A Fast Depth-Map Wedgelet Partitioning Scheme for Intra Prediction in 3D Video Coding

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Abstract—**By employing 35 intra prediction modes, HEVC standard performs better to remove spatial redundancy between the current block and its neighbors. Although 3D video coding has adopted HEVC intra prediction and Depth Modeling Modes (DMM) technology to improve the performance, the Explicit Wedgelet Partition Mode within DMM brings unaffordable complexity to compress depth map. Based on the way of obtaining the picture texture from the mode with Sum of Absolute Transform Difference in rough mode decision, we propose a fast scheme to determine Wedgelet Partition in intra prediction, which leads to significant computational saving with marginal BD-rate increase after decoder-side view synthesis.**

I. INTRODUCTION

The HEVC [1] standard is close to be finalized and will be approved as International Standard in January 2013. Several extensions on top of HEVC are discussed within JCT-VC (Joint Collaborative Team on Video Coding), such as 3D video coding [2]. 3DV-HTM3.0 [3] is the latest the test model released with HEVC technology, where many improved Multiview Video Coding algorithms are contained. The well-known concept of disparity-compensated prediction (DCP) has been added as an alternative to motion-compensated prediction. Then, the QP adjustment method is developed in order to improve perceptual quality of coded texture. What's more, a straightforward approach to the synthesized view distortion change [4] is used as distortion measure to overcome the computational complexity.

In the extension, 3D video is represented by the Multiview Video plus depth [5] with 2-3 views, which includes texture views as well as associated depth maps. The decoding video and depth image synthesize additional intermediate views suitable for displaying the 3D content on an auto-stereoscopic by using the advanced Depth-Image-Based rendering techniques. Although the depth maps are not viewed by end users, they directly affect the image generation in decoding. Therefore, it is important to compress depth maps in a way that it minimizes distortion in views rendered with them.

For compressing depth maps in HTM-3.0, basically the same concepts of intra-prediction, motion-compensated prediction, disparity-compensated prediction, and transform coding as for the coding of the video pictures are used. However, some tools have been modified for depth map coding. Chrominance coding is disabled in the sampling format, and in-loop filters including de-blocking filter, adaptive loop filter, and sample-adaptive loop filter are less useful in coding depth map for saving the encoding and decoding complexity. A new Znear-Zfar compensated weighted prediction is designed especially for inter-frame depth coding to overcome the problem of depth map reference frame choice. Unlike HEVC intra prediction coding, Depth Modeling Modes (DMM) [6] are designed to the intra prediction for the sharp edges mainly charactering the depth map. For avoiding the ring artifacts at sharp edges in depth maps and for decreasing the encoder and decoder complexity, the motion-compensated prediction as well as the disparity-compensated prediction has been modified in a way that no interpolation is used. That means, for depth maps, the inter-picture prediction is always performed with full-sample accuracy. Considering that the video signal and its associated depth is graphically similar from the same viewpoint, the Motion Parameter Inheritance [8] mode is extended to deal with inheriting the motion data and the partitioning of the inter prediction.

However, searching DMM parameters in depth map intra prediction introduces unacceptable consuming time, which is about 30 times as much as encoding the corresponding texture image by HEVC based on the experiment result. This paper analyzes DMM irrational operations and proposes to simplify the searching in Wedgelet Partition of DMM. We make full use of the mode with minimal Sum of Absolute Transform Difference(SATD) cost and find correlations between the mode and Wedgelet Partition to simplify the our experiments.

The rest of this paper is organized as follows. SectionII reviews the Depth Modeling Mode technique in 3D video coding. Section III introduces our proposed method by using the SATD mode for reducing the full Wedgelet Partition process. Experimental results and conclusions are given in Section VI and Section V, respectively.

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II. WEDGELET PARTITION IN DEPTH MODELING MODE

Depth image are characterized by sharp edges and large areas of nearly constant or slowly varying sample values. Besides the 35 intra prediction modes used in HEVC, 3D video coding provides four additional Depth Modeling Modes. By selecting the optimal mode with minimal distortion in the all four modes, a depth map is closely approximated by a model that partitions the area of the block into two non-rectangular regions utilizing the mean value of original depth signal as Constant Partition Value (CPV).

A. Wedgelet Partition

Wedgelet Partition [6] aims to separate one Predict Unit (PU) into two non-rectangular blocks by a straight line. As the Fig.1 (1) showed, the two regions are labelled by $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$. The line consists of the start point $\boldsymbol{S}$ and the end point $\boldsymbol{E}$ in diffident PU borders, and determines the separating area. In order to employ Wedgelet block partitions in depth blocks, the partition information is stored in the form of partition patterns, which contain an array of $\boldsymbol{V_S}$* $\boldsymbol{V_B}$ binary value, as the Fig.1 (2) and (3) illustrated. The two regions $\boldsymbol{P_1}$ and $\boldsymbol{P_2}$ are represented by two CPVs separately for minimal distortion calculation.

B. Explicit Wedgelet Signalization

Explicit Wedgelet [7] is the first search for best matching Wedgelet partition at the encoder, and the search over a set of Wedgelet partitions is carried out by using the original depth signal of the current block as a reference, which yields the minimum distortion between the original depth map and the Wedgelet partition estimation. A Wedgelet pattern lookup list is provided what contains all possible Wedgelet Partition patterns for a certain block size (32*32, 16*16, 8*8, 4*4) for making full search for the optimal line composed with start and end point information. Definitely, all lookup list minimum distortion operation according to the sum of squares due to error (SSE) for the Wedgelet partition will find the optimal line, but the process becomes a burden to encode intra-frame depth map.

C. Intra-predicted Wedgelet Partitions

Intra-predicted Wedgelet partitioning [7] mode is adaptively derived from the information of previous blocks coded in the same frame. Fig.2 shows the start point is obtained from the above or left Intra-predicted PUs, so that only the offset to the line end position is transmitted in the bitstream. Therefore, the main complexity is the search for the end point to find best partition.

To adaptively obtain the optimal partition line, the methods for deriving the start point are different from intra type above or left coded. If the above or left block is Wedgelet partitioned, the start position $\boldsymbol{S_P}$ and the end position $\boldsymbol{E_P}$ are predicted by calculating the intersection points of the continued line with block border samples as Fig.2 (1) laballed. If the above or left block is of traditional intra directions type, the end position is calculated by selecting the sample position with the maximum slope to decide the start point $\boldsymbol{S_P}$ and the gradient of intra prediction direction as Fig.2 (2) showed.

Such the process of Intra-predicted Wedgelet Partitions is much easier than full search of Explicit Wedgelet Partition. In contrast, there's no numerous patterns search like Explicit Wedgelet Partition in rest two mode of DMM, which easily adopt inter-component prediction to calculate distortion between depth block data and co-located Y value in texture views. As a result, it is indispensable to reduce the complexity by exploiting an efficient method instead of the intolerant Explicit Wedgelet full search.

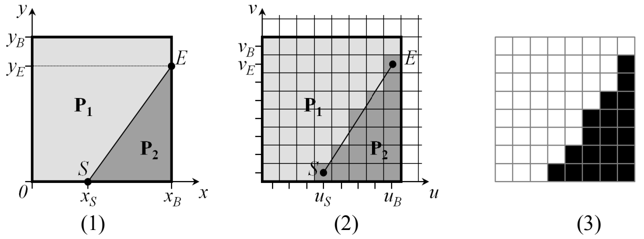

Figure 1. Wedgelet Partition of a PU

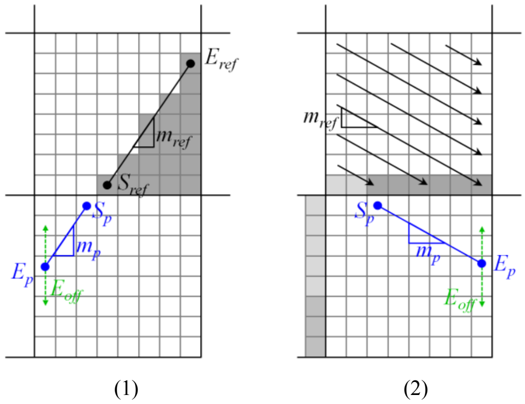

Figure 2. Intra-predicted Wedgelet Partitions:(1) illustrate the Wedgelet Partition mode above;(2) illustrate the regular intra prediction mode above

III. PROPOSED FAST WEDGELET PARTITIONING

A. Complexity Analysis

In 3D video coding based on HEVC, depth map intra prediction provides up to as much as 35 modes for each PU even utilizing neighboring pixels from left down region, and Most Probable Modes from above and left block are still taken into account in Rate Distortion operation process. The 35 regular intra modes are showed in Fig.3 [1].

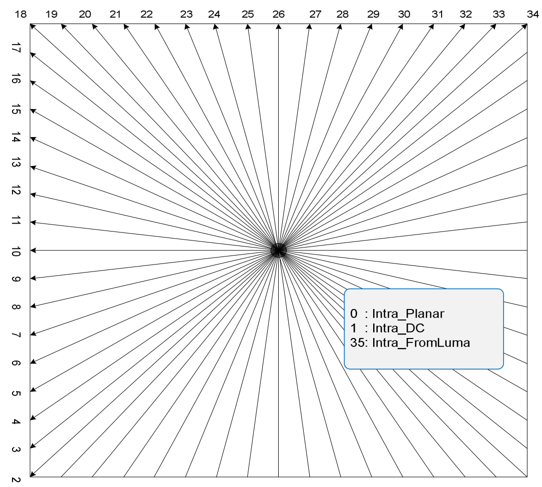

Figure 3. 35 regular intra modes in HEVC

There're four steps to decide the best intra coding mode for depth map. First, a subset of all intra prediction modes is obtained by calculating the SATD in Rough Mode Decision (RMD). The number of the subset is pre-determined to 8 for 4×4, 8×8 PUs, 3 for 16×16 and 32×32 PUs[9]. Next, the MPMs derived from neighboring blocks are added to the subset. Then, the four modes from DMM decision including Explicit Wedgelet Partition are searched, while Explicit Wedgelet Partition operation is mainly time-consuming process in the DMM. Finally, the mode with minimal Rate-Distortion cost is identified the optimal for depth intra prediction.

The complexity of Explicit Wedgelet Partition operation is different depending on different PU's size as the TABLE I described. The search for minimum distortion Wedgelet Partition consists of testing each pattern in the Wedgelet pattern list. Obviously, searching the best Wedgelet pattern in lookup lists is completed up to 1503 times for achieving accuracy of larger block, which is unaffordable to encode intra-depth maps.

B. *Improving Depth-Map Wedgelet Partition*

In previous work [10], it is proved that the block texture is apparently relevant with mode with minimal SATD in the RMD process in HEVC intra prediction. Since the line of Wedgelet Partition has strong relevance with texture features, we can rationally utilize SATD modes to minimize the unnecessary depth Wedgelet partition search. The design of Improving Depth-Map Wedgelet Partition is expatiated as follows.

First of all, the line for separating a block is directionally matched one or two angular modes in HEVC. Since such a line is represented by a Wedgelet Partition Pattern, we classify all Wedgelet patterns into the subset tables of angular mode. The maximum and minimum of the subset table is showed in right part of TABLE I. Then, angular mode with the minimal SATD is obtained before testing DMMs, and each pattern in the corresponding angle subset table above selected is measured to get optimal one with minimal SSE. Finally, such

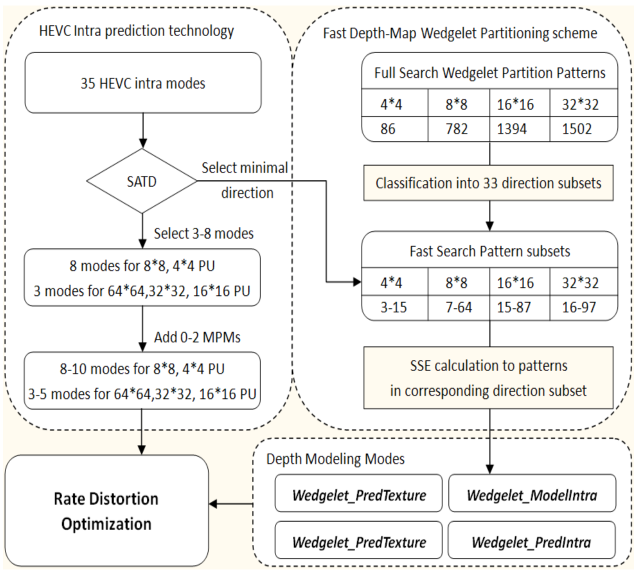

Figure 4. Proposed Fast Depth-Map Wedgelet Partitioning Architecture.

TABLE I. NUMBER OF WEDGELET PATTERNS TESTED FOR FULL SEARCH AND FAST SCHEME DEPENDING ON BLOCK SIZE

Partition Size	Search Times	
	Full	***Fast scheme***
4×4	86	3≤T≤15
8×8	782	7≤T≤64
16×16	1394	15≤T≤87
32×32	1503	16≤T≤97

pattern is to calculate Rate-Distortion cost compared with other 3 DMMs and even angular modes to choose best intra prediction mode. The proposed fast depth-map Wedgelet Partitioning scheme architecture is explicitly depicted in Fig.4.

The situation of 4*4 block size is taken to illustrate the method to decrease all Wedgelet patterns in the first step above mentioned. There're 86 patterns in the Wedgelet partition set as the Fig.5 showed and all of them will be calculated by Sum of Absolute Difference in Explicit Wedgelet partition process. In our scheme, we just add the corresponding Wedgelet lines with similar angle of best SATD mode into the 4*4 table to test the minimal distortion. The search number is 3 to 15 in the table varied from SATD direction. If the optimal SATD mode is selected such as the intra mode 18(135^o) in Fig.6 (1) blue array represented, the Wedgelet partition mode 24, 28, 35, 45, 66, 62 are added into subset table to test which line is optimal. As the Fig.6 (2) showed, the simplest situation in testing 4*4 blocks is absolute vertical or horizontal mode, which contains just 3 Wedgelet partition patterns.

We deal with the PU of 8*8 size, 16*16 size and 32*32 size same as the method of 4*4 size, but the larger PU size to

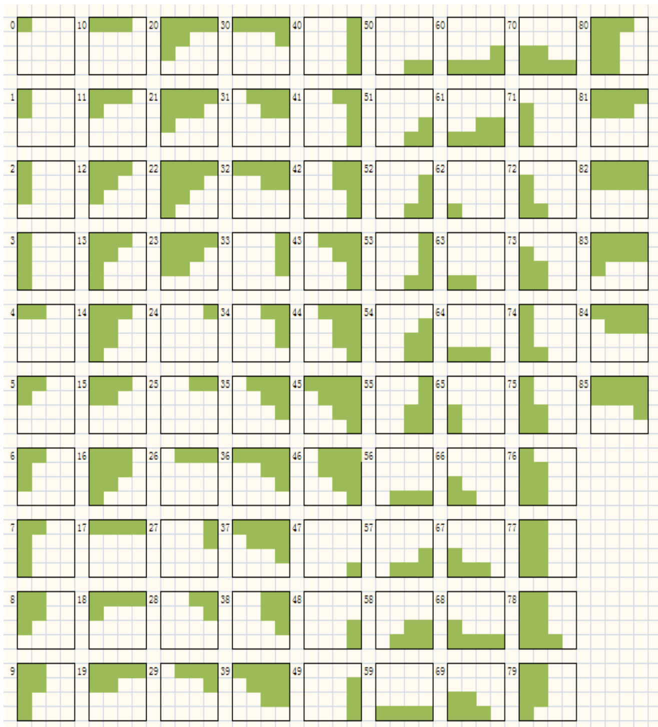

Figure 5. Wedgelet Partition Patterns lookup list of 4*4 block.

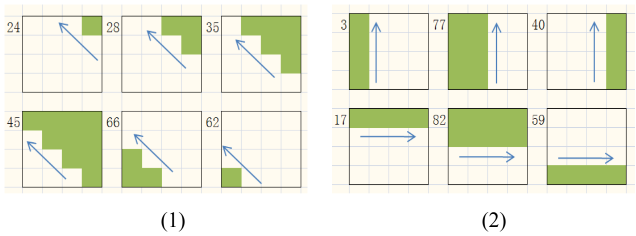

Figure 6. Wedgelet patterns of mode 18(135°), mode 26(90°) and 10(180°)

be processed, the more patterns we will classified even 1503 pattern of 32*32 Wedgelet Partitions. After all, as the TABLE I shown, the improving method provides a subset of full search to reduce nearly 90% complexity of Explicit Wedgelet Partition rather than 86 times SSE evaluation.

IV. EXPERTIMENTAL RESULTS

The coding performance of the improving method used a software implementation base on HTM-3.0. The common test configurations defined in A1100 [11]. Since we focus on the performance of depth intra coding, experiments are carried out for all I-frames depth map sequences. The Group Size is also defined to 1 and the DCP is open in the test experiment to evaluate depth intra coding performance.

Due to DMM technology in intra prediction newly employed, we firstly compare the default configuration of all intra with DMM disabled. In TABLE II, the expressive result shows that it is bought in great BD-rate lose of 5.4% for 2 synthesized views and 5.0% for 3 synthesized views, so that DMM is inevitable tools to improve compressive performance.

For further proving the Explicit Wedge Partition an effective method to compress depth data, we test the performance and complexity by disabling full search for Explicit Wedgelet Pattern in the TABLE III. The tests show that the full search for Wedgelet Partition is mainly time-consuming process account for 90% time of DMM.

TABLE II. BD-RATE AND COMPLEXITY BY DISABLING DMM

Sequence	***BD-Rate (%) of 2 Synthesized views***			***BD-Rate (%) of 3 Synthesized views***			***Time-Saving (%)***
	Y	***U***	***V***	***Y***	***U***	***V***	
Kendo	2.2	0.0	0.2	2.2	0.1	0.1	-74.56
Newspapercc	6.5	0.3	0.2	5.7	0.1	0.2	-84.94
UndoDancer	7.5	0.8	1.0	7.0	1.0	0.9	-74.67
Average	**5.4**	**0.4**	**0.5**	**5.0**	**0.4**	**0.4**	**-78.06**

TABLE III. BD-RATE AND COMPLEXITY BY DISABLING EXPLICIT PARTITION MODE

Sequence	***BD-Rate(%) of 2 Synthesized views***			***BD-Rate(%) of 3 Synthesized views***			***Time-Saving (%)***
	Y	***U***	***V***	***Y***	***U***	***V***	
Kendo	1.5	0.2	0.3	1.5	0.1	0.2	-63.93
Newspapercc	3.5	0.5	0.1	3.1	0.5	0.3	-75.35
UndoDancer	1.7	0.3	0.3	1.6	0.3	0.1	-65.53
Average	**2.3**	**0.3**	**0.2**	**2.0**	**0.3**	**0.2**	**-68.27**

TABLE IV. BD-RATE AND COMPLEXITY OF IMROVING DEPTH-MAP WEDGELET PARTITION

Sequence	***BD-Rate(%) of 2 Synthesized views***			***BD-Rate(%) of 3 Synthesized views***			***Time-Saving (%)***
	Y	***U***	***V***	***Y***	***U***	***V***	
Kendo	1.0	0.2	0.3	1.2	0.2	0.3	-57.57
Newspapercc	2.3	0.5	0.5	2.1	0.5	0.4	-64.57
UndoDancer	1.5	0.0	0.4	1.5	0.2	0.2	-58.46
Average	**1.6**	**0.2**	**0.4**	**1.6**	**0.3**	**0.3**	**-60.20**

The overall experimental results by using improved Wedgelet Partition method are showed in TABLE IV. From the results, our proposed method saving encoding time 60% on average while increase of Y BD-rate are only 1.6% for 2 and 3 synthesized views.

V. CONCLUSION

This paper presents a fast scheme to simplify the Wedgelet Partition process in 3D video depth map coding adaptively utilizing the mode with minimal cost in rough mode decision of HEVC intra prediction. By reducing the complexity in minimal distortion operation of Wedgelet Partition patterns, our proposed method saves encoding time 60% while increase of BD-rates are 1.6% in depth intra coding.

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