

Efficient Mode Decision with Enhanced Sampling Algorithm for HEVC

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Abstract—Compared with H.264/AVC, H.265/HEVC achieves better image quality at the same coding bit rate, but requires more complexity in its coding process. In this paper, we propose a fast inter/intra decision method that can reduce the required encoding time with very little increase in required rate and PSNR degradation. We also introduce the weighted sampling and adaptive threshold condition to determine the CU splitting. In addition, a fast CU size selection algorithm based on image complexity for inter-frame coding is proposed. Experiments show that the proposed method provides a significant improvement in computing requirements, and can achieve a reasonable compromise between coding quality and efficiency.

Keywords—Adaptive Threshold; High Efficient Video Coding; Inter/Intra Prediction; Weighted Sampling;

I. INTRODUCTION

With the popularity of mobile devices and smart multimedia technology, people can freely enjoy high-quality video programs through various channels. Video compression systems to provide better image quality and coding efficiency in the competitive market play a key role in the success of such services. There is a need to deliver higher resolution and better picture quality than video coding standards such as H.264/AVC [1] or H.265/HEVC [2]. H.265/HEVC, achieves better image compression and good quality at the same coding bit-rate compared to H.264/AVC, but requires more time and greater complexity in the encoding process. However, in the standardization process, intra-frame is an important coding tool in the video, not only being used as the reference frame for the inter-frame coding in the video coding, but also independently used for the still images in intra-mode prediction during video coding. In general, inter-predicted coding will require much less bits than intra-predicted coding without time correlation between the frames, but needs more time for the motion decision.

In the literature, it has been known that a recursive quad-tree-based structure for the Coding Unit (CU) can improve the processing efficiency, also making the mode prediction and encoding more adaptive and diverse, but at the expense of increasing the computation complexity significantly [3] [4]. So the mode decision process is the most important part of the complexity of the HEVC coding calculation. Therefore, an efficient prediction algorithm needs to be developed.

HEVC uses a similar block-based video coding framework, providing a highly flexible unit representation hierarchy that includes the three major units: Coding Unit (CU), Prediction Unit (PU) and Transform Unit (TU) [3]. The size of the PU and TU should not exceed the size of the CU (see Fig. 1). The CU is the basic unit for inter/intra coding. It allows recursively segmenting into smaller equal-sized CUs in the next depth layer, and the splitting of the CU is also content dependent. The PU is the basic unit used in the prediction process, and the TU is the basic unit for transformation and quantization. However, since the motion prediction of the block size is related to not the only current CU being encoded but also to the reference frame, the prediction mode will be much more complex than for the intra mode.

The rest of the paper is organized as follows. Section 2 discusses the related work in fast inter/intra prediction. Section 3 gives the details of the proposed weight sampling and adaptive threshold. We then have the experimental results and discussions about other references in Section 5. Section 6 concludes the paper.

II. RELATED WORK

For H.265/HEVC, many proposed research works aiming to improve the performance of intra encoding can be found in the literature. Most of the related work in the literature focuses on fast intra prediction and fast CU size decision. In [5], the CU size can be quickly determined based on the statistics of variance in image. [6] proposed the Most Probable Mode (MPM) method for the Rough Mode Decision (RMD) applied to all candidate modes. [7] and [8] proposed utilizing RMD to reduce the Rate-Distortion Optimization (RDO) calculation.

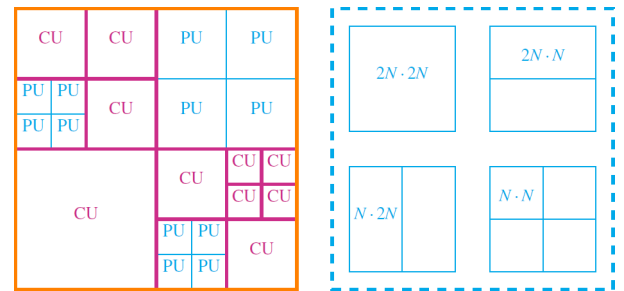


Fig. 1. Partitioning structure of CU and splitting of PU, here N is half of the CU size.

For a CU quad-tree structure, the CU splitting and pruning process are performed to get the optimal Coding Tree Unit (CTU) partition [9] [10]. In [11], it proposed to skip the large CU based on its sub-CUs structures and [12] skips the further splitting of CU based on the RD cost between the parent CU and its partial sub-CUs. Also, an early termination method based on the statistics of RD costs in CU splitting process with threshold wetting related to QP was introduced in [13]. In [14], we proposed to use an adaptive threshold for intra-mode encoding. The result of the performance in terms of required time is shown to offer a more significant gain in the higher resolution video sequence coded with all intra mode. Our proposed method was examined using different versions of HM reference software.

In the literature, fast mode decisions for inter prediction were proposed in the frame layer. The major idea of that approach is to reduce the current depth layer and the search range based on the depth information of the CTU structure. [15] proposed a simplifying RDO search process to reduce the encoding complexity. [16] skips some CU depths that are rarely used in the previous frames. Besides, [17] reduces the encoding time by pruning the quad-trees with prediction residuals statistics. A fast motion divergence based CU selection algorithm was presented for inter prediction in [18], allowing a large portion of modes to be removed from the computation. In [19], it proposes a fast inter mode decision method for HEVC to check whether the best prediction mode of $2N \cdot 2N$ size of CU is skip mode or not by utilizing the correlated tendency of PU mode. However, these papers presented fast algorithms with early termination of CU splitting and mode decision. The algorithms can reduce the computational complexity without too much compromise of video quality.

III. EFFICIENT MODE DECISION

The intra mode prediction defined in the H.265/HEVC standard allows 35 (including Planar, DC mode and 33 angular) predictions. Planar and DC prediction can provide the image areas with flat area and gradually changing sample values for predictions. For inter mode, RD cost is the determining factor for the choice of CU size. Therefore, there is no need to perform mode decisions for large size CUs with high complexity, and small size CUs with low complexity will also not be considered for mode decisions. When the Largest Coding Unit (LCU) is selected as the optimum size for mode decisions, the distortion for the current area is close to the distortion for small CUs that require a small number of coded bits. Conversely, the coding bits of an image area that selects the Smallest Coding Unit (SCU) can be increased, but the distortion must be more effectively reduced. In contrast, the use of a small CU for these areas is less than the RD cost of using a large CU. Hence, a fast CU decision method can improve the performance in inter/intra encoding.

A. Image Complexity

For complex textures, there is a lower frequency component that does not apply any direction predictor variables. It is easy to know that the bigger CU is suitable for some flat or smooth

regions in the frame. Conversely, an area with colorful edges or object boundaries is usually split into smaller sub-CUs. For discriminating complexity, since the homogeneous region is featured by sampling results close to the average, the Sum of Absolute Difference (SAD) can represent the image complexity. In extreme cases, ($SAD = 0$) means fully homogeneity: *i.e.* there is exactly one value in the whole image. Applying fast prediction algorithm, we calculate the image complexity before the 33 angular intra predictions as:

$$mean = \frac{1}{N \times N} \sum_{i=1, j=1}^{N, N} C(i, j) \quad (1)$$

and

$$SAD = \sum_{i=1, j=1}^{N, N} |mean - C(i, j)| \quad (2)$$

where $N \in \{64, 32, 16\}$ is the size of the current CU, $C(i, j)$ is the (sub)-sampling method that is exploited by a weighted sampling operator. The image complexity is represented by the SAD, which will be used to determine whether the CU should be necessary to perform angular prediction. After the calculation, if the SAD is smaller than or equal to the corresponding threshold, the image will be considered as smooth enough to skip the following processes.

B. Weighted Sampling Operator

For CU at a given depth, all encoding modes will be tested and the mode with the best RD cost is selected. Early termination methods can stop the splitting process if the SAD is lower than a given threshold, meaning that the best setting has already been obtained. Searching for smaller CUs will not be performed as it can only slightly improve the overall performance. In order to enhance the sampling to the reference results, threshold calculation must consider the weighted sampling/subsampling of *Luma* and *Chroma* components. According to the efficiency of different configurations quantization settings, we propose the weighted geometric mean of sampling values for *Luma* and *Chroma* components, defined by

$$C = {}^{w_y + w_{uv}}\sqrt{(Luma)^{w_y} \cdot (Chroma)^{w_{uv}}} \quad (3)$$

where the weights value (w_y, w_{uv}) must satisfy the conditions $w_y > 0$, $w_{uv} > 0$ and $w_y + w_{uv} > 1$, depending on the color sampling modes,

$$(w_y, w_{uv}) = \begin{cases} (8, 0), & type = 4: 0: 0 \\ (8, 2), & type = 4: 1: 1 \\ (8, 2), & type = 4: 2: 0 \\ (8, 4), & type = 4: 2: 2 \\ (8, 4), & type = 4: 4: 0 \\ (8, 8), & type = 4: 4: 4 \end{cases} \quad (4)$$

where *type* means the type of *Luma* sampling and *Chroma* subsampling. To approximate the accurate quality using the

average bit-rate of generated bitstreams and the PSNR, the weighted sampling better identifies the homogeneous area.

C. Adaptive Threshold

Since our algorithm avoids checking the RD costs when early termination occurs, the values for the threshold (T) play a major role in the trade-off between encoding quality and efficiency. With different QP and CU sizes, it is impossible to find a static threshold to approximate various configurations. In order to find suitable threshold, we first analyze the SAD of different sizes of CU in the HM reference software. When the CU texture is complex, then the CU is split into smaller subunits to find the best size. If the CU texture is flat enough it will not be divided further into subunits. In particular, coding with higher QP will lose the detail in video reconstruction, which may lead to lots of homogeneous areas that can be split into bigger CU than coding with lower QP case. For this reason, we consider the SAD as a threshold (T) to determine the CU splitting and find the relation representing the threshold as $T(QP, CU_{size})$. According to statistics from various videos, the threshold is adaptive to video content, CU size and QP , given by,

$$T(QP, CU_{size}) = \left[E(C) - \frac{QP}{2} \right] \cdot CU_{size}^2 \quad (5)$$

where $E(C)$ is the expected value of sampling, and the partial differential equation of (5) about QP and CU_{size} is shown as follows:

$$\frac{\partial T}{\partial QP} = -\frac{CU_{size}^2}{2} \quad (6)$$

and

$$\frac{\partial T}{\partial CU_{size}} = 2 \cdot \left[E(C) - \frac{QP}{2} \right] \cdot CU_{size} \quad (7)$$

Therefore, the relationship between the SAD and CU size is not very sensitive to QP . As the depth increases, the CU will be evenly split into four sub-CUs, while the threshold is scaled down into approximately one quarter. Using a large threshold will achieve a highly accurate decision but the complexity reduction for intra mode decisions will be very small, and using small thresholds will reduce the complexity but lose accuracy. The threshold should be determined to provide a good compromise between encoding quality and performance. In order to enhance the threshold (T) to make it more suitable for tracking changes, a weighting function is adopted which is similar to (4), and corresponds to the (sub)-sampling method. This allows smooth updating of the expected values to better take into account the most recent *Luma* and *Chroma* components, defined by

$$E(C) = {}^{w_y+w_{uv}}\sqrt{E(Luma)^{w_y} \cdot E(Chroma)^{w_{uv}}} \quad (8)$$

D. Inter-Mode Depth Selection

In general, when the best PU mode for the CU is Merge or Inter $2N \cdot 2N$, then the current CU covers a smaller amount of motion and a simpler texture (with very low complexity). There is also a low probability of selecting the Asymmetric Motion Partitioning (AMP) mode. Analysis shows that the current CU has a strong relationship between the best PU mode and its CU complexity. In particular, the best PU mode of the parent CU is Skip mode or $2N \cdot 2N$ size, and the Rate-Distortion cost can be used as the lowest in current prediction, so inter mode can skip the current depth of PU prediction.

IV. IMPLEMENTATION

The algorithm presented in this paper was implemented in the HM 16.15 reference software. Since the number of candidate modes selected in the HM intra prediction method is modified, the overall proposed fast inter/intra mode prediction process for each CU is now described as integration of the weighted sampling and adaptive threshold.

As shown in Fig. 2 for intra mode, we first start from the Planar and DC mode since these modes occur with high probability. Then we calculate the SAD of CU that is used to compare with the threshold (T) by considering the current QP and CU_{size} . If the SAD is smaller than the threshold, it means that the texture is flat enough for finding the smallest RD cost between intra Planar, DC and 33 angular modes in the current depth layer, and no further CU splitting is needed. Otherwise, it means that the texture is too complex to be intra predicted in the current *Depth*, so we can skip the remaining angular predictions and there is no need to check the intra mode in the current depth layer anymore. We then consider the next *Depth* to find the smallest RD cost between intra Planar, DC and sum of sub-CUs RD cost.

As shown in Fig. 3 for inter mode, it is unnecessary to perform motion predictions for CUs with low complexity and

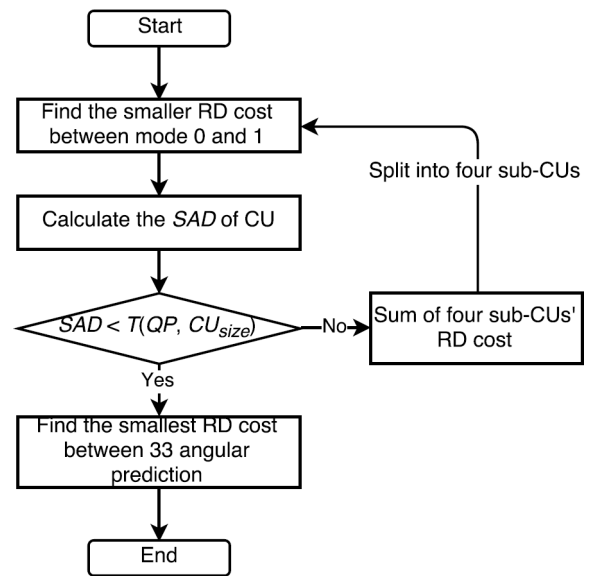


Fig. 2. The flowchart of fast intra mode prediction algorithm.

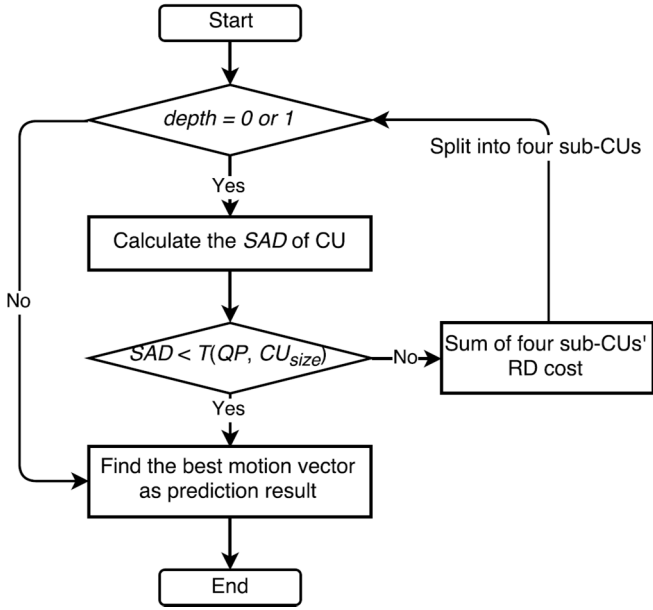


Fig. 3. The flowchart of fast inter mode prediction algorithm.

higher depth level because the improvement is very low and time consuming. Hence, we first calculate the SAD of the CU that is also used to compare with the threshold (T) by using (5), while operating in depth layer 0 and 1. If the SAD is bigger than the adaptive threshold (meaning high complexity), the motion prediction of depth layer 0 and 1 can be skipped directly. Otherwise, we can only find the best motion vector as the prediction result in the current depth layer.

V. EXPERIMENT RESULTS AND DISCUSSION

To verify our method, these experiments look into the RD cost degradation for CUs resulting from the full searching of the H.265/HEVC Test Model and our modified HM software. The H.265/HEVC reference software HM 16.15 was modified to handle our proposed method. For most of the comparisons with other research, the difference between Bjontegaard Bit-Rate and PSNR between the reference and proposed method is shown in Tab. I. It shows the SAD of reference HM software in different configurations. The QP values are taken into consideration as the QP will scale the range of sample values. Note that these results are matched to (6) and (7), so the difference between each sample and the *mean* of sampling CU becomes smaller as QP increases.

TABLE I. MEAN OF SAD OF DIFFERENCE CU SIZE AND QP IN HM REFERENCE SOFTWARE.

QP	64×64 , $depth = 0$	32×32 , $depth = 1$	16×16 , $depth = 2$	8×8 , $depth = 3$
20	481236.87	120007.25	30044.54	7479.20
24	472784.87	118100.85	29540.11	7030.81
28	464040.13	115765.73	29057.78	5899.01
32	455679.14	113168.00	28498.35	6827.27
36	448174.94	111326.90	28006.23	6987.15
40	437079.86	108763.22	27449.52	5667.41

TABLE II. H.265/HEVC, PROPOSED VS. REFERENCE HM 16.15, 4CIF@30HZ, ALL INTRA PICTURES WITH BD-RATE, BD-PSNR AND TIME REDUCTION.

4CIF_INTRA	BD-RATE (%)	BD-PSNR-Y (dB)	Time Reduction (%)
<i>aspen</i>	+0.124	-0.006	-27.91
<i>blue_sky</i>	+0.298	-0.019	-47.32
<i>in_to_tree</i>	+0.081	-0.003	-38.70
<i>life</i>	+0.443	-0.022	-44.59
<i>park_joy</i>	+0.085	-0.006	-41.26
<i>riverbed</i>	+0.122	-0.005	-27.56
<i>rush_hour</i>	+0.143	-0.005	-43.67
<i>sunflower</i>	+0.201	-0.011	-28.11

TABLE III. H.265/HEVC, PROPOSED VS. REFERENCE HM 16.15, 4CIF@30HZ, INTER-IPPP PICTURES WITH BD-RATE, BD-PSNR AND TIME REDUCTION.

4CIF_IPPPP	BD-RATE (%)	BD-PSNR-Y (dB)	Time Reduction (%)
<i>aspen</i>	+0.104	-0.011	-18.68
<i>blue_sky</i>	+0.098	-0.008	-19.33
<i>in_to_tree</i>	+0.092	-0.015	-32.81
<i>life</i>	+0.111	-0.010	-32.94
<i>park_joy</i>	+0.090	-0.009	-31.08
<i>riverbed</i>	+0.113	-0.012	-20.04
<i>rush_hour</i>	+0.110	-0.014	-21.05
<i>sunflower</i>	+0.104	-0.018	-19.46

TABLE IV. H.265/HEVC, PROPOSED VS. REFERENCE HM 16.15, 4CIF@30HZ, INTER-IBBBP PICTURES WITH BD-RATE, BD-PSNR AND TIME REDUCTION.

4CIF_IBBBP	BD-RATE (%)	BD-PSNR-Y (dB)	Time Reduction (%)
<i>aspen</i>	+0.238	-0.023	-10.42
<i>blue_sky</i>	+0.220	-0.019	-10.15
<i>in_to_tree</i>	+0.266	-0.013	-10.01
<i>life</i>	+0.163	-0.014	-10.77
<i>park_joy</i>	+0.372	-0.036	-12.38
<i>riverbed</i>	+0.330	-0.037	-11.55
<i>rush_hour</i>	+0.277	-0.026	-12.12
<i>sunflower</i>	+0.282	-0.020	-11.20

A. Performance Verification

The procedure setting in [20] calculates the BD-PSNR and BD-RATE with different QP controls. For all tests the main-profile with 100 frames of video in progressive format are enabled in HM 16.15 with an intra update in every second.

Tab. II to IV shows the BD-RATE and BD-PSNR results of our proposed method. The proposed fast inter/intra-prediction has been added into the H.265/HEVC coding process; the proposed algorithm with weighted sampling and adaptive threshold calculation can generate similar video quality in term of PSNR degradation for 0.03dB for all intra pictures compared to the original H.265/HEVC process with a very small increase of BD-rate for at most 0.5%. Experiment results show that our

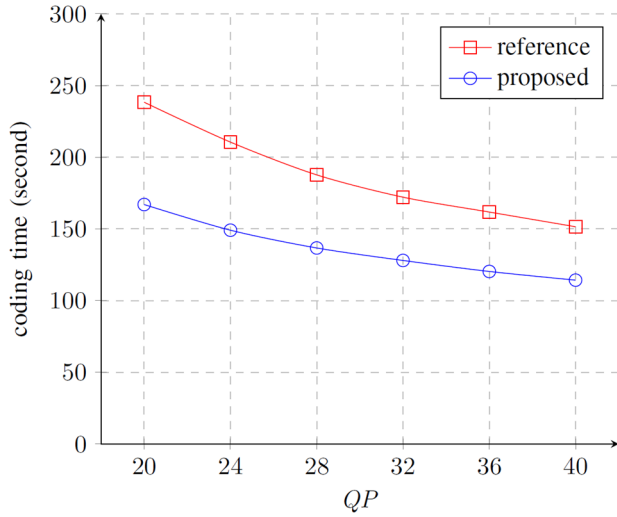


Fig. 4. H.265/HEVC, coding time curves proposed vs. reference HM 16.15, *aspen* 4CIF@30Hz, all Intra pictures.

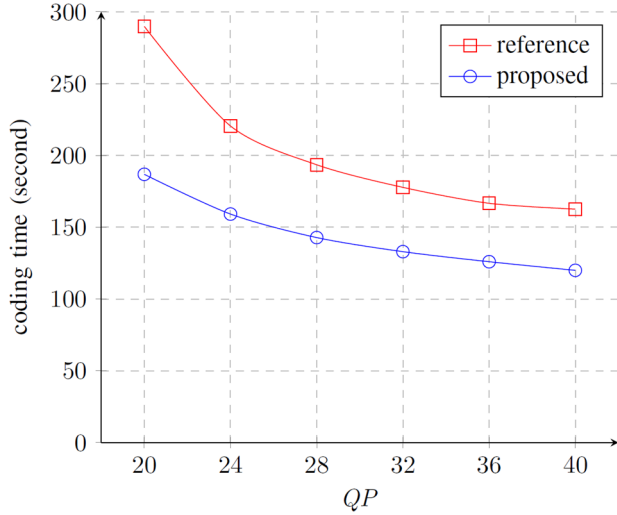


Fig. 5. H.265/HEVC, coding time curves proposed vs. reference HM 16.15, *riverbed* 4CIF@30Hz, all Intra pictures.

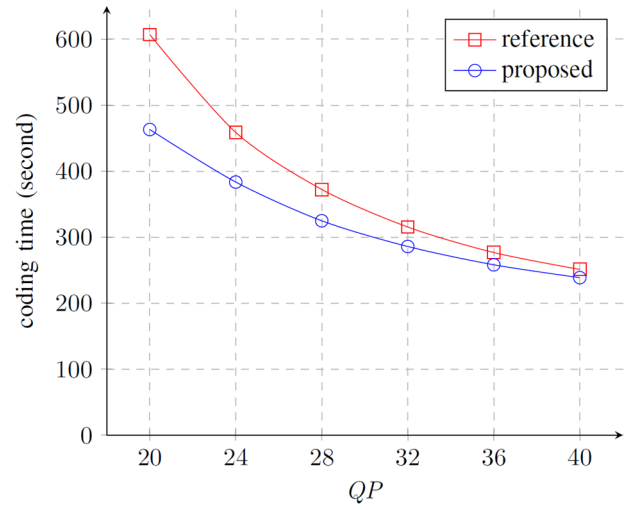


Fig. 6. H.265/HEVC, coding time curves proposed vs. reference HM 16.15, *blue_sky* 4CIF@30Hz, Inter-IPPP pictures.

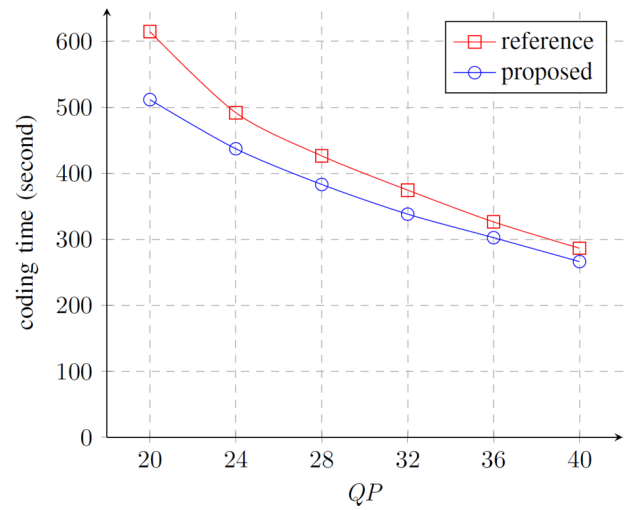


Fig. 7. H.265/HEVC, coding time curves proposed vs. reference HM 16.15, *rush_hour* 4CIF@30Hz, Inter-IPPP pictures.

proposed method can generate a significant reduction of coding time on average between 25.0% and 45.0%.

Our proposed algorithm does not affect video quality in term of PSNR for inter pictures. For inter-IPPP pictures, the average reduction in coding time is from 15.0% to 30.0% with BD-PSNR degradation of less than 0.02dB. For inter-IBBBP pictures, the average reduction in coding time is 10.0% with BD-PSNR degradation of less than 0.03dB. As coding of inter P and B-frames requires more time for complex processes of inter predictions than coding of I-frames, so the reduction of time gained by skipping of motion decisions is less obvious compared to intra mode. Inter-frame with depth layers 2 and 3 will not be considered for skipping of motion predictions because reduction of coding time for those P and B-frames is minimal.

As shown in Figs 4 to 9, the percentage of time reduction will decrease when the QP value increases. Our proposed method is more effective for pictures will small QP because our

method skips lots of angular predictions. This is because pictures with complex texture coded using small QP values require a significant amount of time to perform angular predictions.

VI. CONCLUSION

This paper proposed a fast inter/intra prediction algorithm to significantly reduce encoding time of video. Our algorithms introduce the weighted sampling and adaptive threshold condition to determine CU-splitting. It offers no divergence from the H.265/HEVC standards and can be used in current systems with including a controlled precision and adjustable complexity overload. At the same bit rate and PSNR, our proposed fast prediction algorithm outperforms other similar algorithms in the literature due to our adaptive threshold calculation, whereas other threshold methods are based on simple empirical results.

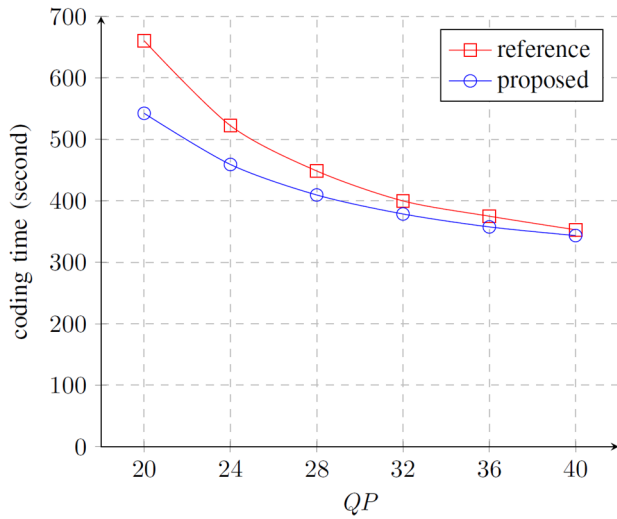


Fig. 8. H.265/HEVC, coding time curves proposed vs. reference HM 16.15, *life* 4CIF@30Hz, Inter-IBBBP pictures.

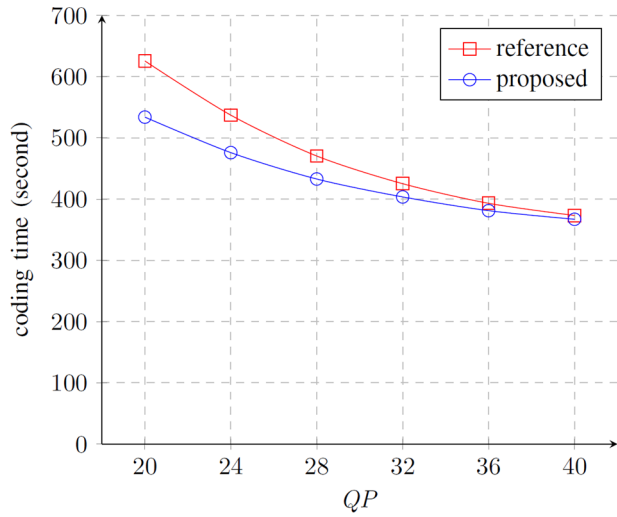


Fig. 9. H.265/HEVC, coding time curves proposed vs. reference HM 16.15, *sunflower* 4CIF@30Hz, Inter-IBBBP pictures.

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