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Complexity Optimization for the Upcoming Versatile Video Coding Standard

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Abstract

The Versatile Video Coding (VVC) is forseen as the next generation video coding standard. The main objective is to achieve coding efficiency improvement of about 50% bit-rate reduction compared to the previous standard HEVC at the same visual quality by 2020. In this paper, a fast VVC encoder is proposed based on an early split termination for fast intra CU selection. Taking into account edge complexity of the block and the best intra prediction mode obtained at the current block size, an early split termination is proposed. Using spatial neighboring coding unit depths (quad-tree, binary-tree and ternary-tree depths), the depth probability measure is computed and used to define the stopping criterion. The proposed algorithm is evaluated on nine commoly used test video sequences. Compared to the current VTM3.0 in all intra high efficiency and LowDelayP configuration cases, the proposed algorithm outperforms the anchor scheme in terms of encoding time with a slightly degradation in coding efficiency.
***Keywords** : Early split, low complexity, Versatile Video Coding, textureness.*

Introduction

No doubt that there is widespread interest for higher video-quality service and video technologies such as high-dynamic-range (HDR) video and 360 video. Reducing storage and bandwidth requirements for these applications is of paramount importance. Consequently, many efforts have been done to improve coding performance and visual quality of the videos coding schemes.

The Joint Video Exploration Team JVET composed of ITU-T Video Coding Experts Group (VCEG) and ISO/IEC Moving Picture Experts Group (MPEG) is created in October 2015 to develop and investigate new coding tools beyond HEVC [1]. Compared to HEVC, the JEM achieves bitrate saving that reaches 30% at the same perceived quality [2, 3].

The real start of the new video coding standard named Versatile Video Coding (VVC) was in October 2017 [4, 5]. VVC inherits most of its coding tools from the JEM software [6]. The main objective of VVC is to achieve coding efficiency improvement of about 50% bit-rate reduction compared to HEVC at the same visual quality by 2020.

The video frame is partitioned into a sequence of blocks named coding tree units (CTUs). The CTU is composed of Luma Coding Tree Blocks (CTBs), the corresponding Chroma CTBs. The largest size of the luma block in a CTU is specified to be 128×128. Aiming to exploit the local characteristics of the frame, the CTU is partitioned into Coding Units (CU)s by using the quad-tree structure based on the rate-distortion cost. VVC has further extended the flexibility of the partitioning by the introduction of the binary and ternary trees which further split the square CUs into horizontal or vertical rectangles. To do so, VVC uses the quad-tree plus binary and ternary tree (QTBTT) [4, 7] illustrated in Fig. 1. First, the CTU is partitioned into a quadtree, then the sub-partitions could be further split into a multi-type tree structure.

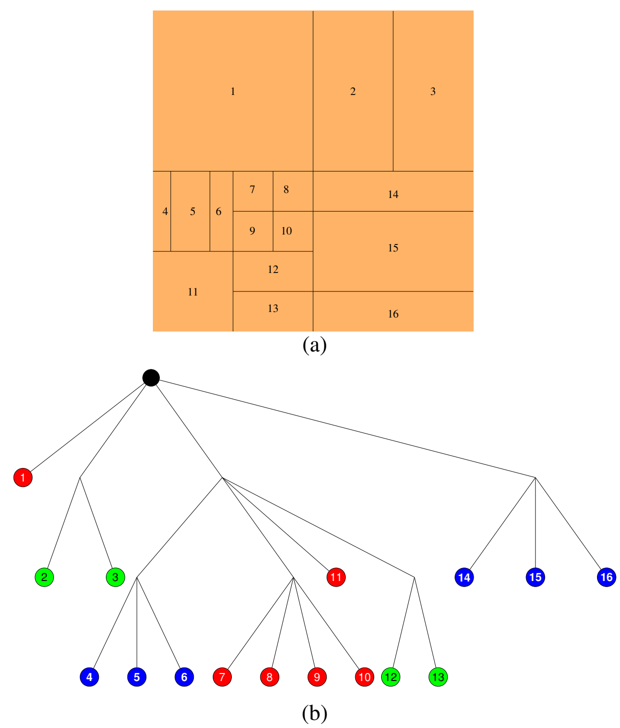

Figure 1: Example of QTBTT partition of the CTU. (a) QTBTT partition of the CTU in blocks. (b) Corresponding tree representation of the CTU : Quad-tree (in red), binary-tree (in green) and ternary-tree (in blue) splits.

As in HEVC, the best coding structure of the CTU is determined by checking the inter- and intra-modes for different partition depths and shapes based on the rate-distortion optimization (RDO). Therefore, some new features are introduced in the inter-picture prediction process such as the bi-directional optical flow (BIO) [8] and the overlapped block motion compensation (OBMC) [9, 10]. To further exploit the spatial redundancies within the same frame, the intra-prediction in VVC is enhanced as well by some new features and is adapted to the new coding unit size and shapes. VVC adopts the same principle as in HEVC by using the boundary pixels of the already encoded neighbors to predict the target block. Furthermore, it provides

67 prediction modes, including 65 angular prediction modes and two non-directional ones (DC and Planar), employed for luma samples. The number of most probable modes (MPM)is set to six [4, 11]. In the intra-prediction process, chroma samples could be predicted directly from their corresponding luma sample using the cross-component linear model prediction [12]. Furthermore, the Position-Dependent Prediction Combination (PDPC) that employs a weighted combination of unfiltered and filtered references is adoped [13]. To cope with the new coding block structure and shapes, larger block-size transform high-frequency zeroing has been designed for VVC transform coding process. The transform kernel sizes range from 4×4 to 64×64 and are used to accommodate the higher partitions. HEVC defines two types of transform, namely $DCT-II$ as the main transform kernel and the $DST-VII$ employed for 4×4 Intra blocks. In turn, VVC introduces a new technique called Adaptive Multiple Transform (AMT) involving three DCT transform types (DCT-II, DCT-V, DCT-VIII) and two DSTs (DST-I, DST-VII) [4, 14]. Another major transform coding tools employed in VVC is the Non-Separable Secondary Transforms (NSST) [15] which is about a low-complexity variant of non-separable transforms. In addition, new filtering tools such as the Adaptive Loop Filter (ALF), the Four-tap intra prediction filter, and the Bilateral in-loop filtering are adopted. Based on number of improvements in most of coding tools, VVC shows better coding performance compared to state-of-the-art video codecs such as AV1, VP10 and much higher performance than its predecessor, HEVC. However, this performance comes at the expense of higher computational complexity causing thus a serious problem for several real-time applications.

In this paper, we propose a fast VVC encoder based on an early partition split termination. By accounting for the smoothness of the block, measured using the Sobel edge detector algorithm in addition to the best intra prediction mode obtained at the CU block-size, an early split criterion is defined. Furthermore, the depth probability is derived from the spatial neighboring coding unit depths (global, quaternary tree, binary tree, and ternary tree depths) and used to refine the stopping criterion. In order to limit QP variation effect, a threshold based on QP values is defined.

The remainder of this paper is organized as follows. In section , we describe the proposed early intra CU split termination. The experimental results and comparisons are provided in section . Finally, the contributions of this paper are summarized and the future work is outlined in section .

Related works

Many researchers have proposed a variety of contributions to reduce the coding complexity of HEVC. Most of those approaches are articulated around two categories: fast intra prediction mode decision and early partition split approaches.

To mitigate the coding complexity of HEVC, edge-based methods are proposed to reduce the number of intra prediction modes in [16–20] by using edge information to determine the dominant direction within a block and its corresponding mode. Based on the dominant edge assent standard deviation, Yao et *al.* propose to reduce the number of prediction models to eleven/two, DC and Planar modes [19]. The experimental results reveal that this approach can reach time saving up to 36.26% compared to the test reference model. In [18], a fast mode decision approach is proposed by Na *et al.* using the edge map characterized by a Sobel edge detector. A subset of prediction modes in accordance with the dominant edge is chosen for the RMD process. This approach can reach up to 56.8% of time saving with 2.5% BD-BR increase on average.

Fast CU size decision and early split termination are widely proposed in the literature. It is mainly about avoiding unnecessary CU size or mode evaluation using the rate distortion optimization (RDO). Authors in [21], propose an early skip and split algorithm for fast intra CU size decision in HEVC. Oztekin *et al.* use the coefficient variation as a robust region complexity indicator. In [22], a fast PU skip and split termination approach for HEVC intra prediction is proposed by Lim *et al.*. The proposed approach consists of three different algorithms: early skip, PU skip and PU split. Based on the neighboring PUs, the early skip performs immediate skipping of the RD cost computation for large PUs. The PU skip algorithm allows skipping of the full RD cost computation using Bayes's rule. Finally, based on the cost of the rough mode decision (RMD) a split termination algorithm stops further PU splitting. In order to reduce the computational complexity of the HEVC intra frame coding, Ramezanpour *et al.* propose an early termination algorithm for CU size decision [23] using a CU smoothness parameter that is generated by computing SAD in four directionsThe proposed approach reaches on average 27.5% time saving with a coding performance loss of 0.4% BD-rate.

Machine learning techniques gained interest in the video coding field lately, especially for reducing coding complexity. A clustering-based approach is proposed by Jaballah *et al.* to reduce the number of evaluated intra modes in [24]. The intra modes are clustered into K clusters by means of the K-medoid clustering algorithm, and each IPM cluster center represents all the IPMs within a cluster for the RDO process. An early CU splitting based on a weighted SVM is proposed in [25]. The SVM is used to classify a CU size to be split or not while taking RD losses, due to miss-classification, as weights in the SVM training. A convolution neural network (CNN) is used to reduce the hardware complexity of HEVC in [26]. The CNN analyzes the textures of CU, and then selects the optimal CU and PU sizes.

Despite their outstanding performance, those techniques proposed for HEVC cannot be applied straightforwardly to VVC because of the new coding structures adopted by VVC, the QTBTT in particular.

Proposed approach

The main goal of the proposed low complexity VVC encoder is to reduce the coding time with a minimum degradation on the bit-budget or the visual aspect.

Motivation

In order to develop an effective intra CU split termination algorithm, an investigation about the correlation between the partition size and the textureness of the block within a CU is carried out. While coding video scenes, the encoder tends to select larger blocks to represent the regions with lower spatial frequencies (no edge) and smaller blocks for textured regions of the frame as shown in Fig. 2.

Furthermore, the intra angular prediction modes in video coding are designed to predict the orientations inside the block based on the reference samples. However, DC and planar modes are introduced to predict blocks not containing edges (smooth or

Figure 2: Example of CU structure partition of the VTM3.0 for sequence CatRobot (3840×2160).

gradually smooth blocks). For example, a CU block not containing edges and having Planar or DC as the best-obtained intra mode, no further partition split is needed. Obviously, one can conclude from this observation that the textureness (complexity) of the region is highly correlated to the CTU partitioning.

Sobel Edge Detection

The purpose of the Sobel filter is to detect edges within an image and compute its strength and orientation. In this context, the Sobel filter is used to compute the block complexity.

The Sobel operator makes use of 3×3 kernel mask and rotates it according to the horizontal and vertical directions namely G_x and G_y, respectively.

$$G_x = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix} \quad G_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \tag{1}$$

For pixel P at (i, j) in a coding block, its horizontal-direction $X_{i,j}$ and vertical-direction $Y_{i,j}$ gradients are calculated as follows:

$$\begin{aligned} \Delta X_{i,j} = \quad & P_{i+1,j-1} + 2 \times P_{i+1,j} + P_{i+1,j+1} \\ & -(P_{i-1,j-1} + 2 \times P_{i-1,j} + P_{i-1,j+1}) \end{aligned} \tag{2}$$

$$\begin{aligned} \Delta Y_{i,j} = \quad & P_{i-1,j+1} + 2 \times P_{i,j+1} + P_{i+1,j+1} \\ & -(P_{i-1,j-1} + 2 \times P_{i,j-} + P_{i-1,j-1}) \end{aligned} \tag{3}$$

The edge magnitude for each pixel is determined as the gradient magnitude of horizontal and vertical directions and is computed as in Eq. 4.

$$Mag_{i,j} = \sqrt{(\Delta X_{i,j})^2 + (\Delta Y_{i,j})^2} \tag{4}$$

For the sake of normalized values of magnitude in the range of $[0,1]$, the normalized edge magnitude μ is computed as:

$$\mu = \frac{Mag_{i,j}}{4 \times \left(2^{nbit} - 1\right) \times (S)} \tag{5}$$

where *nbit* is the number of bits needed to code a pixel (BitDepth) and S represents the size of the block.

Depth probability

The intra- and inter-prediction modes are highly correlated with the already coded modes of the spatial neighboring CUs. Generally, the CU can inherit some coding information form its spatial and/or temporal neighbors. In the same vein, we propose a depth probability which is measured based on the depths of spatial neighboring CUs. The left, top-left and top CUs are used as the spatial neighboring blocks as illustrated in Fig. 3

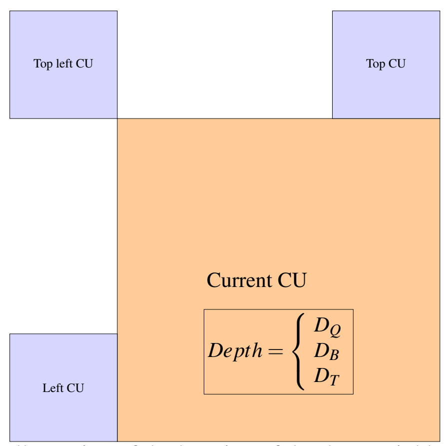

Figure 3: Illustration of the location of the three neighboring coding units.

In VVC, a CU is characterized by its global split depth and three other specific split depths: quad-tree D_Q, binary-tree D_B and ternary-tree D_T depths.The three specific depths (D_Q, D_B, D_T) of each CU are compared with their corresponding depths in the neighboring CUs.

For each depth, we compute the number of times the depth of the current CU is equal to its corresponding depth in each neighboring CU as follows:

$$D(S) = \sum_{CU=1}^{3} (Check^S_{CU}) \tag{6}$$

where S represents the type of specific depth D and $Check^S_{CU}$

is calculated as in Eq 7.

$$Check^S_{CU} = \begin{cases} 1, & if \quad Depth^S_{CU} == Depth^S_{CU_0} \\ 0, & otherwise \end{cases} \tag{7}$$

Based on this match up test of each depth types, the depth probability *DP* is computed as:

$$DP = 0.4 \times \frac{D(Q)}{3} + 0.3 \times \frac{D(B)}{3} + 0.3 \times \frac{D(T)}{3} \tag{8}$$

$(0.4, 0.3, 0.3)$ are fixed weights that have been defined empirically. They represent the effect of each depth on the final depth probability. An additional investigation could be done in order to fix them adaptively.

General scheme

Based on the aforementioned features, an early CU split termination is performed. The first step to verify the smoothness of the current block is to check whether the result of the intra-prediction best mode selection is Planar or DC mode. Once the last criterion is verified, the strength of the edge within the block has to be computed (using Sobel edge detector in this work) to check whether the current block is smooth or gradually smooth which means that the selected mode (Planar or DC) is the optimal one and there is no need for further splitting of the CU.

We empirically found out that for edge strength $\mu < 0.05$ (5% of the block samples represent the edge) the processed block is considered as smooth and further splitting of the CU is not needed. Otherwise, we define the no-split probability *NSP* based on depth probability *DP* and Sobel normalized magnitude μ of the CU. It is computed as:

$$NSP = DP \times (1 - max(\mu, 0.1)); \tag{9}$$

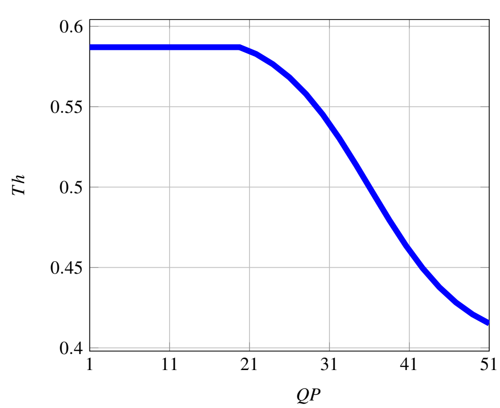

Figure 4: No-split probability threshold values according to QP.

For *NSP* values higher than a defined threshold Th in the range of $[0.4, 0.6]$, an early CU split termination is performed. This threshold is computed based on the QP value of the CU. In the Intra prediction process, the CU edge complexity is related to QP values, due to the fact that the edge distortion is more visible in higher QP values than in lower ones. Based on this observation, we design an adaptive threshold Th with higher values at lower QPs and a smooth transition between higher and lower values. A graphical representation of the adaptive threshold is given in Fig. 4.

This threshold is calculated as:

$$Th = 0.5 + 0.1 * tanh((-(TQ + 5))/3); \tag{10}$$

Where TQ is computed as:

$$TQ = (max(QP >> 2, 5) - 4); \tag{11}$$

" $>>$ " represents the bit-wise right shift operator.

The global scheme is depicted in Fig. 5.

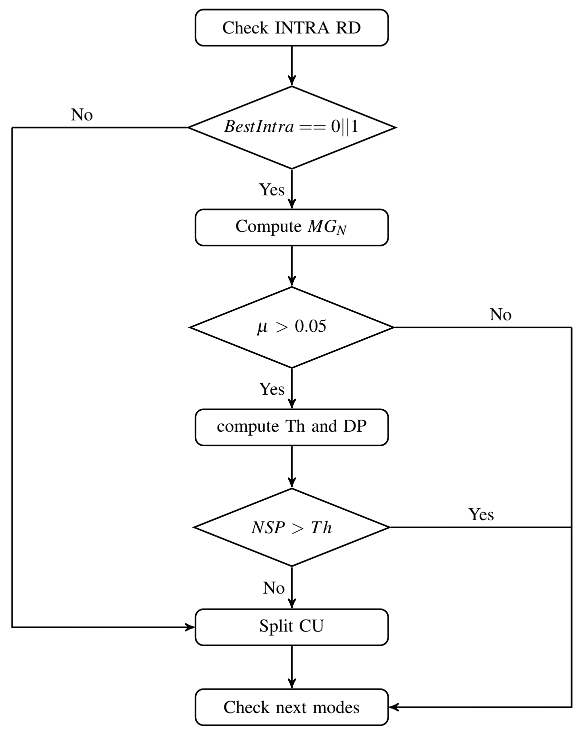

Figure 5: Flowchart of the proposed early CU split termination in VVC encoder based on Sobel operator and the depth of spatial neighbouring CUs. Intra mode 0 and 1 are Planar and DC modes, respectively.

Experimental results

Comprehensive experiments are conducted in order to evaluate the computational complexity of the proposed scheme and its impact on coding efficiency. All the experiments are performed under all-intra, LowdelayP configuration cases and the common test condition (CTC) defined by the JVET [27]. The proposed scheme is implemented on VVC test model VTM3.0 [28]. Nine video sequences recommended by the CTC are used in the simulation with the quantization parameters 22, 27, 32 and 37.

In this work, the proposed approach is evaluated using the *Bjontegaard* measure (BD-rate), which represents the average bitrate differences [29]. In addition, we use the average percentage difference in coding time (ATS) defined by Eq.12 to compare our method with the anchor VTM3.0.

$$ATS = \frac{1}{4} \times \left(\sum_{QP=22}^{QP=37} \frac{Time_{VTM3.0} - Time_{proposed}}{Time_{VTM3.0}} \right) \times 100. \tag{12}$$

Table 1: Simulation results of the fast intra CU split termination method in terms of BD-rate and ATS compared to VTM-3.0.

Sequences	Class	Proposed				Oztekin [21]			
		All intra		LowdelayP		All intra		LowdelayP	
		BD-rate	ATS	BD-rate	ATS	BD-rate	ATS	BD-rate	ATS
Tango2	A1	3.62	48.65	0.91	16.42	5.63	37.15	1.37	12.65
Campfire	A1	2.32	46.90	0.73	11.56	5.47	38.46	1.12	13.21
CatRobot1	A2	2.87	41.21	1.13	18.12	5.78	40.25	1.45	10.48
Cactus	B	2.89	42.02	0.63	16.74	4.69	30.04	1.07	09.96
BasketballDrill	C	3.74	49.73	0.83	15.19	4.26	35.12	0.85	10.82
BasketballPass	D	2.53	52.40	0.78	18.54	3.92	27.83	1.26	07.15
BlowingBubbles	D	3.81	56.28	1.32	23.73	4.18	24.19	1.03	09.71
FourPeople	E	2.59	58.30	0.31	13.12	4.34	27.76	0.74	10.59
KristenAndSara	E	1.89	33.46	0.58	15.62	3.86	23.47	0.92	09.34
Average	-	2.91	47.66	00.88	16.56	4.68	31.59	1.08	9.76

Table 1 reports the results obtained with our fast intra CU split termination algorithm using VTM3.0 as an anchor for both all intra and LowdelayP configuration cases. It can be noticed that in the all intra configuration cases our proposed algorithm achieves very high performance reaching nearly 47.66% of complexity reduction in average. This very significant reduction of complexity comes at a price of a little amount of BD-rate impairment (2.59% in average). By observing the results of the proposed algorithm obtained in the lowdelayP configuration case, we can obviously notice that the complexity gain has been reduced compared to the all intra case with an average of time reduction of 16.56%. However, applied in the lowdelayP this approach brings a negligible reduction of bitrate around 0.88%.

For the sake of a fair comparison, we applied the Oztekin algorithm [21] on the top of the VTM-3.0. We can observe from Table 1 that our approach achieves higher savings than Oztekin *et al.* method [21], almost by a factor of 1.5 for both configuration cases. In the same vein, our proposed approach outperforms the state-of-the-art algorithm in term of bitrate increase (2.91 vs. 4.68) for intra configuration and (0.88 vs. 1.08) for the LowdelayP configuration.

Conclusion

This paper describes a novel VVC intra CU split termination algorithm aiming to reduce VVC encoder computation time. The edge complexity of the block using the Sobel edge detector algorithm is employed along with the depth probability and the best intra prediction mode obtained at the current block size to check whether an early split of the CU is needed or not. Experiments were carried out on nine video sequences, objective results demonstrated that the proposed method can provide important time saving for all-intra and LowdelayP configurations with less amount of perceived quality distortion. The natural extension of this work lies in exploration of the temporal correlation between frames of the same group of picture to further reduce the encoder computation complexity. Besides, a subjective quality evaluation will be run to demonstrate the almost perceptually lossless of the proposed method.

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