0.47	-16.15	-0.02	0.45	-24.87	-0.01	0.52	-31.80
Poznan_Street	0.03	0.00	+6.51	0.01	0.28	-23.73	0.01	0.29	-31.11
Shark	0.00	0.00	+3.25	0.15	0.51	-22.69	0.14	0.52	-33.08
Average	0.01	0.11	-5.14	0.07	0.51	-24.41	0.07	0.54	-32.87

mes and all the encoding parameters are specified in the common test conditions [26]. The simulations were conducted on the platform with the CPU of Intel Xeon(R) E3-1230 @3.3GHz and RAM 16.0GB. The algorithm in [16] was used as an anchor. It is noted that the fast algorithms in [17]-[18], [20] and [24] adopted by HTM-13.0 were enabled for both of the proposed and reference algorithms. The BDBR and time saving (ΔT) were used to evaluate the coding performance of the proposed algorithm. BDBR (video) denotes the BDBR calculated using the total bitrate and the PSNR of texture videos. BDBR (synth) indicates the BDBR calculated from the total bit rate and the PSNR of synthesized views.

Experiment results of the proposed hierarchical-friendly intra mode decision algorithm and the anchor algorithm are tabulated in TABLE III compared with HTM-13.0. Our algorithm achieves 24% time reduction for depth intra mode decision while the time saving is only 5% on average in the anchor algorithm in [16]. The reason behind this is that the algorithm in [16] shares the similar idea with the algorithm in [18] adopted by HTM that DMM are skipped for smoothness PUs in the same PU-Level. However, the proposed algorithm can take advantage of the prior information from different PU levels and is compatible with [18] well. In addition, using both of the proposed mode and SDC decision, about 33% time reduction is provided, which preponderates over the algorithm in [16] greatly. Besides, the BDBR (synth) only increased by 0.54%, which can be negligible.

V. CONCLUSIONS

In this paper, an efficient algorithm for mode decision has been proposed to accelerate the speed of depth intra coding in 3D-HEVC. The proposed algorithm explores the hierarchical quadtree coding structure, in which the mode decision of the children PUs only employs in the subset of mode candidates corresponding to the optimal mode of the parent PU. Besides, an early determination of segment-wise DC coding has also been proposed to speed up the mode decision of depth maps. Simulation results show that about 33% encoding time saving is achieved compared to the HTM-13.0 without significant increase in BD-Rate.

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