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Fast Intra Mode Decision in High Efficiency Video Coding

H. Brahmasury Jain and K.R. Rao

***Abstract*—In this paper a coding unit early termination algorithm resulting in a fast intra prediction is proposed that terminates complete full search prediction for the coding unit. This is followed by a prediction unit mode decision to find the optimal modes HEVC encoder 35 prediction modes. This includes a two-step process: firstly calculating the Sum of Absolute Differences (SAD) of all the modes by down sampling method and secondly applying a three-step search algorithm to remove unnecessary modes. This is followed by early RDOQ (Rate Distortion Optimization Quantization) termination algorithm to further reduce the encoding time. Experimental results based on several video test sequences for 30 frames from each test sequence show for HEVC a decrease of about 35%–48% in encoding, with negligible degradation in peak signal to noise ratio (PSNR). Metrics such as BD-bitrate (Bjøntegaard Delta bitrate), BD-PSNR (Bjøntegaard Delta Peak Signal to Noise Ratio) and RD plots (Rate Distortion) are also used.**

***Index Terms*—HEVC, Fast intra coding, Early CU Termination, Early RDOQ Termination, PU Splitting.**

I. Introduction

HEVC is the latest video standard introduced by the Joint Collaborative Team on Video Coding (JCT-VC) in January, 2013 which contains three profiles namely; main (8-bit), main10 (10-bit) and still frame [1]. Here only the main (8-bit) profile is considered since it is most widely used profile. The HEVC standard is designed to achieve multiple goals, including coding efficiency, ease of transport system integration, data loss resilience, and implementation using parallel processing architectures. The HEVC standard has been designed to address essentially all the existing applications of the H.264/MPEG-4 AVC standard [1] and to focus particularly on two key issues: increased video resolution and increased use of parallel processing architectures [1]. The major achievements of the HEVC standard in comparison with the H.264 [1] standard are flexible prediction modes, larger transform block sizes, better partitioning options, improved interpolation and deblocking filters, prediction, signaling of modes and motion vectors and support efficient parallel processing [1]. The HEVC syntax should be generally suited for other applications and not specifically to two applications mentioned above [1]. This is not the result of optimizing a single step in the encoding process, but a combined result of optimization of many processes together.

HEVC supports 2k and 4k video coding and hence with increase in video resolution encoder complexity of HEVC has increased. In order to reduce the encoder complexity there are many fast intra prediction algorithms [20-28] proposed for HEVC. In this paper, a fast intra coding algorithm is proposed to reduce the encoder complexity. The block diagram of HEVC encoder is shown in Figure 1.

II. Proposed Algorithm

A three step method is proposed as a solution. In CU splitting, decision is made whether to split the current CU further by analyzing the CU texture characteristics. In PU partition, down sampling prediction followed by three—step search is exploited similar to one proposed in [24]. In the last step the early RDOQ termination is implemented [25, 28].

III. CU Early Termination

When the CU texture is complex, the CU is split into smaller sub units to find the best size and when the CU texture is flat, the CU is not divided further into subunits. This has already been proved [12].

In the first stage, to decrease the computational complexity, the down-sampling method is exploited by applying a 2:1 down sampling filter by a simple average operator to the current CU and other CU have the similar operation as shown in Figure 2.

After the downsampling, the complexity of the original LCU can be calculated by the following formula:

$$Ecom = \sum_{i=0}^{N-1}\sum_{j=0}^{N-1}\left[p(i,j) - \frac{1}{N}\frac{1}{N}\left(\sum_{i=0}^{N-1}\sum_{j=0}^{N-1} p(i,j)\right)\right]$$

where $Ecom$ is the texture complexity, N is the size of the current CU, $p(i,j)$ is the pixel, and (i, j) is the coordinates in CU.

Depending on the texture calculation, two thresholds are set with a tradeoff on coding quality and complexity reduction as Thres1 and Thres2. The CU is split when the complexity is greater than Thres1 and when complexity is less than Thres2, the CU is not split further. If the complexity is between the Thres1 and Thres2, HEVC reference software is referred [4].

IV. PU Mode Decision

At the second stage, PU modes decision is obtained by calculating the Sum of Absolute Differences (SAD), which is

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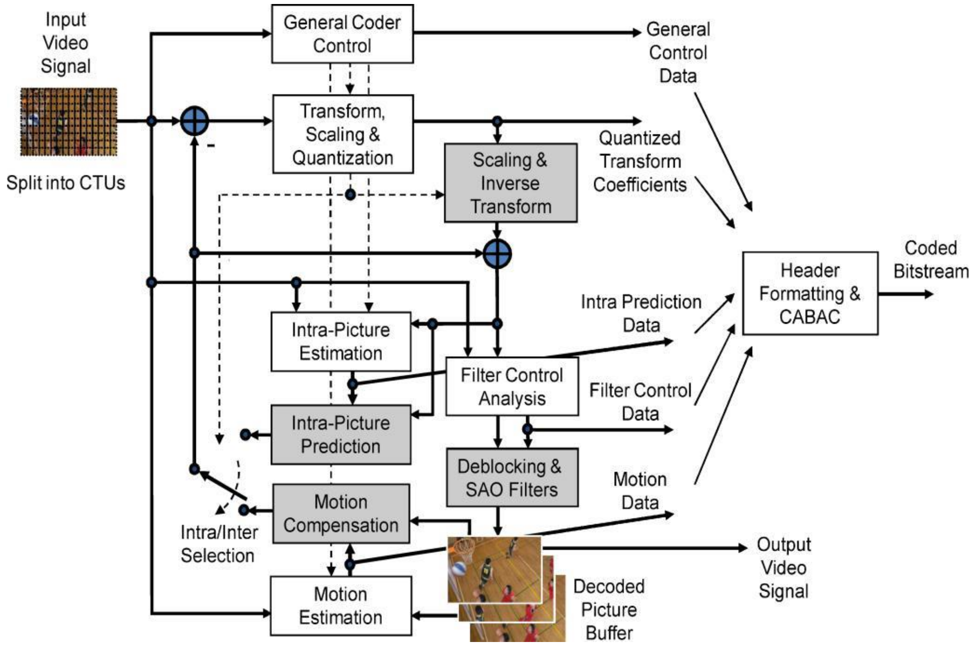

Fig. 1. HEVC encoder block diagram [1]

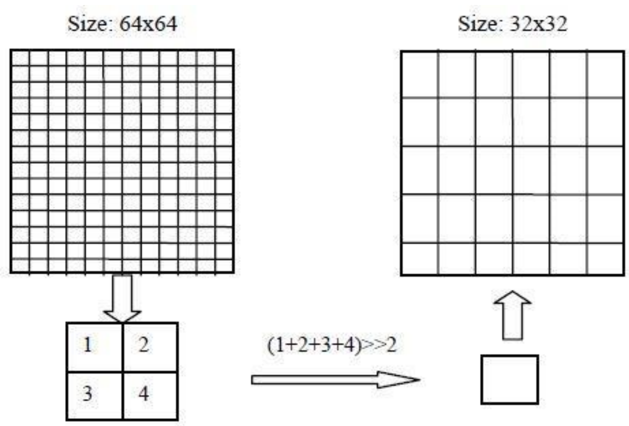

Fig. 2. Simple averaging based on down-sampling on 64 × 64 CU [27]

performed by downsampling and then by applying similar three step search algorithm. The detailed operation is as follows.

- List of candidates is created, S1 = {0, 1, 2, 6, 8, 12, 16, 20, 24, 28, 30, 32, 34} from the 35 prediction modes and then 5 optimal modes by SAD is check on S1, suppose 5 modes are S2 = {0, 3, 12, 16, 34}.
- From the three-step algorithm [27], list S2 is extended on to the 2-distance neighbors and S3 = {2, 10, 20, 32} for both the modes 0 and 2 and then S1, S2, S3 are checked for optimal modes S4 = {8, 14, 24}. Suppose modes of upper and left PUs are S5 = {1, 6}, then checking optimal modes and if the optimal two modes are S6 = {2, 6}.
- Then 1-distance neighbors of S6 are S7 = {3, 5, 9} then we choose the best M modes as the candidates for RDOQ. Tables 1 and 2 show the HEVC encoder complexity for CU and PB blocks. Figure 3 shows the luma intra prediction modes for HEVC.

TABLE 1.
LUMA INTRAPREDICTION MODES SUPPORTED BY DIFFERENT PU SIZES [14]

PU Size	Intraprediction Modes
4 × 4	0–16,34
8 × 8	0–34
16 × 16	0–34
32 × 32	0–34
64 × 64	0–2, 34

TABLE 2.
CURRENT PROBLEM-COMPLEXITY FOR HEVC [33]

Size of PB	Number of PBs in a 64x64 CU	Number of modes to be tested in each PB	Total number of modes to be tested at this level
32 × 32	4	35	140
16 × 16	16	35	560
8 × 8	64	35	2240
4 × 4	256	35	8960
		Total	11900

V. EARLY RDOQ TERMINATION

At the third stage, there are M modes selected from the result of the second step which are put into a group, Ψ, that go through the RDOQ process to get the best mode, mopt. An early RDOQ termination is proposed for further encoder time reduction. For each intra mode $m \in \Psi$, its overall cost $J(m)$ as the combination of SATD cost and associated mode index bits consumption is calculated. Within Ψ there is a mode with minimal $J_{\min}$ defined as rough best mode mopt_rough. If mopt_rough is Planar or DC

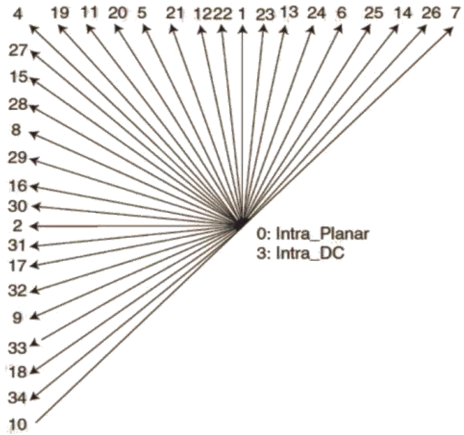

Fig. 3. Luma intra prediction modes of HEVC [14]

mode, all other modes in Ψ are skipped. If mopt_rough is not 0 or 1 and |m−mopt_rough| > 3, such mode *m* is skipped also; meanwhile, if $J(m) > \alpha J_{\min}$, mode m will not be checked and $\alpha = 1.08$ is considered. After such early termination procedure, all the remaining modes are checked by RDOQ. The next section outlines the experimental results of the implemented algorithm vs. the original HM 13.0 [4].

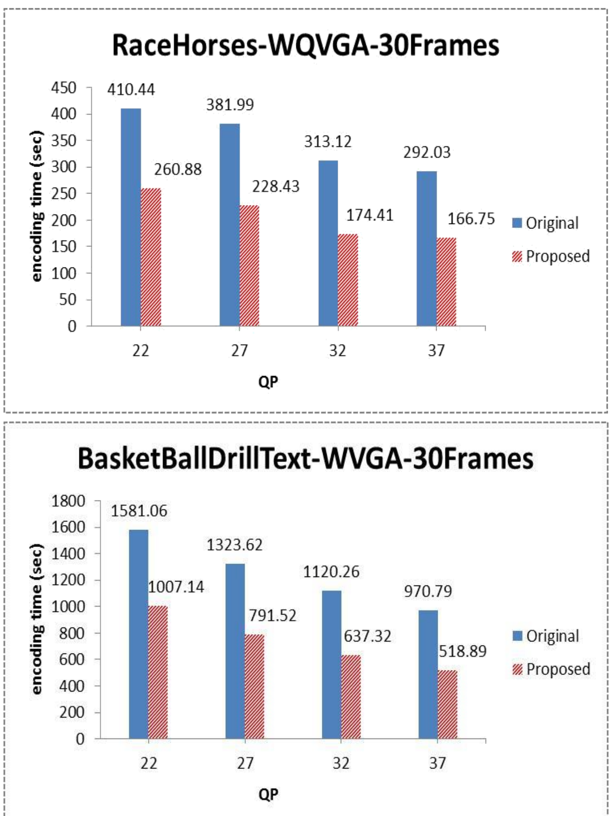

Fig. 4. Encoding time vs. quantization parameter for Racehorses and BasketBallDrillText

VI. Results

In order to evaluate the performance of the proposed intra prediction algorithm, the algorithm is implemented on the recent HEVC reference software (HM 13.0) [4]. The intra main profile is used for coding with the intra period set as 1 and frame rate set at 30 fps. The proposed algorithm is evaluated with 4 QPs of 22, 27, 32 and 37 using the test sequences recommended by JCT-VC [35].

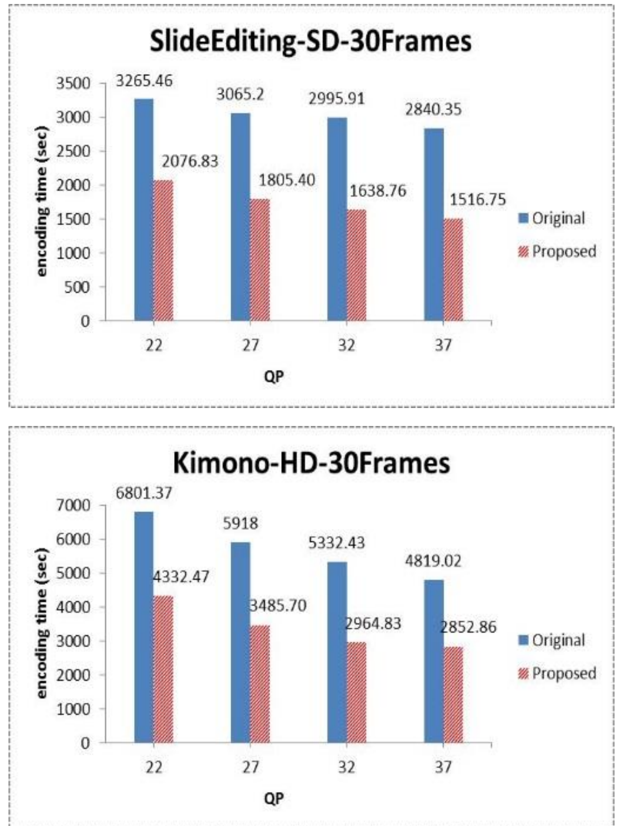

Fig. 5. Encoding time vs. quantization parameter for SlideEditing and Kimono

A. Encoder Complexity Reduction

With the proposed CU early termination algorithm, encoder complexity in terms of encoding time for the test sequences is reduced by 35-48% as compared to the unmodified encoding HM13.0 [4].

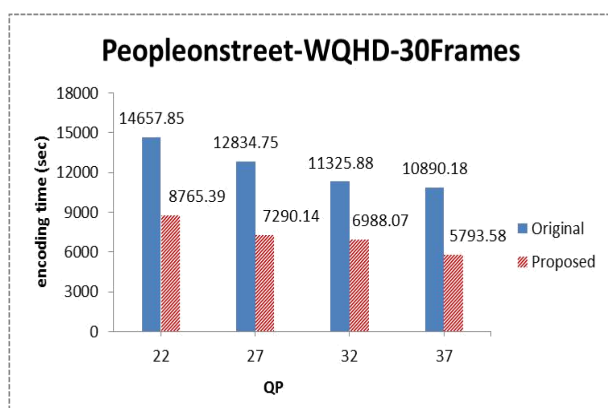

Fig. 6. Encoding time vs. quantization parameter for PeopleOnStreet

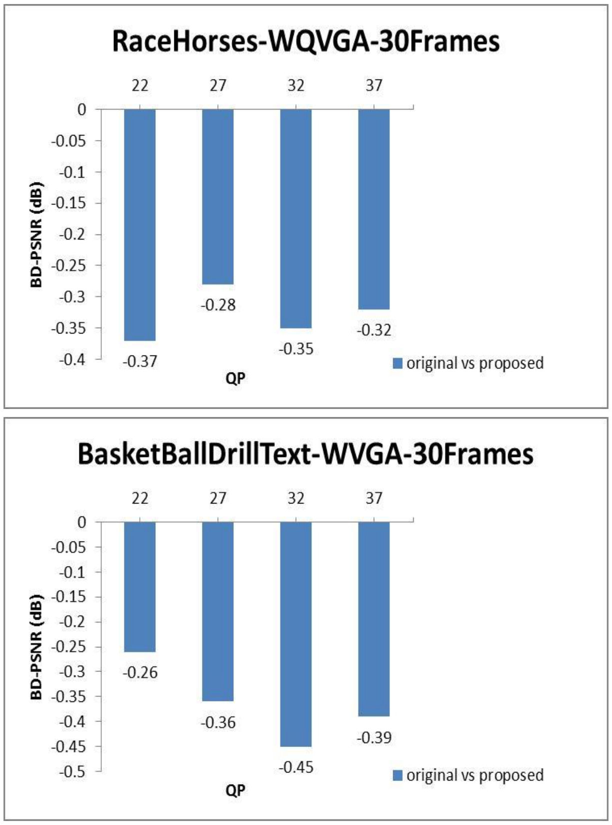

Fig. 7. BD-PSNR vs. quantization parameter for RaceHorses and BasketBallDrillText

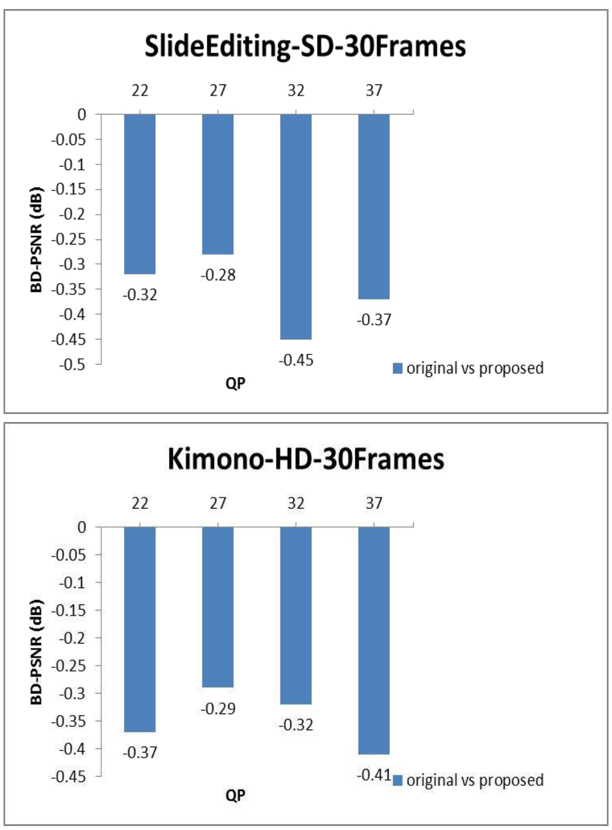

Fig. 8. BD-PSNR vs. quantization parameter for SlideEditing and Kimono

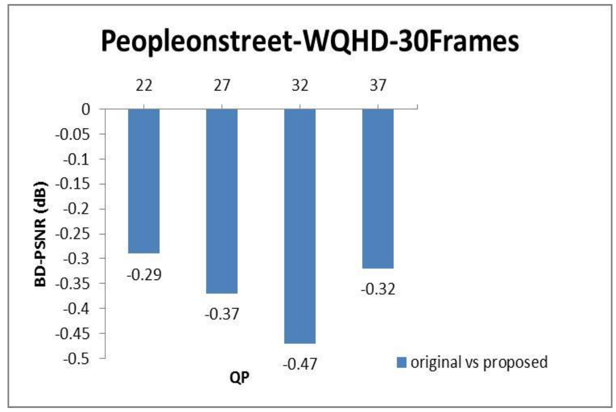

Fig. 9. BD-PSNR vs. quantization parameter for Peopleonstreet

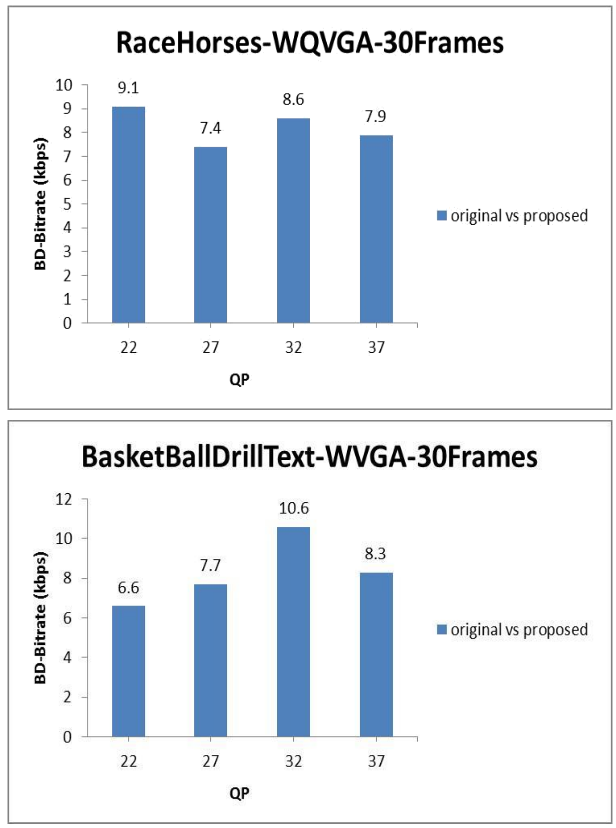

Fig. 10. BD-bitrate vs. quantization parameter RaceHorses and BasketBallDrillText

B. BD-PSNR

To evaluate objectively the coding efficiency of video codecs, Bjøntegaard Delta PSNR (BD-PSNR) was proposed [36]. Based on the rate-distortion (R-D) curve fitting, BD-PSNR is able to provide a good evaluation of the R-D performance [36]. BD-PSNR is a curve fitting metric based on rate and distortion of the video sequence. However, this does not take into account the complexity of the encoder, but the BD metric tells a lot about the quality of the video sequence [30, 31]. Ideally, BD-PSNR should increase and BD-bitrate should decrease. The following results show a plot of BD-PSNR versus the quantization parameter (QP).

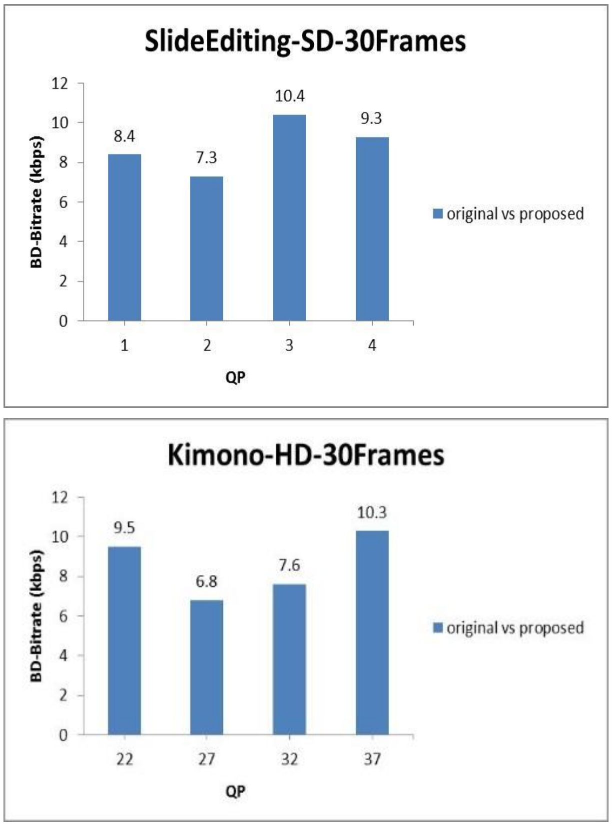

Fig. 11. BD-bitrate vs. quantization parameter SlideEditing and Kimono

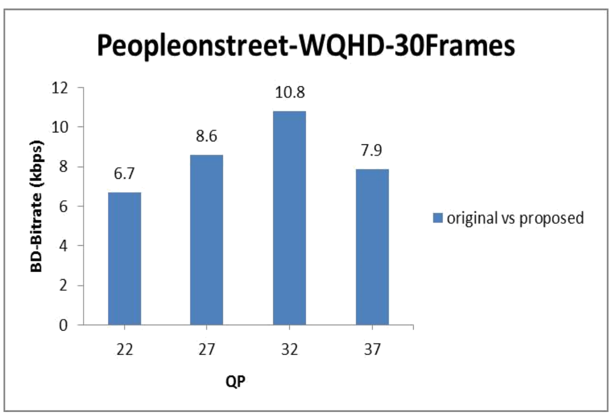

Fig. 12. BD-bitrate vs. quantization parameter Peopleonstreet

C. *BD-Bitrate*

BD-bitrate is a metric similar to the BD-PSNR metric which determines the quality of encoded video sequence along with the measure of the output bitstream of encoded video sequence.

D. *Rate Distortion Plot (RD Plot)*

The results related to the Rate Distortion Plot (RD Plot) are shown in Figures 13 to 15.

E. *Percentage Decrease In Encoding Time*

The results related to the Percentage Decrease in Encoding Time is shown in Figures 16 to 18.

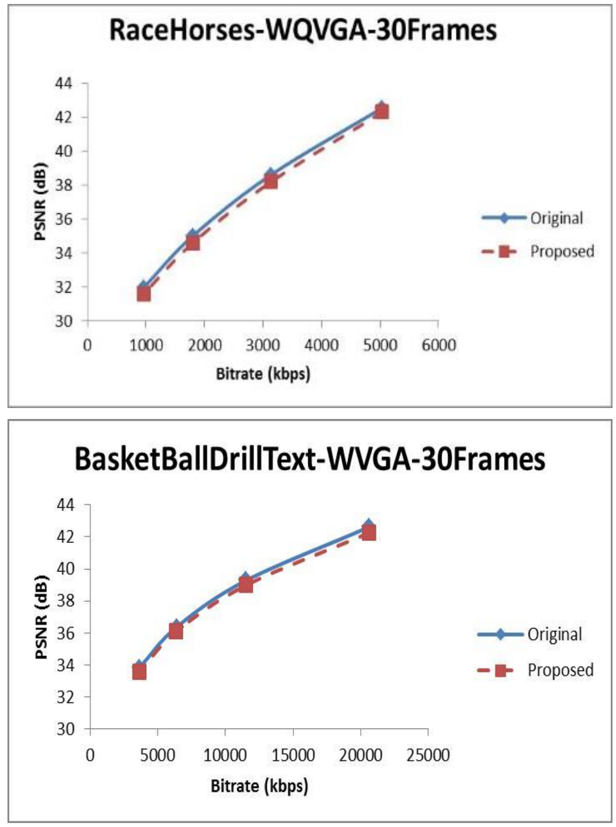

Fig. 13. PSNR vs. bitrate for RaceHorses and BasketBallDrillText

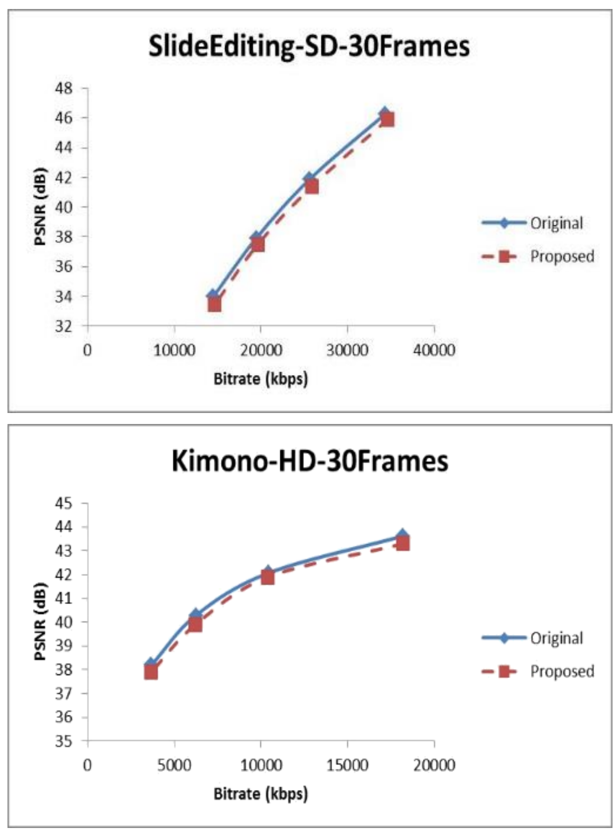

Fig. 14. PSNR vs. bitrate for SlideEditing and Kimono

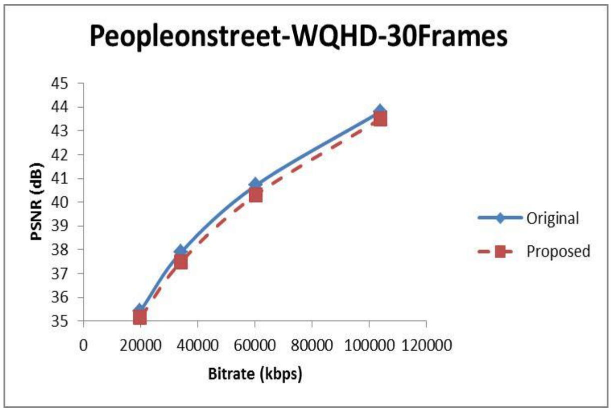

Fig. 15. PSNR vs. bitrate for Peopleonstreet

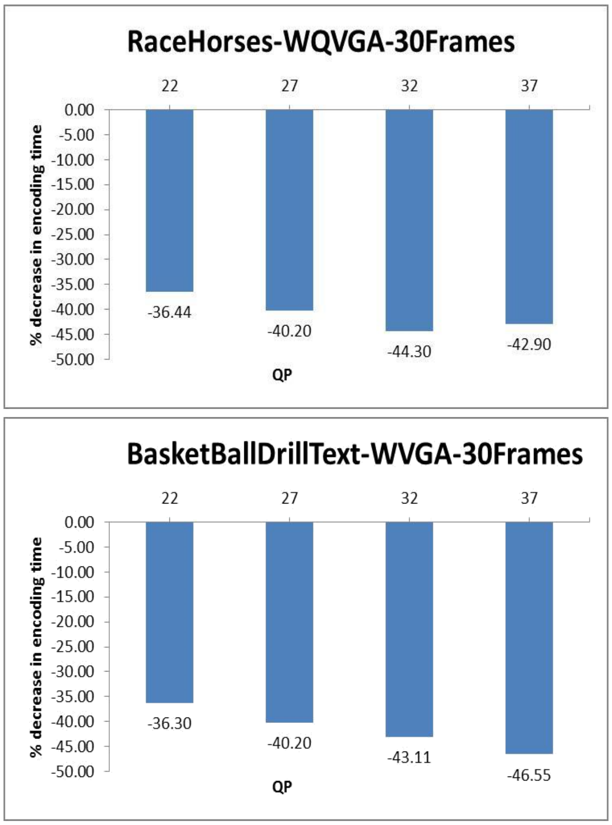

Fig. 16. Percent decrease in encoding time vs. quantization parameter for RaceHorses and BasketBallDrillText

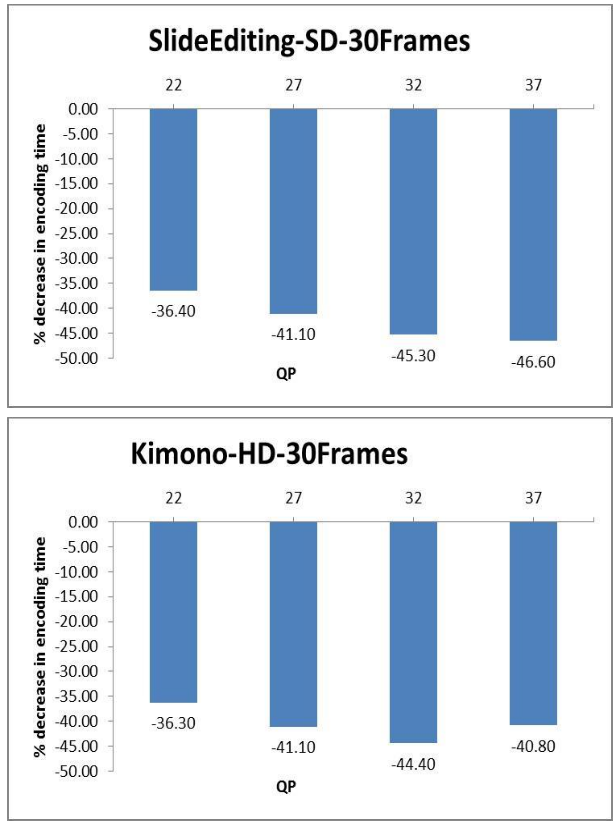

Fig. 17. Percent decrease in encoding time vs. quantization parameter for SlideEditing and Kimono

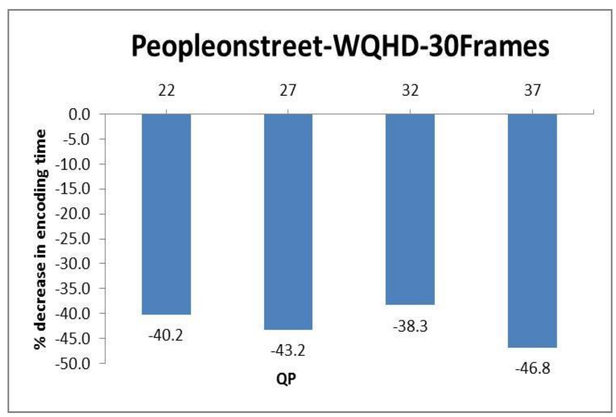

Fig. 18. Percent decrease in encoding time vs. quantization parameter for Peopleonstreet

VII. CONCLUSIONS AND FUTURE WORK

In this paper, a CU early termination algorithm and fast intra mode decision algorithm are proposed to reduce the computational complexity of the HEVC encoder, which includes three strategies, i.e., CU early termination, PU mode decision and early RDOQ termination. The results of comparative experiments demonstrate that the proposed algorithm can effectively reduce the computational complexity (encoding time) by 35–48% (see Figures 4–6) on average as compared to the HM 13.0 encoder [4], while only incurring acceptable drop in the PSNR (see Figures 7–9) and a negligible increase in the bitrate (see Figures 10–12) and encoding bit stream size for different values of the quantization parameter based on various standard test sequences [29]. The results of simulation also demonstrate negligible decrease in BD-PSNR [30] i.e. 0.25 dB to 0.48 dB as compared to the original HM13.0 software [4]. RD distortion plots and percentage decrease in encoding time are shown in Figures 13–15 and Figures 16–18, respectively.

There are many other ways to explore in the CU early termination and fast intra prediction in the intra prediction area as suggested by research [25],[33]. Many of these methods can be combined with this method, or if needed, one method may be replaced by a new method and encoding time gains can be explored.

Similar algorithms can be developed for fast inter-prediction in which the RD cost of the different modes in inter-prediction are explored, and depending upon the adaptive threshold [34], mode decision can be terminated resulting in less encoding time and reduced complexity combining with the above proposed algorithm.

Tan et al. [37] proposed a fast RQT algorithm for both intra and inter mode coding in order to reduce the encoder complexity. In [37], for all intra case, 13% encoding time can be saved, However, BD-Rate just increases by 0.1%. For random access and low delay constraints it reduces by up to 9% encoding time with 0.3% BD-Rate performance degradation. This method can be integrated with the proposed algorithm to increase the encoding time.

Tian et al [38] proposed a PU size decision algorithm to speed up the intra coding. In this method, two-stage is applied. In the pre-stage, filtering the unnecessary PU by analyzing the texture complexity of the LCU and its four sub-blocks secondly, skipping the small PU candidates by referring the neighboring PU. The simulation results show that proposed method can speed up by average of 44.91%, with only PSNR degradation less than 0.04dB. This method can be combined with the proposed algorithm.

The Bayesian decision [39] rule can be applied to calculate the CU size, and then this information can be combined with the proposed method to achieve further encoding time gains.

Complexity reduction can also be achieved through hardware implementation of a specific algorithm, which requires much computation. The FPGA implementation can be useful to evaluate the performance of the system on hardware in terms of power consumption and encoding time.

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