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A Fast Block Size Decision for Intra Coding in HEVC Standard

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Abstract

Intra coding in High efficiency video coding (HEVC) can significantly improve the compression efficiency using 35 intra-prediction modes for $2^N \times 2^N$ (N is an integer number ranging from six to two) luma blocks. To find the luma block with the minimum rate-distortion, it must perform 11932 different rate-distortion cost calculations. Although this approach improves coding efficiency compared to the previous standards such as H.264/AVC, but computational complexity is increased significantly. In this paper, an intra-prediction technique has been described to improve the performance of the HEVC standard by minimizing its computational complexity. The proposed algorithm called prediction unit size decision (PUSD) was introduced to decrease evaluation of block sizes. The simulation results show that the time complexity is decreased by ~36% while the bit-rate is increased by 1.1 kbps, and PSNR is decreased by 0.6 db. Accordingly, the proposed algorithms have negligible effect on the video quality with great saving in the time complexity.

Keywords: *Block Size Decision, HEVC, Intra Coding, Temporary Direction Map, Prediction Unit*

1. Introduction

The high efficiency video coding (HEVC) is the newest generation of video coding standard jointly recommended by joint collaborative team on video coding (JCT-VC). It adopts several advanced technique to achieve prominent coding performance compared to previous standards [1, 2]. However, the computational complexity of the encoder in HEVC is also increased drastically than previous one. Complexity increase is especially intensive due to great flexibility in coding unit sizes, from 64×64 to 8×8, more flexibility in directional prediction modes, more complex deblocking filters and interpolation, and features to support efficient parallel processing.

In HEVC standard, each frame of the video is split up into square or rectangular blocks, each predicted either from neighboring pixels in the same frame (intra prediction) or from other frames (inter prediction)[3]. In HEVC, the intra prediction for luminance and chrominance components are separately performed. For luma components, there are five kinds of block sizes from 64×64 to 4×4. Thirty- five prediction modes are supported for luminance component, and five prediction modes are supported for chrominance component. For luma component, encoder uses DC mode (an average value for the block), planar mode (fitting a plane surface to the block) or directional modes (extrapolating from neighboring pixels). Also, encoder selects the best chroma prediction modes among five modes including planar, DC, horizontal, vertical and a direct copy of the intra prediction mode from the luma component. As a result, luma prediction performance affects U and V prediction performance as well [3-5]. Prediction mode decision has high computational load compared with intra prediction in H.264/AVC, which is substantially computation intensive [6].

HEVC replaces macroblocks were used with the previous video standards, with Coding Tree Units (CTUs). It can use larger block structures of up to 64×64 pixels and can better sub-partition the picture into variable sized structures. CTUs are then divided into one or more coding units (CUs), so that the CTU size is also the largest coding unit size. Since a subdivision results in four smaller regions, the arrangement of CUs in a CTU is known as a quad-tree. CUs are divided into prediction units (PUs) of either intra or inter prediction which can vary in size from 64×64 to 4×4. An intra CU generally consists of one PU but 8×8 CUs can be further partitioned into smaller PUs. To code the prediction residual, a CU is divided into a quad-tree of transform units (TUs). TUs contain coefficients for spatial block transform and quantization. The supported TU sizes are $2^K \times 2^K$ where K can vary within the range from two to five. PUs and TUs cannot exceed the CU boundaries for an intra CU [3]. More information about intra coding in the HEVC model can be found in [3], [7].

In this paper, an algorithm have been developed to improve the performance of the intra coding of HEVC by minimizing its computational complexity. This algorithm is named Prediction Unit Size Decision (PUSD) is introduced to decrease evaluation of number of block sizes. The simulation results show that the proposed method can minimize the computational complexity of the HEVC with limited degradation in both the peak signal to noise ratio (PSNR) and the bit-rate.

The rest of the paper is organized as follows: section 2 reviews the previous fast intra mode prediction methods; section 3 first introduces TDM which will be used for block size decision and then presents the proposed method. Section 4 show simulation results of the proposed algorithm. Finally, section 5 concludes the paper.

2. Related Works

To achieve high coding efficiency, HEVC adopts a technique called rate-distortion optimization (RDO) to determine the best block size and the best prediction modes for each CTU [8]. This RDO process has extremely high computational complexity which accounts for most of the computation of intra prediction. Therefore fast intra prediction algorithms are needed to speed up the computation.

Ramezanpour and Zargari [9] proposed a fast algorithm to reduce the complexity of I-frame coding which is based on smoothness spatial feature. They reported that their method achieves coding time reduction whereas maintaining negligible degradation in bit-rate and video quality. In another work, Ramezanpour and Zargari [10] proposed an algorithm for fast intra PU size by using homogeneity of PUs in HEVC standard. They predicted PU size by dominant direction strength. The algorithm performance showed a 34.8% time saving with a 1.03% bitrate increase. A fast PU splitting algorithm is proposed for HEVC intra coding by Cho and Kim [11], which achieves significant reduction in encoding time with negligible degradations in R-D performance. Their method used Bayes decision rule at each PU size to find the best PU size. Experimental results show that their method reduces the coding time ~ 30% with ~0.6% increases in bit-rate. Shen et al. [12] proposed a method for reducing the number of possible PU sizes that must be tested for each tree block by adjacent PU sizes. The authors reported ~21% time reduction and ~1.74% increase in the bit-rate for similar distortion. Shen and Yu [13] modeled PU splitting as a binary classification problem and applied a support vector machine to reduce computational burden in HEVC standard. They show that this method can achieve ~ 27% time saving with ~1.7% increase in bit-rate. To speed up PU size decision process, Shen et al. [14] used information of neighboring coded PUs and texture homogeneity. Lin and Lai [15] used simple Sobel filter to measure edge strength in a PU and constrained the number of PU sizes that be evaluated. This method achieves computational complexity of 13.4% with an average efficiency drop of 0.02%. Ting and Chang [16] used a method based on simple gradient to reduce the number of evaluated PU sizes. Tian and Goto [17] evaluated texture complexity by variance of pixels to remove unimportant PU sizes. They down sampled each luma 64×64 PU to 16×16 block to make variance calculation easier. The time has been saved by %29 and BD-rate has been increased by %0.47 as the result of their simulation for class B (1920 ×1080) of JCT-VC sequences. For rich texture video sequences, this method is not practical and for smooth video sequences it also leads to the reduction of the coding performance, both because down sampling cannot detect edges [18].

3. Proposed Algorithm

One reason for taking several dissimilar block sizes in HEVC intra coding is to characterize consistent data while the permanent block size is utilized. Consequently, the multiple directional intra modes are utilized for blocks of each size to decrease inaccuracy in prediction. All potential intra prediction modes of every block are checked by HEVC standard to attain ideal coding efficiency. The RDO process of intra modes is somewhat complex. To moderate this complexity, we suggest a fast intra prediction algorithm to increase the encoding rate without much cost at the R-D performance. The proposed method known as PUSD is introduced to predict the appropriate block sizes.

Due to the reasonable accuracy of the prediction and lowness of the prediction mode overhead, larger PUs seem more efficient in homogenous regions of the frame with largely uniform texture. Since reduced residual size offsets the increased rate needed to signal the prediction mode, smaller PUs are often chosen in more complex regions of the frame. This fact is ignored by the HEVC encoder and PU sizes are tested completely to select PU which leads to the best trade-off for the target application. This approach significantly increases the intra prediction coding time in the HEVC encoder. Smoothness parameter is proposed in this paper as a measure to estimate the homogeneity of a PU. One texture or prediction mode can estimate the PU entirely and it is not necessary to test the smaller PU sizes whenever PU smoothness parameter is less than a predefined threshold. To measure the PU smoothness parameter, we consider the dominant direction for 4×4 blocks in that PU. The direction of a 4×4 block is found by Temporary Directory Map (TDM) in five directions. TDM is a 4×4 matrix that maintains similarity among adjacent pixels. The five directions are calculated using the P (i,j) values in equation (1)-(5), respectively.

$$T_1 = \left| P(i,j) - P(i+1, j-1) \right| \tag{1}$$

$$T_1 = \left|P\left(i\,,j\right) - P\left(i\,,j-1\right)\right| \tag{2}$$

$$T_1 = \left|P\left(i\,,j\right) - P\left(i-1,j-1\right)\right| \tag{3}$$

$$T_1 = \left|P\left(i\,,j\right) - P\left(i-1,j\right)\right| \tag{4}$$

$$T_5 = \left|P\left(i\,,j\right) - P\left(i-1,j+1\right)\right| \tag{5}$$

where, T_1 to T_5 indicate the similarities between the adjacent pixel to current pixel in horizontal, vertical, 45^o, 135^o, and -135^o directions. Each cell of TDM is calculated as:

$$TDM[i][j] = K \tag{6}$$

where, k is the index of T with minimum value. As a result, the direction which generates minimum residuals, is selected for that pixel. The dominant texture of each 4×4 block is the direction that has highest label. Each 64×64 PU is divided to 4×4 non-over-lapping blocks and the direction for each 4×4 block is detected. The dominant texture of each PU is the direction that has highest number of label in TDM. The ratio of the number of blocks with dominant texture to the total number of 4×4 blocks in the PU is known as the strength of dominant texture in PU. If strength of dominant texture of a PU is lower than 50%, we assume that the prediction modes in the PU should not be tested and the PU should be split to lower size PUs. Otherwise the prediction modes are evaluated for the PU. Figure 1 indicates the flowchart of the proposed fast block size decision algorithm.

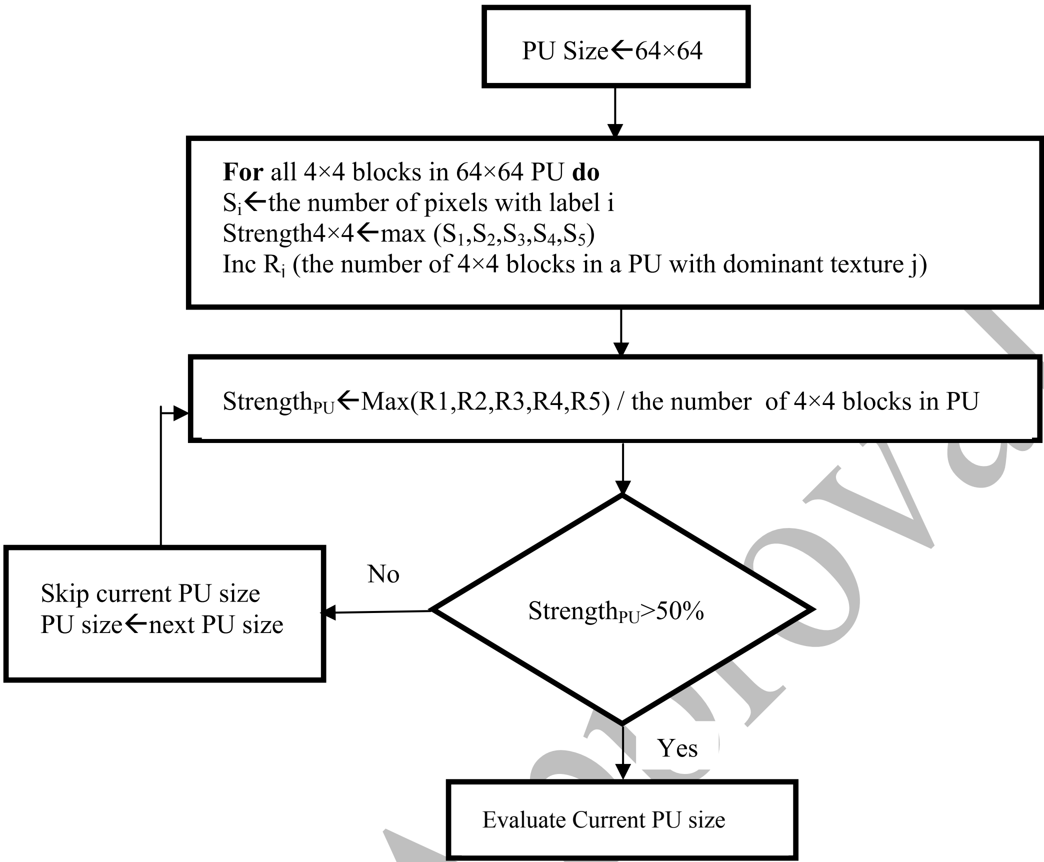

Figure 1. The proposed algorithm for fast block size decision

Table 1 Percentage of the cases that PUs with dominant texture strength of less than 50% is selected in intra coding condition

Test sequences	Resolution	Percentage
Basketballpass	416×240	1%
Blowingbubbles	416×240	2%
RaceHorses	416×240	2%
Partyscene	832×480	3%
Basketballdrill	832×480	2%
Fourpeople	1280×720	1%
Kimono1	1920×1080	3%
Parkscene	1920×1080	2%
Traffic	2560×1600	1%
Peopleonstreet	2560×1600	2%

Several standard test video sequences are encoded by HM16.0 software of the HEVC (the anchor). The percentage of PUs where our assumption may fail is indicated in Table 1. Ten video sequences in different resolutions from class A (2560×1600) to class E (416×240) with quantization parameters of 22, 27, 32 and 37 are used in this experiment (specified by [19]). 50 frames are encoded for each sequence, using intra-main configuration. Our assumption has very low negative impact on the compression performance of HEVC (as indicated in Table 1) whereas it can significantly reduce the coding time and complexity.

4. Simulation Results

In this section, we present an evaluation of the proposed method discussed in the previous section. The proposed method is implemented by the HEVC test model, HM16.0 to validate the effectiveness of the proposed method. The coding efficiency and computational complexity of the proposed method are evaluated according to the test conditions recommended by the JCT-VC [19] with 10 test sequences at five resolutions (from class A to class E). Two coding configurations are selected in our simulation: intra main and intra main10. Detailed encoding parameters for the reference software are shown in Table 2.

Table 2 Encoder parameters setting

Codec	**HM16.0**
Configuration	All Intra main
Max CU size	64×64
Max CU depth level	4
QP values	22,27,32,37
Deblock filter	On
Sample Adaptive Offset	On
Fast intra prediction	On

The efficiency of the proposed method is measured by the BD-Rate [20] and BD-PSNR [21]. The reduction in the coding time is employed as a measure for improvement in the computational complexity. The time saving (TS) is defined as:

$$TS = \left(\frac{1}{4}\sum_{i=1}^{4}\frac{Time_{proposed}(QP_i) - Time_{anchor}(QP_i)}{Time_{anchor}(QP_i)}\right)\times 100 \tag{7}$$

where $Time_{proposed}\ (QPi)$ is encoding time of the proposed method and $Time_{anchor}\ (QPi)$ is the encoding time of anchor with QP = 22, 27, 32, and 37.

Tables 3 and 4 tabulate the BD-rate and time saving of the proposed method compared with the anchor in two coding configurations. The negative numbers in tables showed that the reduction in the measured parameters with respect to anchor. According to the experimental results given in Tables 3 and 4, we conclude that the proposed method can reduce the encoding time on average about 36 % and 27.9 % in main and main10 configurations, respectively. Whereas, the compression performance reduction compared with the anchor is negligible and on average amounts to 1.1 % increase in BD-rate. In main configuration, the maximum encoding time reduction is 46.1% in *BasketballDrill*, whereas the minimum encoding time reduction is 31.4% in *Traffic* sequence.

Table 3 simulation results in all intra-main configuration

Test sequences	Resolution	BD-Rate(%)	BD-PSNR(db)	TS(%)
Basketballpass (500 f)	416×240	1.3	-0.07	-43.4
Blowingbubbles (500 f)	416×240	1.6	-0.08	-33.8
RaceHorses (300 f)	416×240	1.3	-0.07	-32.6
Partyscene (500 f)	832×480	2.1	-0.14	-31.5
Basketballdrill (500 f)	832×480	0.7	-0.03	-46.1
Fourpeople (600 f)	1280×720	0.9	-0.05	-33.7
Kimono1 (240 f)	1920×1080	0.5	-0.02	-37.8
Parkscene (240 f)	1920×1080	0.6	-0.03	-34.3
Peopleonstreet (150 f)	2560×1600	1.2	-0.06	-35.6
Traffic (150 f)	2560×1600	0.8	-0.03	-31.4
Average		1.10	-0.06	-36.0

Table 4 Simulation results in all intra-main10 configuration

Test sequences	Resolution	BD-Rate(%)	BD-PSNR(db)	TS(%)
Basketballpass (500 f)	416×240	1.1	-0.05	-34.3
Blowingbubbles (500 f)	416×240	1.5	-0.07	-29.6
RaceHorses (300 f)	416×240	1.3	-0.05	-26.8
Partyscene (500 f)	832×480	2.0	-0.09	-25.9
Basketballdrill (500 f)	832×480	0.5	-0.04	-31.7
Fourpeople (600 f)	1280×720	0.7	-0.04	-27.1
Kimono1 (240 f)	1920×1080	0.4	-0.02	-28.3
Parkscene (240 f)	1920×1080	0.4	-0.03	-24.9
Peopleonstreet (150 f)	2560×1600	1.1	-0.05	-23.4
Traffic (150 f)	2560×1600	0.7	-0.02	-27.6
Average		0.97	-0.05	-27.9

R-D curve of the proposed method and the anchor for "peopleonstreet" test sequence are shown in Fig. 2. We magnify a part of curve to provide more precise observation of it. The proposed method significantly reduces the encoding time whereas it imposes negligible degradation in R-D curve because it cancel out the PU sizes that have negligible chance to be selected as the best PU and reduce computational complexity both in the RMD and the RDO stages.

The performances of seven different fast intra prediction algorithms which are recently suggested for HEVC are compared with the proposed method (Table 5). Comparison results are given in terms of relative BD-Rate and coding time increase compared with the anchor. The comparison of coding time and efficiency given in Table 5 indicate that the proposed method achieves the maximum reduction in average coding time for the given average increase in the bit-rate. The achieved reduction in the coding time by the proposed method is higher than the other methods except Ruiz et al. [25] and Song et al. [26]. Even though these methods achieve higher reduction in the coding time compared with the proposed method, its BD-rate increases about two times higher than the proposed method in comparison with anchor. By considering the experimental results and comparison with the other methods, it can be deduced that the proposed method achieves high reduction in the coding time of the HEVC encoder with minimum increase in the rate of coded video.

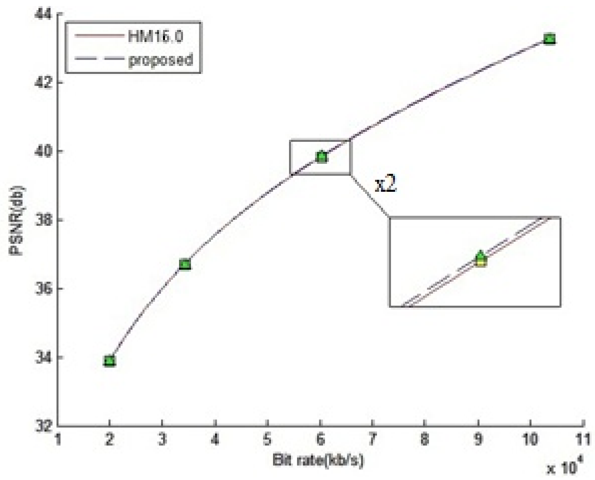

Figure 2. Rate–Distortion performance comparison for intra-main configuration in "peopleonstreet" test sequence

Table 5 Simulation results for different methods

Methods	BD-Rate [%]	Time Saving [%]
Shen et al.[14]	1.74	-21.1
Ting et al.[16]	0.74	-19.9
Yan et al.[22]	1.30	-23.5
Wang et al.[23]	-0.18	-5.7
Yao et al.[24]	1.86	-36
Ruiz et al.[25]	1.97	-52.4
Song et al.[26]	1.73	-42.2
Proposed method	1.1	-36

5. Conclusions

In this paper, the reduction in the computational complexity of the HEVC intra coding is considered as a fast method for intra prediction. To rescind the PU sizes that have negligible chance to be selected for coding of the block, the strength of dominant texture of 4×4 blocks is used. The proposed method are implemented in the HEVC test model (HM16.0). Simulation results indicate that the proposed method reduces encoding time, while maintaining negligible degradation in objective and subjective video quality. The performance of the proposed method is compared with other methods in the literature, which made improvements in HEVC intra prediction to achieve reduction in coding time. In comparison with other methods, it indicates that the proposed method obtains higher reduction in coding time whereas imposes 1.1% increase in the rate of the coded video.

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