FAST HEVC INTRA PREDICTION MODE DECISION BASED ON EDGE DIRECTION INFORMATION

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ABSTRACT

The High Efficiency Video Coding (HEVC) is an emerging standard that achieves higher encoding efficiency when compared to previous standards such as H.264/AVC. One key contributor to this improvement is the new intra prediction method that supports a large number of prediction directions at a cost of very high computational complexity. This paper presents a fast intra prediction mode decision algorithm, which instead of taking into account only the modes of the neighbor PUs (prediction units) uses edge information of the current PU to choose a reduced set of directions from which the best prediction mode (direction) is finally selected. The proposed method provides a decrease of up to 32.08% in the HEVC intra prediction processing time, with a little increase in the bit-rate (0.9% on average) and a negligible reduction in PSNR values.

Index Terms— video coding, HEVC, intra prediction, edge computation, complexity reduction

1. INTRODUCTION

The increasing availability and use of devices and applications supporting high-resolution video capture and the call for applications such as video surveillance to support high-definition video with real-time encoding has put a strain on the capabilities of current generation video coding standards such as H.264/AVC. In response to these ever increasing demands for higher compression ratios new video coding solutions, such as the emergent High Efficiency Video Coding (HEVC) [1], have been developed aiming at reducing the bit rate without jeopardizing the image quality (high coding efficiency) at an acceptable computational complexity level.

Since April 2010 the Joint Collaborative Team on Video Coding (JCT-VC) of ITU-T and ISO/IEC has been working on the development and standardization of the HEVC standard with the major goal of achieving a better tradeoff between coding efficiency and complexity than the current state-of-the-art video coding standard H.264/AVC [2][3].

Recent results obtained from comparisons made between the H.264/AVC and the current version of HEVC [1] showed that the HEVC can achieve an average bit-rate improvement of approximately 33% for *random access - high efficiency* (RA-HE) configuration [4] when compared to H.264/AVC. However, for the *all intra - high efficiency* (AI-HE) case was observed only a minimum gain in the bit-rate of about 22%, with a similar complexity increase than that of RA-HE configuration [4].

The intra prediction mode decision is responsible for more than a half of the total computational complexity of the intra frame coding when using the HEVC Test Model [5]. This paper presents a fast intra coding mode decision algorithm, which uses edge information of the image to speed-up the best intra prediction mode selection procedure. As it will be shown the method proposed significantly reduces the intra prediction computational complexity, while causing negligible losses in terms of encoding efficiency.

This paper is structured as follow: Section 2 outlines the intra prediction framework used in HEVC, Section 3 presents in detail the intra mode decision algorithm being proposed and in Section 4 the experimental results are analyzed and discussed. Finally, the conclusions and some indications of future explorations are presented in Section 5.

2. INTRA PREDICTION IN HEVC

The HEVC emerging standard defines that a frame is divided in large coding units (LCU) which are then partitioned into coding units (CU) using a quad-tree structure. Each leaf CU can also be further partitioned into prediction units (PUs) [1] as shown in Figure 1, and each PU can employ a different intra prediction direction.

An intra coded CU can consist of one 2Nx2N PU or four NxN PUs (Figure 1), where N is half of the CU size.

The HEVC proposal further defines another type of unit, the TU (transform unit), which represents a block of prediction residues that is transformed and quantized.

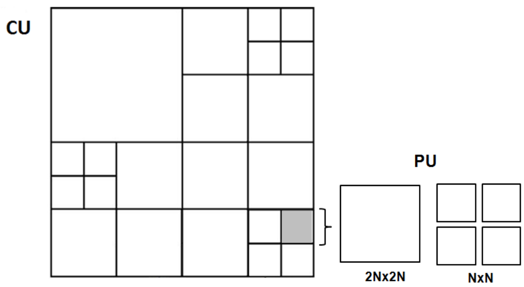

Fig. 1. Types of partitioning of intra coded CU into PUs.

The intra prediction defined in the HEVC reference model version 4.0 - HM 4.0 [6] allows 33 angular prediction directions (modes), as shown in Figure 2 [1], as well as two additional prediction modes: DC and planar.

The number of available intra modes is a function of the PU size: 18 modes for 4x4 PUs; 35 modes for 8x8, 16x16 and 32x32 PUs; and four modes for 64x64 PUs [1].

The intra prediction of the current PU is obtained through the extrapolation of values derived from reference pixels of the neighboring PUs, a process which requires many arithmetic operations per predicted pixel value, making it quite computationally complex.

HM4.0 [6] defines a simplified version of the intra prediction which reduces the number of intra modes to be evaluated when looking for the best performing one. This simplified intra decision mode is based on the selection of a subset of candidate prediction modes (as shown in the Figure 3). This subset is composed of the modes that yield the smallest sum of absolute transformed differences (SATD) between original pixels and predicted pixels (i.e. prediction residue) and its size is chosen according to the PU size as shown in Figure 3. To this subset is added a most probable mode (MPM), which is derived from the intra modes of the left and top neighboring blocks or PUs.

Finally, the R-D cost of each prediction mode belonging to this subset is computed and the mode with the best R-D cost is selected to (intra) encode the PU. The definition of the optimal residual tree (RQT) for the intra prediction mode selected concludes the process.

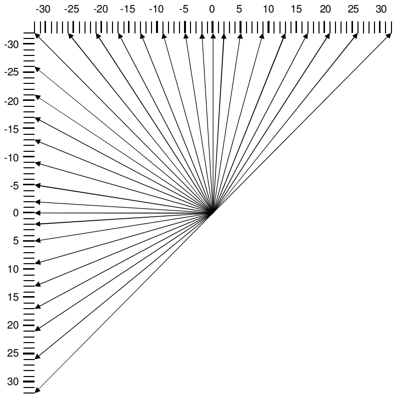

Fig. 2. HEVC intra prediction directions.

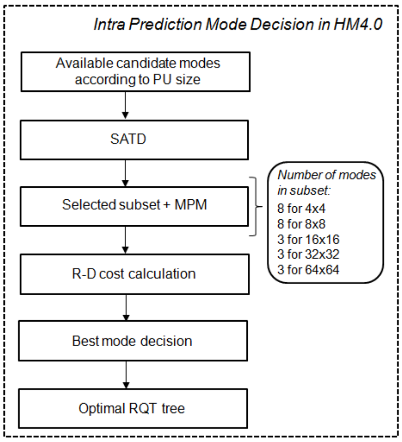

Fig. 3. Intra prediction mode decision in HM4.0.

Even though the simplified version used in HM4.0 optimizes the intra prediction process, the choice of the best intra mode is still critical, because notwithstanding its simplified nature it still requires a lot arithmetical operations.

3. PROPOSED ALGORITHM

As mentioned in section 2, the HEVC intra prediction has 33 possible angular modes plus the DC and the Planar modes. The intra prediction mode choice process used in the HM4.0 provides a simplified version of this decision, which selects a subset of candidate modes to the prediction of each PU. But the need to assess in advance all the 33 modes available to compose this subset still remains. Thus the computational complexity is still quite large, and the encoding time is still significant.

The algorithm developed in this work significantly reduces the number of modes that have to be evaluated in intra prediction, and consequently makes the HEVC intra prediction decision mode computationally more efficient.

This algorithm evaluates the edges directions present in the PU to be predicted categorizing these edges in five types; four directional, horizontal, vertical and two diagonals (45° and 135°), and one non-directional edge [7].

The dominant edge computation, presented in Figure 4, is performed on the pixels of the original PU to be predicted. This computation is made from 4x4 PUs, so that each 4x4 PU is divided in four blocks with 2x2 pixels, as shown in Figure 4.

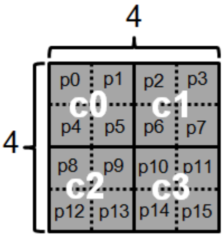

Fig. 4. 4x4 PU edge computation.

Next, the following equations are applied on the pixels of each block that composes the 4x4 PU (Figure 4):

$$c0 = \frac{p0 + p1 + p4 + p5}{4} \tag{1}$$

$$c1 = \frac{p2 + p3 + p6 + p7}{4} \tag{2}$$

$$c2 = \frac{p8 + p9 + p12 + p13}{4} \tag{3}$$

$$c3 = \frac{p10 + p11 + p14 + p15}{4} \tag{4}$$

From the values calculated in equations (1) to (4), five edge strengths are calculated as per equations (5) to (9) [7] applying five different filters according to the edge type, as described below:

$$eV = \left|c_0 - c_1 + c_2 - c_3\right| \tag{5}$$

$$eH = \left|c_0 + c_1 - c_2 - c_3\right| \tag{6}$$

$$e45^\circ = \left|\left(c_0 \times \sqrt{2}\right) - \left(c_3 \times \sqrt{2}\right)\right| \tag{7}$$

$$e135^\circ = \left|\left(c_1 \times \sqrt{2}\right) - \left(c_2 \times \sqrt{2}\right)\right| \tag{8}$$

$$eND = \left|(2\times c_0) - (2\times c_1) - (2\times c_2) + (2\times c_3)\right| \tag{9}$$

With the strength of each type of edge calculated, the maximum value among the five edge strengths is selected through equation (10). The orientation of the dominant edge of the 4x4 PU is defined as the one corresponding to maximum edge value defined by equation (10)

$$eS = \max\left\{eV, eH, e45^\circ, e135^\circ, eND\right\} \tag{10}$$

A set of intra prediction modes is selected to be evaluated in the prediction process according to the dominant edge. Each set is composed of 9 modes taken from the 33 angular modes available in HM4.0 (Figure 5). DC and Planar modes are also included in this set, resulting in sets of 11 modes for intra prediction of each PU.

The five sets of angular modes associated with the five different dominant edge orientations are as follows:

$$eV = \{0,4,5,11,12,20,21,22,23\}$$

$$eH = \{1,7,8,15,16,28,29,30,31\}$$

$$e45^\circ = \{5,6,9,13,17,24,25,32,33\}$$

$$e135^\circ = \{3,4,7,10,14,18,19,26,27\}$$

$$eND = \{0,1,3,4,5,6,7,8,9\}$$

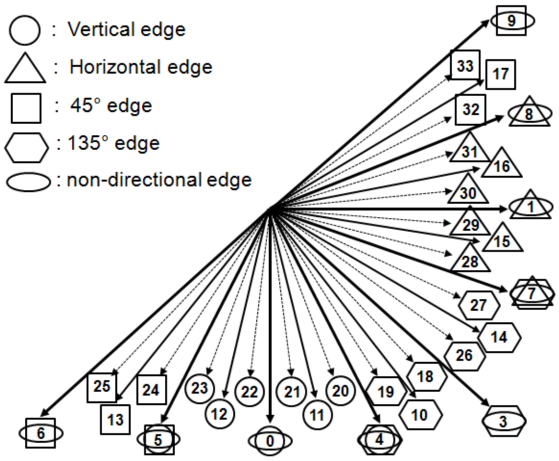

Fig. 5. Intra prediction angular modes in HM4.0.

Each set was defined selecting the nine main modes, i.e., most often selected as the best mode, for each angle. The non-directional set was constructed from the most frequently chosen modes of each one of the directional sets. In Figure 5, each modes set is represented by a geometric shape, as specified in the caption.

The algorithm proposed is applicable to the prediction for 4x4, 8x8, 16x16 and 32x32 PUs, which have a high number of intra modes to be assessed during the HM4.0 intra prediction: 17, 34, 34 and 34 modes, respectively.

In 8x8, 16x16 and 32x32 PUs, the computation is done for each 4x4 PU, as shown in Figure 6, which exemplifies the edge computation of a 16x16 PU. Thus, after the edge computation of the all 4x4 PUs that compose the larger PU, the edge which has the highest number of occurrences is defined as the dominant edge of the bigger PU (16x16 PU in the example of the Figure 6).

Since the number of intra modes available for the prediction of each PU was reduced, the number of candidate modes selected in the HM4.0 intra prediction method was also modified. The list of eight candidate modes for the 4x4 and 8x8 PUs was reduced to five candidate modes, as presented in Figure 7. Figure 7 presents a detailed flowchart of the intra mode decision algorithm presented in this work.

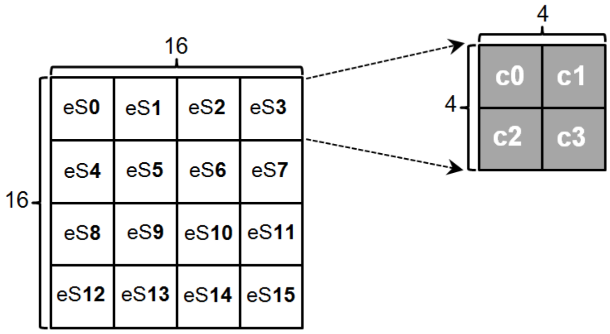

Fig. 6. Edge computation of a 16x16 PU.

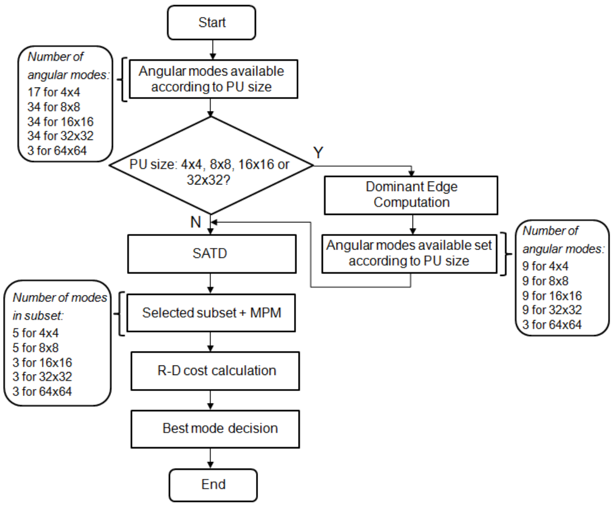

Fig. 7. Flowchart of the proposed intra mode decision algorithm.

4. EXPERIMENTAL RESULTS

The algorithm presented in this paper was implemented in the HM4.0 reference software. To evaluate the coding performance and computational complexity of the proposed algorithm in relation to the HM4.0, a group of experiments were carried out using five high-resolution video sequences from [8]. Details of the selected sequences are summarized in Table 1.

The test video sequences were encoded using four quantization parameter (QP) values: 22, 27, 32 and 37. The entropy coder used was CABAC and the intra coding was done using the *all intra - high efficiency* configuration.

The coding efficiency was evaluated using the BD-PSNR/Rate [9] [10] measures. Furthermore, the percentage difference in bit-rate (Δ Bitrate), the percentage difference in encoding time (Δ Time) and the luminance PSNR difference (Δ PSNR) were also used to compare our algorithm with HM4.0 and the results are presented in Table 2.

The presented criteria were calculated using equations (11), (12) and (13) described below.

$$\Delta PSNRY = PSNRY_{proposed} - PSNRY_{HM\,4.0} \quad (11)$$

$$\Delta Bitrate = \frac{(Bitrate_{proposed} - Bitrate_{HM\,4.0})}{Bitrate_{HM\,4.0}} \times 100 \quad (12)$$

$$\Delta Time = \frac{Time_{proposed} - Time_{HM\,4.0}}{Time_{HM\,4.0}} \times 100 \quad (13)$$

According to the simulation results shown in Table 2, we conclude that the new method proposed in this work achieves an encoding time reduction of up to 32.08% in relation to HM4.0 (about 20% on average) with slight degradation of PSNR and bit-rate.

Table 1. Test Video Sequences

Sequence	Resolution (pixels)	Frame rate (frames/s)	# frames
SteamLocomotive	2560x1600	60	300
PeopleOnStreet	2560x1600	30	150
Kimono	1920x1080	24	240
ParkScene	1920x1080	24	240
BQTerrace	1920x1080	60	600

The bit-rate presented an average increase of 0.9% considering all evaluations. However, two simulations with the ParkScene test sequence (QPs 22 and 27) showed a small decrease in bit-rate of 0.09% and 0.01%, respectively. The BD-Rate loss averaged over all test sequences was about 1.3%. The PSNR degradation ranged from 0.001dB to 0.057dB, with an average loss of 0.02dB considering all evaluations.

Figure 8 shows the plots of the R-D curves for the Kimono test sequence (HD 1080p) to illustrate the reached results. Each point in the curves represents one QP value.

Table 2. Comparison of complexity reduction and coding performance with original HM4.0.

Sequence	QP	ΔBitrate [%]	ΔTime [%]	ΔPSNR [dB]	BD-rateY	BD-PSNRY
Steam Locomotive	22	0.08	-12.71	-0.001	0.5	-0.01
	27	0.37	-16.07	-0.003		
	32	0.49	-12.44	-0.006		
	37	0.48	-20.30	-0.007		
People on Street	22	1.12	-23.09	-0.048	2.3	-0.13
	27	1.81	-17.42	-0.045		
	32	1.98	-20.91	-0.049		
	37	2.36	-24.71	-0.057		
Kimono	22	0.51	-29.92	-0.007	1.1	-0.04
	27	0.71	-31.39	-0.011		
	32	0.81	-31.73	-0.014		
	37	0.88	-32.08	-0.016		
ParkScene	22	-0.09	-8.76	-0.041	0.7	-0.03
	27	-0.01	-10.57	-0.041		
	32	0.03	-8.74	-0.030		
	37	0.22	-9.63	-0.017		
BQTerrace	22	0.66	-14.06	-0.005	1.9	-0.10
	27	1.46	-14.82	-0.015		
	32	2.26	-17.45	-0.028		
	37	2.96	-20.86	-0.040		

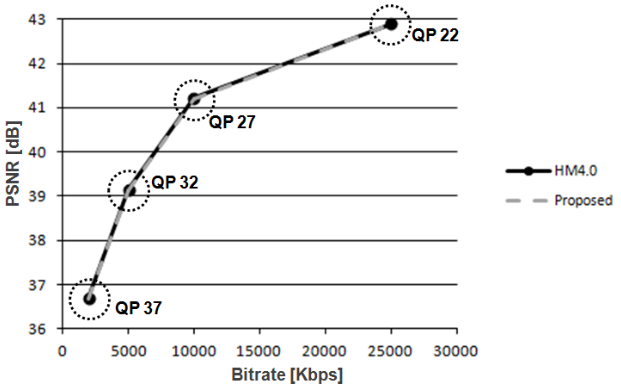

Fig. 8. RD-curves of the proposed algorithm when applied over the Kimono video sequence (1920x1080 pixels).

From this figure it is possible to conclude that the encoding efficiency of the algorithm proposed in this paper is very similar to that reached with the HM4.0, presenting a minimal loss in performance. This loss is almost imperceptible in Figure 8. The complete results corresponding to Kimono video sequence are shown in Table 2.

Figure 9 shows the encoding times as a function of QP for the two methods, and it is possible to notice that the proposed algorithm saves a significant time in relation to the HM4.0.

Finally, considering that the algorithm proposed in this paper reduced the number of angular modes to be evaluated in the intra prediction process from 33 to 9, the number of mode evaluations was reduced by 73%.

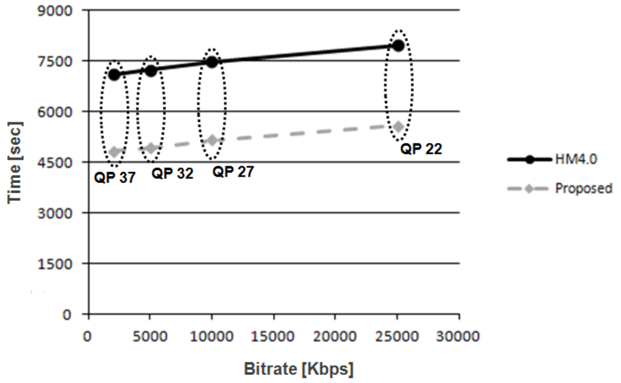

Fig. 9. Encoder time comparison of the proposed algorithm in relation to HM4.0 (Kimono 1920x1080 pixels).

5. CONCLUSIONS

This work presented a fast intra prediction mode decision algorithm for high resolution applications. This algorithm calculates the predominant orientation of the edge of the current PU pixels and based on this orientation defines a reduced set of intra modes to be evaluated. This algorithm is able to reduce the number of evaluated angular modes from 33 to 9 and then, the number of evaluated modes was decreased in 73%. The experimental results demonstrated that the method presented in this work obtained better results than the HM4.0 method. Comparing with the HM4.0 method, the intra encoding processing time was reduced by up to 32.08%, with slight degradation of PSNR (with an average decrease of 0.02dB) and bit-rate (with an average increase of 0.9%).

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