COMPLEXITY REDUCTION OF MOTION ESTIMATION IN HEVC

by

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Abstract

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The High Efficiency Video Coding (HEVC) standard is the latest video coding project developed by the Joint Collaborative Team on Video Coding (JCT-VC) which involves the International Telecommunication Unit (ITU-T) Video Coding Experts Group (VCEG) and the ISO/IEC Moving Picture Experts Group (MPEG) standardization organizations. The HEVC standard is an optimization of the previous standard H.264/AVC (Advanced Video coding) with the bit-rate reduction of about 50% at the same visual quality.

The most complex and time consuming process in the HEVC encoding is the motion estimation. The process involves finding the best matching block in the current frame by comparing it with a reference frame. Unlike, H.264 which had fixed sized blocks, HEVC has variable sized blocks which reduce the number of bits required by certain blocks in the frame where there is no motion change. But still the process of finding the best match is very time consuming and imposes computational complexity. Various algorithms like three-step search, diamond search and square search have been developed to reduce the computational complexity of the motion estimation module. The complexity can be further reduced by using an early termination technique to end the search process once it reaches a certain threshold. In this thesis, an algorithm is proposed for early termination of the search points by calculating a threshold. The algorithm is based on the predicted motion vector and the sum of absolute differences of the predicted motion vector for the

search points. It is observed that if the prediction to the starting point is precise, then it can be used to calculate a threshold value and if any search point goes below the threshold, it can be declared as the best match. The experimental results based on the proposed algorithm tested on various video sequences show a reduction of the encoding time by about 5% to 17% with negligible Peak Signal to Noise Ratio (PSNR) loss (less than 1 dB) as compared to the existing algorithm. The algorithm is more efficient for SD and HD resolution videos. The bit-rate increase is from 2% to 13.8 %. Metrics like Bjontegaard (BD)-PSNR and BD-Bit-rate are also used.

Table of Contents

List of Illustrations

List of Tables

Chapter 1

Introduction

1.1 Basics of video compression

A video is comprised of a number of moving images. An image is comprised of a number of pixels depending upon the resolution of the image. An image has certain characteristics like height and width which are the number of pixels along the vertical and horizontal directions respectively. Also it is characterized by its color and brightness.

When a number of images, also known as frames, are sent at a constant interval known as frame rate, it makes up a video. Frame rate is an important factor in video technology.

Video compression is the ability to exploit the temporal and spatial redundancies while sending the images. The temporal redundancies are exploited by a technique called inter frame coding which generates all the P-frames or predictive frames and B-frames or bi-predictive frames. It compares the current frame with a reference frame and sends only the change in the images. The spatial redundancies are exploited by a technique called intra-frame coding. This technique takes advantage of the fact that pixels tend to have intensities that are very close to the neighboring pixels. Intra-frame technique generates all the I-frames. The three types of frames are shown in fig 1.1 [15]

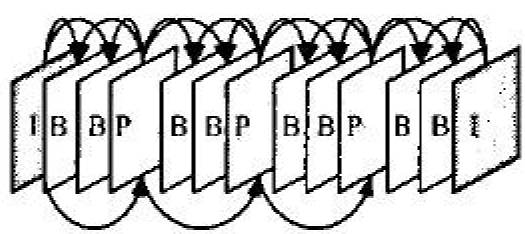


Figure 1.1 I, P and B frames [15]

1.2 Need for video compression

Video compression is required in order to reduce the redundancies in video data. Uncompressed video requires high bit rate which makes its transmission very difficult. The higher the number of bits required, the higher is the memory space required to store the bits. Even if the transmission and storage of such a video is taken care of, processing power to manage such a volume of data would make the receiver hardware very expensive. Therefore video compression is essential to overcome all these problems.

High Efficiency Video Coding (HEVC) by JCT-VC is the latest video compression standard which has a 50% bit rate reduction compared with the H.264 standard for the same perceptual quality [2]. HEVC has 3 profiles Main, Main intra and Main10. These were finalized in January, 2013. In August 2013 five additional profiles Main 12, Main 4:2:2, Main 4:4:4 10 and Mai 4:4:4 12 were released. Other range extensions include increased emphasis on high quality coding, lossless coding and screen content coding. Scalability extensions and 3D video extensions which enable stereoscopic and multi-view representations and consider newer 3D capabilities such as the depth maps and view-synthesis techniques are expected to be finalized in 2014. For work on 3D video topics for multiple standards including 3D video extensions JCT-VC formed a team known as JCT on 3D Video(JCT-3V) in July 2012..

1.3 Video Compression standards

Compression of a video, while keeping the same quality, is very important since it determines the total storage required and also affects the transmission. There have been several video coding standards introduced by organizations like the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T), Moving Picture Experts Group (MPEG) and the Joint Collaborative Team on Video Coding (JCT-

VC). Each standard is an improvement over the previous standard. Figure 1.2 shows the evolution of the video coding standards.

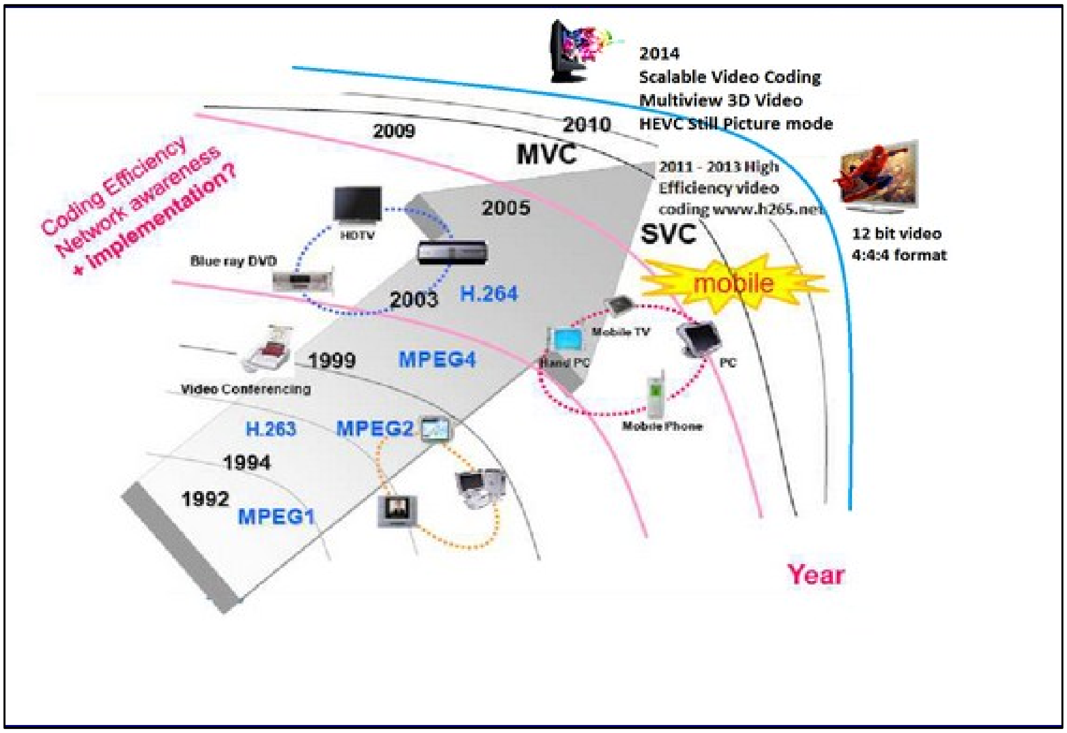


Figure 1.2 Evolution of video coding standards [45]

1.4 Thesis outline

Chapter 2 describes the high level encoding process using the HEVC standard and various features already present in the standard like motion estimation, motion compensation, types of predictions used, quantization and parallel processing features. Chapter 3 describes various aspects of the inter-picture prediction of HEVC and the motion estimation process in detail. Chapter 4 describes the analysis of the proposed algorithm and compares it with the existing algorithm in HEVC. Chapter 6 gives the conclusions and describes the topics that can be explored in the future.

Chapter 2

Overview of High Efficiency Video Coding

HEVC, the High Efficiency Video Coding standard, is the most recent joint video project of the ITU-T VCEG and ISO/IEC MPEG standardization organizations, working together in a partnership known as the Joint Collaborative Team on Video Coding (JCT-VC) [1]. The HEVC standard is designed to achieve multiple goals: coding efficiency, transport system integration and data loss resilience, as well as implementability using parallel processing architectures [2].The main goal of the HEVC standardization effort is to enable significantly improved compression performance relative to existing standards – in the range of 50% bit rate reduction for equal perceptual video quality [3][4].

The block diagram of HEVC encoder is shown in figure 2.1 [2]. The corresponding decoder block diagram is shown in figure 2.2 [5].

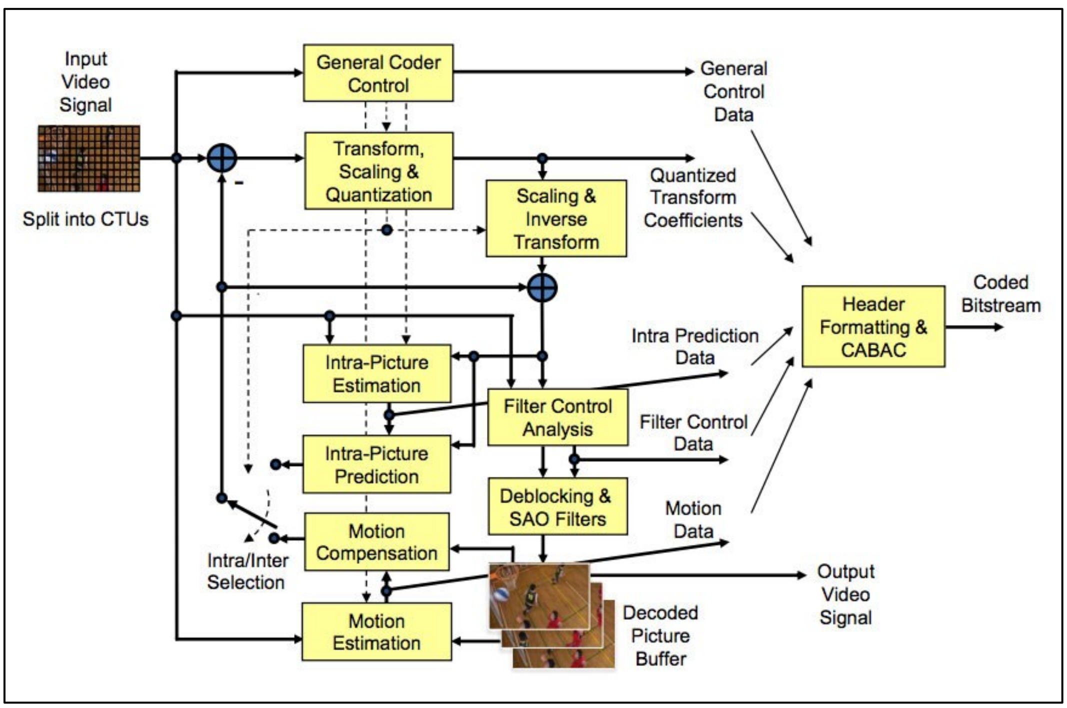


Figure 2.1 HEVC encoder block diagram [2]

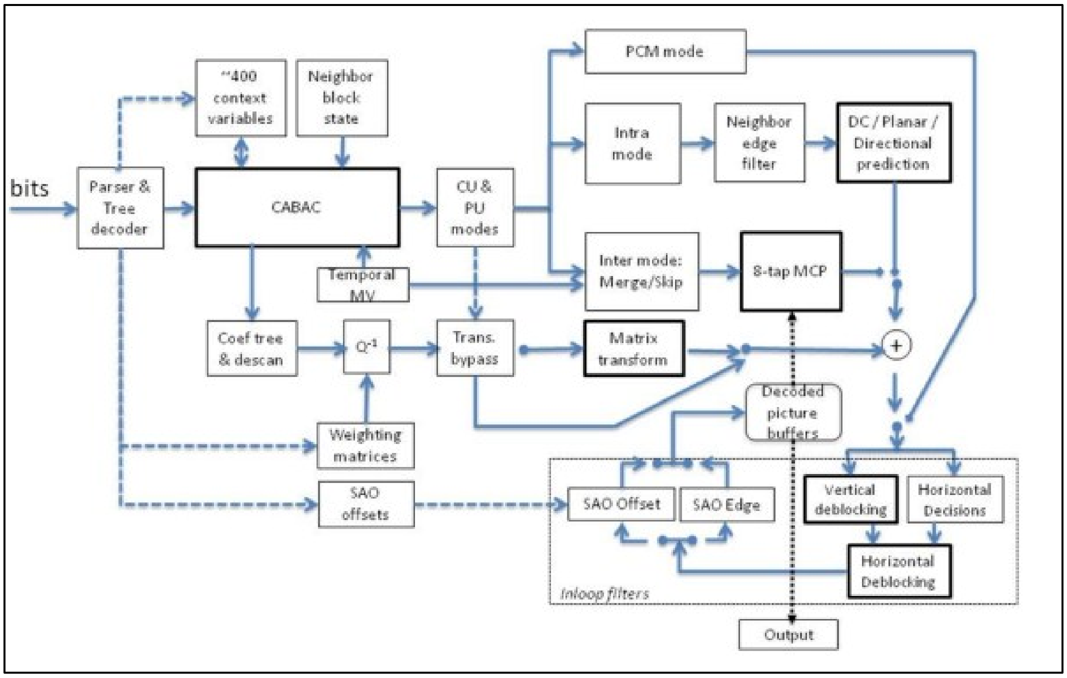


Figure 2.2 HEVC decoder block diagram [5]

The video coding layer of HEVC employs the same “hybrid” approach (inter-/intra-picture prediction and 2D transform coding) used in all video compression standards since H.261 [2]. Some differences in HEVC are coding tree units instead of macro blocks, single entropy coding-Context Adaptive Binary Arithmetic Coding (CABAC) and features like tiles, wave front parallel processing and dependent slices to enhance parallel processing. The residual signal of the intra or inter prediction, which is the difference between the original block and its prediction, is transformed by a linear spatial transform [2]. The transform coefficients are then scaled, quantized, entropy coded, and transmitted together with the prediction information. The residual is then added to the prediction, and the result of that addition may then be fed into one or two loop filters to smooth out artifacts induced by the block-wise processing and quantization. The final picture representation, which is a duplicate of the output of the decoder, is stored in a decoded picture buffer to be used for the prediction of subsequent pictures [2].

2.1 Coding tree unit

HEVC has replaced the concept of macro blocks (MBs) with coding tree units. The coding tree unit has a size selected by the encoder and can be larger than the traditional macro blocks. It consists of luma coding tree blocks (CTB) and chroma CTBs. HEVC supports a partitioning of the CTBs into smaller blocks using a tree structure and quad tree-like signaling [2][6].

The quad tree syntax of the CTU specifies the size and positions of its luma and chroma coding blocks (CBs). One luma CB and ordinarily two chroma CBs, together with associated syntax, form a coding unit (CU) for 4:2:0 format.

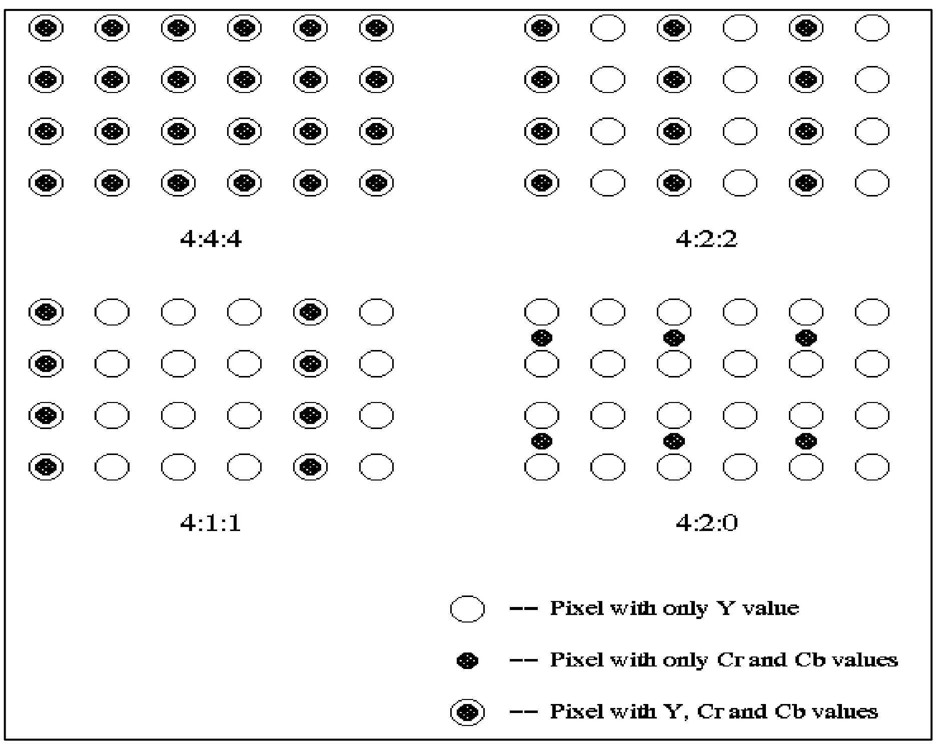


Figure 2.3 Format for YUV components [44]

Each CU has an associated partitioning into prediction units (PUs) and a tree of transform units (TUs). Similarly, each CB is split into prediction blocks (PB) and transform blocks (TB) [7].The decision whether to code a picture area using inter-picture or intra-picture prediction is made at the CU level. Figure 2.4 shows different sizes of a CTU [36].

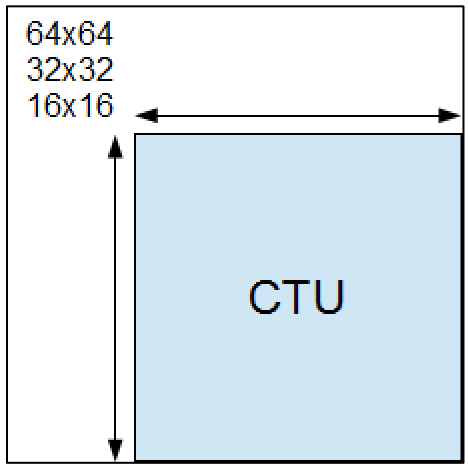


Figure 2.4 different sizes of CTU [36]

Figure 2.5 shows the sub-division of a CTB into TBs and PBs [8].

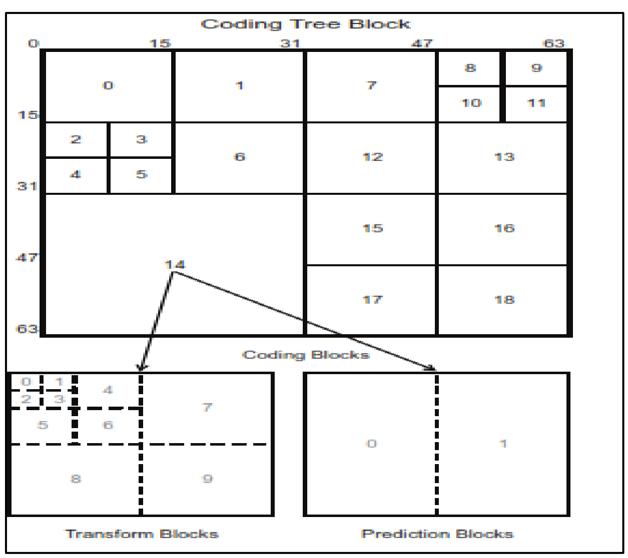


Figure 2.5 Sub-division of a CTB into TBs and PBs [8]

2.2 Encoder Features

2.2.1 Motion vector signalling

The HEVC standard uses a technique called advanced motion vector prediction (AMVP) to derive several most probable candidates based on data from adjacent PBs and the reference picture. A “merge” mode for MV coding can be also used, allowing the inheritance of MVs from neighboring PBs [2]. Moreover, compared to H.264/MPEG-4 AVC, improved “skipped” and “direct” motion inference are also specified [2].

2.2.2 Motion compensation

The HEVC standard uses quarter-sample precision for the MVs, and for interpolation of fractional-sample positions it uses 7-tap (filter co-efficients: -1, 4, -10, 58, 17, -5, 1) or 8-tap filters (filter co-efficients: -1, 4, -11, 40, 40, -11, 4, 1). In H.264/MPEG-4 AVC there is 6-tap filtering (filter co-efficients: 2, -10, 40, 40, -10, 2) of half-sample positions followed by a bi-linear interpolation of quarter-sample positions [2]. Each PB can transmit one or two motion vectors, resulting either in uni-predictive or bi-predictive coding, respectively [2]. As in H.264/MPEG-4 AVC, a scaling and offset operation may be applied to the prediction signals in a manner known as weighted prediction [2].

2.2.3 Intra-picture prediction

Intra prediction in HEVC is quite similar to H.264/AVC [7]. Samples are predicted from reconstructed samples of neighboring blocks. The mode categories remain identical: DC, plane, horizontal/vertical, and directional; although the nomenclature for H.264’s plane and directional modes has changed to planar and angular modes, respectively [7]. For intra prediction, previously decoded boundary samples from adjacent PUs must be used. Directional intra prediction is applied in HEVC, which supports 17 modes for 4x4 block and 34 modes for larger blocks, inclusive of DC mode [37]. Directional intra prediction is based on the assumption that the texture in a region is directional, which means the pixel values will be smooth along a specific direction [37].

The increased number of directions improves the accuracy of intra prediction. However it increases the complexity and increased overhead to signal the mode [37]. With the flexible structure of the HEVC standard, more accurate prediction, and other coding tools, a significant improvement in coding efficiency is achieved over H.264/AVC [37]. HEVC supports various intra coding methods referred to as Intra_Angular, Intra_Planar and Intra_DC. In [11], an evaluation of HEVC coding efficiency compared with H.264/AVC is provided. It shows that the average bit rate saving for random access high efficiency (RA HE) case is 39%, while for all intra high efficiency (Intra HE) case this bit rate saving is 25%, which is also considerable. It seems that the improvement of intra coding efficiency is still desirable. Figure 2.6 shows different intra prediction modes for HEVC [37].

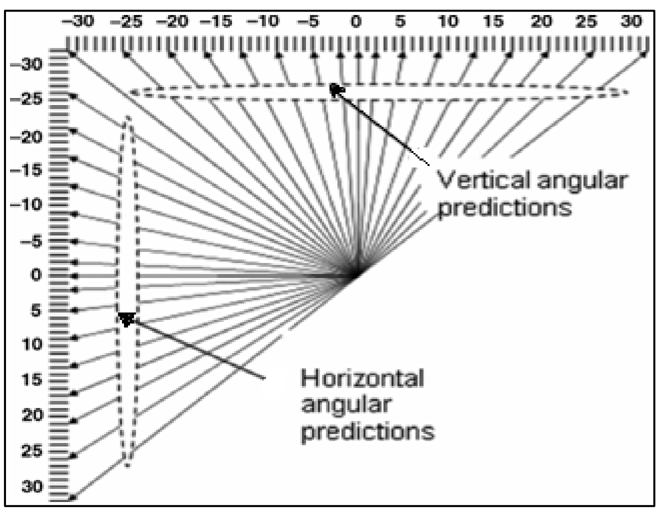


Figure 2.6 Thirty-three Intra prediction modes for HEVC [37]

2.2.4 Quantization control

As in H.264/MPEG-4 AVC, uniform reconstruction quantization (URQ) is used in HEVC, with quantization scaling matrices supported for the various transform block sizes [2].

2.2.5 Entropy Coding

HEVC uses context adaptive binary arithmetic coding (CABAC) for entropy coding which is similar to the one used in H.264/MPEG-4 AVC. It has some changes to improve its throughput speed. These improvements can be used for parallel processing architectures and its compression performance, and to reduce its context memory requirements.

2.2.6 In-loop deblocking filter

The HEVC standard uses a deblocking filter in the inter-picture prediction loop as used in H.264/MPEG-4 AVC. But design has been simplified in regard to its decision-making and filtering processes, and is made more friendly to parallel processing [2].

2.2.7 Sample adaptive offset

A non-linear amplitude mapping is introduced in the inter-picture prediction loop after the deblocking filter. The goal is to better reconstruct the original signal amplitudes by using a look up table that is described by a few additional parameters that can be determined by histogram analysis at the encoder side [2].

2.3 High level syntax architecture

The high-level syntax architecture used in the HEVC is similar to the one used in the H.264/MPEG-4 AVC standard which includes the following features:

2.3.1 Parameter set structure

Parameter sets contain information which can be used in the decoding of various regions of the decoded video [2]. The concepts of sequence and picture parameter sets from H.264/MPEG-4 AVC are augmented by a new video parameter set (VPS) structure [2].

2.3.2 NAL unit syntax structure

Each syntax structure is placed into a logical data packet called a network abstraction layer (NAL) unit. Depending on the content of a two-byte NAL unit header, it is possible to readily identify the purpose of the associated payload data [2].

2.3.3 Slices

A slice is the part of a data structure that can be decoded independently from other slices of the same picture, in terms of entropy coding, signal prediction, and residual signal reconstruction [2]. It can be a picture or a region of a picture and is mainly used for re-synchronization in case of data losses. In case of packetized transmission, the maximum number of payload bits within a slice is typically restricted, and the number of CTUs in the slice is often varied to minimize the packetization overhead while keeping the size of each packet within this bound [2].

2.3.4 SEI and VUI metadata

The syntax includes support for various types of metadata known as supplemental enhancement information (SEI) and video usability information (VUI). Such data provides information about the timing of the video pictures, the proper interpretation of the color space used in the video signal, 3D stereoscopic frame packing information and other “display hint” information [2].

2.4 Parallel processing features

HEVC has four new features to enhance parallel processing capability or modify the structuring of slice data for packetization purposes.

2.4.1 Tiles

HEVC has an option of partitioning its picture into rectangular independently decodable regions called as tiles. Its main purpose is for parallel processing. Tiles can also be used for random access to local regions in video pictures. Tiles provide parallelism at a more coarse level (picture/sub-picture) of granularity, and no sophisticated synchronization of threads is necessary for their use.

2.4.2 Wavefront parallel processing (WPP)

This is a new feature in HEVC which when enabled allows a slice to be divided into rows of CTUs. The processing of each row can be started only after certain decisions in the previous row have been made. WPP provides parallelism within slices [2]. Figure 2.7 shows how WPP works [7].

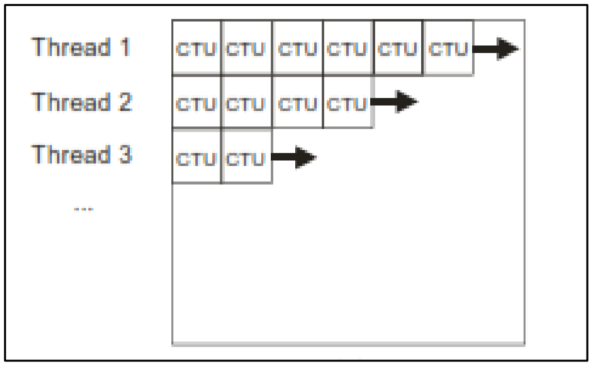


Figure 2.7 CTBs processed in parallel using WPP [7]

2.4.3 Dependent slices

Dependent slices allow data associated with a particular wave front point entry or tile to be carried in a separate NAL unit. It also allows fragmented packetization of the data with lower latency than if it were all coded in one slice [2].

2.5 Summary

Chapter 2 describes the overview of the HEVC standard, encoder features, high level syntax architecture and parallel processing capabilities. Chapter 3 will describe the details regarding different blocks of inter picture prediction and motion estimation.

Chapter 3

Inter Picture Prediction

Inter picture prediction in the HEVC standard is divided into prediction block partitioning, fractional sample interpolation and motion vector prediction for merge and non-merge modes. The HEVC standard supports more PB partition shapes for inter-coded CBs. The samples of the PB for an inter-coded CB are obtained from those of a corresponding block region in the reference picture identified by a reference picture index, which is at a position displaced by the horizontal and vertical components of the motion vector.

The HEVC standard only allows a much lower number of candidates to be used in the motion vector prediction process for the non-merge case, since the encoder can send a coded difference to change the motion vector. Further, the encoder needs to perform motion estimation, which is one of the most computationally expensive operations in the encoder, and complexity is reduced by allowing less number of candidates [2]. When the reference index of the neighboring PU is not equal to that of the current PU, a scaled version of the motion vector is used [2]. The neighboring motion vector is scaled according to the temporal distances between the current picture and the reference pictures indicated by the reference indices of the neighboring PU and the current PU, respectively [2]. When two spatial candidates have the same motion vector components, one redundant spatial candidate is excluded [2].

Figure 3.1 illustrates the block based motion estimation process [5].

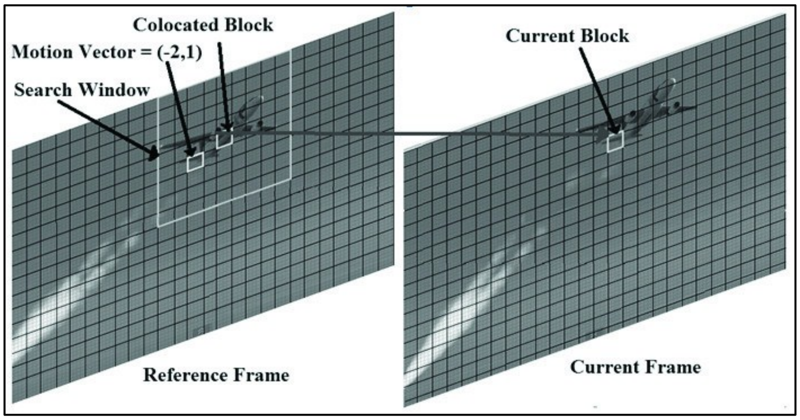


Figure 3.1 block based motion estimation process [5].

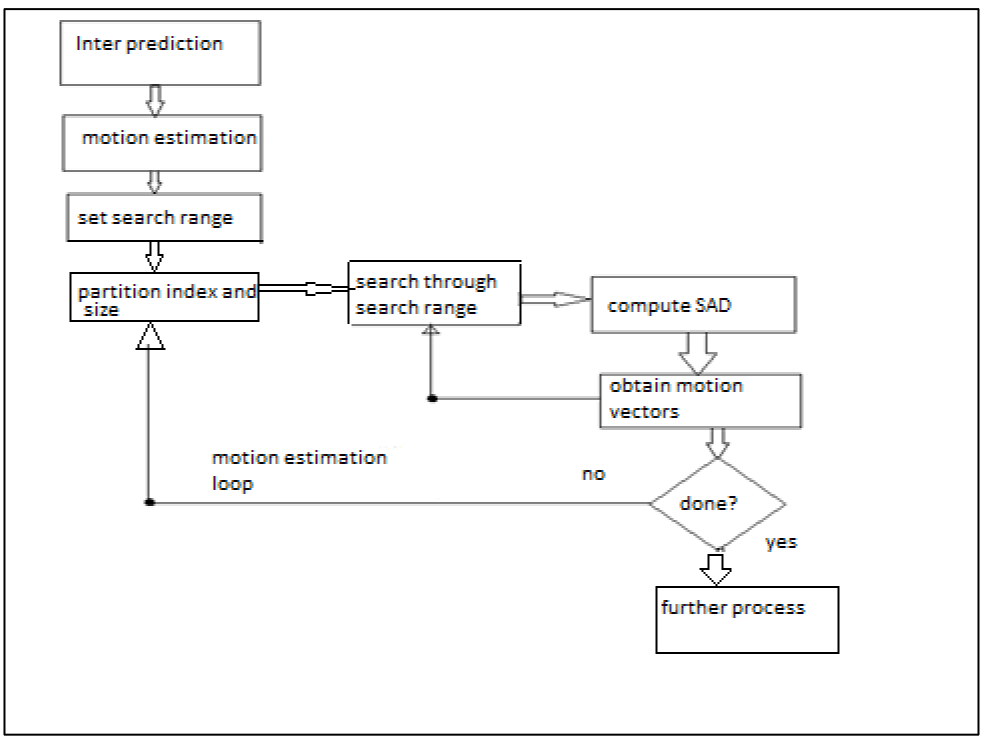


Figure 3.2 HEVC motion estimation flow

In multi-view video coding, both temporal and interview redundancies can be exploited by using standard block based motion estimation (BBME) [38]. Due to its simplicity and efficiency [38], the BBME [39] has been adopted in several international video coding standards such as MPEG-x, H.26x and VC-1 [40][41]. In the BBME, the current frame is divided into NxN pixel size macroblocks (MBs) and for each MB a certain area of the reference frame is searched to minimize a block difference measure (BDM), which is usually a sum of absolute differences (SAD) between the current MB and the reference MB [21]. The displacement within the search area (SA) which gives the minimum BDM value is called a motion vector [21]. With the development of video coding standards, the basic BBME scheme was extended by several additional techniques such as sub-pixel, variable block size, and multiple reference frame motion estimation [39]. Figure 3.3 shows multiple frame reference frame motion estimation [25].

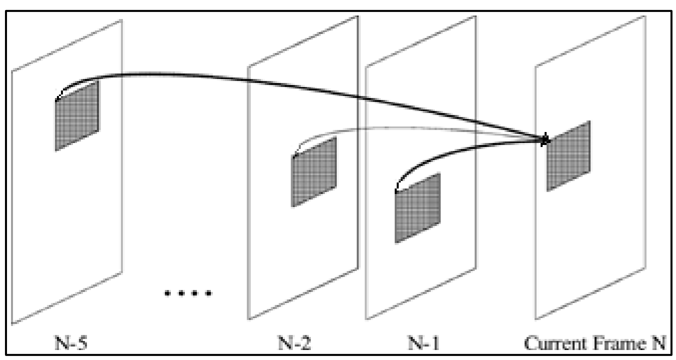


Figure 3.3 Multiple frame reference frame motion estimation [25]

Figure 3.4 shows variable block sizes in motion estimation [33].

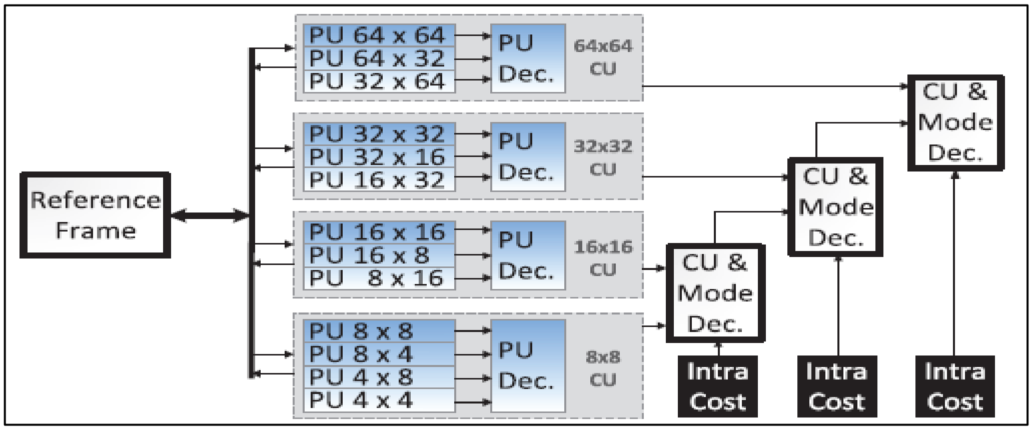


Figure 3.4 Variable block sizes in motion estimation HEVC [33]

3.1 Prediction block partitioning

Compared with intra coded CBs, HEVC provides a greater number of partition shapes for inter coded CBs [2]. The partition mode PART_2Nx2N means there is no partition of the CB whereas PART_Nx2N and PART_2NxN means the CB is split in equal size vertically and horizontally respectively. PART_NxN means that the CB is split equally into four parts but this mode is only supported when the size of the CB is equal to the smallest allowed size [2]. The HEVC standard also supports asymmetric motion partitions PART_2N×nU, PART_2N×nD, PART_nL×2N and PART_nR×2N. Figure 3.5 shows the partition sizes.

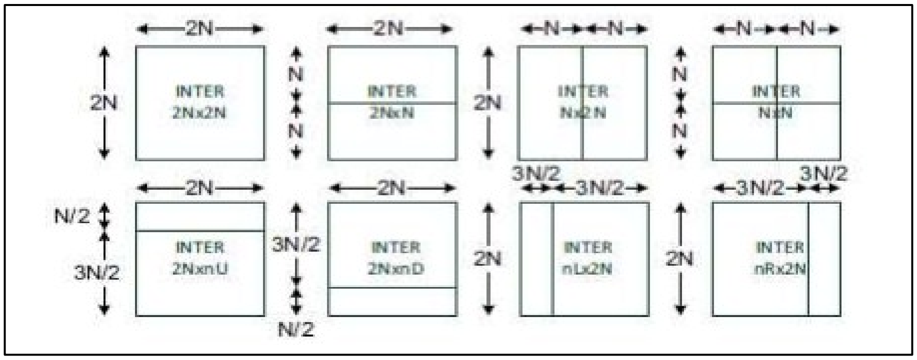


Figure 3.5 Inter picture partitions in HEVC [43]

3.2 Fractional sample Interpolation

The samples of the PB for an inter-coded CB are obtained from those of a corresponding block region in the reference picture identified by a reference picture index, which is at a position displaced by the horizontal and vertical components of the motion vector [2]. Fractional sample interpolation is used to generate the prediction samples for non-integer sampling positions when the motion vector does not have an integer value.

HEVC uses an 8-tap filter (weights: -1, 4, -11, 40, 40, -11, 4, 1) for the half-sample positions for fractional sample interpolation of luma samples and a 7-tap filter (weights: -1, 4, -10, 58, 17, -5, 1) for quarter sample positions. Figure 3.6 shows the fractional sample interpolation used in HEVC.

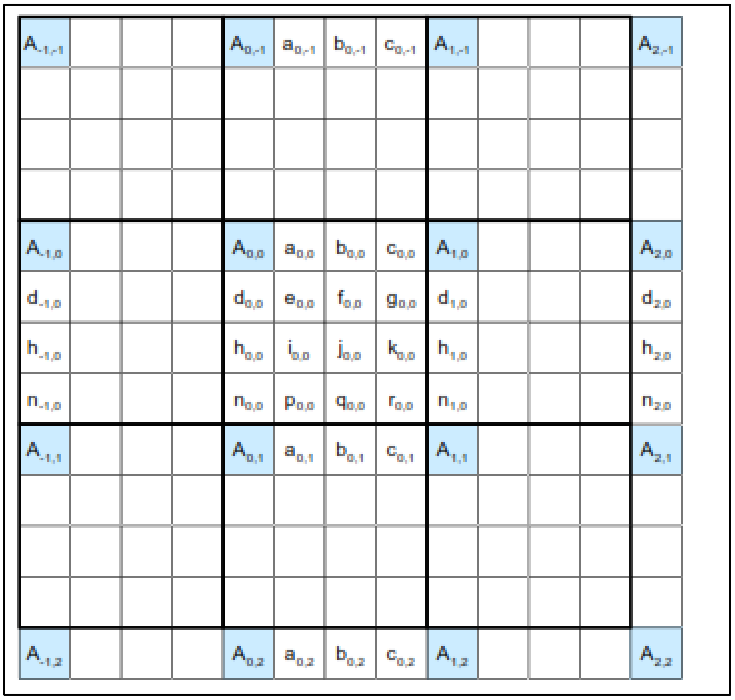


Figure 3.6 Integer and fractional sample positions for luma interpolation [2]

Unlike H.264/AVC which uses a two-stage interpolation process by first generating the values of one or two neighboring samples at half-sample positions using 6-tap filtering, rounding the intermediate results, and then averaging two values at integer or half-sample positions which is as follows:

$$a_{0,j} = \left(\sum_{i=-3..3} A_{i,j}\, qfilter[i] \right) \quad >> (B-8)$$

$$b_{0,j} = \left(\sum_{i=-3..4} A_{i,j}\, hfilter[i] \right) \quad >> (B-8)$$

$$c_{0,j} = \left(\sum_{i=-2..4} A_{i,j}\, qfilter[1-i] \right) \quad >> (B-8)$$

$$d_{0,0} = \left(\sum_{j=-3..3} A_{0,j}\, qfilter[j] \right) \quad >> (B-8)$$

$$h_{0,0} = \left(\sum_{j=-3..4} A_{0,j}\, hfilter[j] \right) \quad >> (B-8)$$

$$n_{0,0} = \left(\sum_{j=-2..4} A_{0,j}\, qfilter[1-j] \right) >> (B-8)$$

The constant B>=8 is the bit-depth of the reference samples(B=8 for most applications) [2]. In these formulas, '>>' denote an arithmetic right shift operation.

The samples labeled $e_{0,0}$, $f_{0,0}$, $g_{0,0}$, $i_{0,0}$, $j_{0,0}$, $k_{0,0}$, $q_{0,0}$, $p_{0,0}$ and $r_{0,0}$ can be derived by applying the corresponding filters to samples located at vertically adjacent $a_{0,j}$, $b_{0,j}$ and $c_{0,j}$ positions as follows:

$$e_{0,0} = \left(\sum_{v=-3..3} a_{0,v}\, qfilter[v] \right) \quad >> 6$$

$$f_{0,0} = \left(\sum_{v=-3..3} b_{0,v}\, qfilter[v] \right) \quad >> 6$$

$$g_{0,0} = \left(\sum_{v=-3..3} c_{0,v}\, qfilter[v] \right) \quad >> 6$$

$$i_{0,0} = \left(\sum_{v=-3..4} a_{0,v}\, hfilter[v] \right) \quad >> 6$$

$$j_{0,0} = \left(\sum_{v=-3..4} b_{0,v}\, hfilter[v] \right) \quad >> 6$$

$$k_{0,0} = \left(\sum_{v=-3..4} c_{0,v}\, hfilter[v] \right) \quad >> 6$$

$$p_{0,0} = \left(\sum_{v=-2..4} a_{0,v}\, qfilter[1-v] \right) >> 6$$

$$q_{0,0} = \left(\sum_{v=-2..4} b_{0,v}\, qfilter[1-v] \right) >> 6$$

$$r_{0,0} = \left(\sum_{v=-2..4} c_{0,v}\, qfilter[1-v] \right) >> 6$$

The HEVC standard instead uses a single, consistent, separable interpolation process to generate all fractional positions without intermediate rounding operations. It improves precision and simplifies the architecture of the fractional sample interpolation. The fractional sample interpolation process for the chroma components is similar to the one for the luma component. But the number of filter taps is 4 and the fractional accuracy is 1/8 for the usual 4:2:0 chroma format case (fig. 2.3).

3.3 Merge mode in HEVC

In inter-prediction, motion information basically consists of horizontal and vertical motion vector displacement values, and one or two reference picture indices in the case of prediction regions in B slices, an identification of which reference picture list is associated with each index [2]. A merge mode is used in HEVC to get this information from spatially or temporally neighboring blocks. Since it uses a merged region sharing all motion information, it is called as merge mode in HEVC. The merge mode is conceptually similar to the direct and skip modes in H.264/MPEG-4 AVC; however, there are two important differences. First, the HEVC standard transmits index information to select one out of several available candidates, in a manner sometimes referred to as a motion vector “competition” scheme. The HEVC standard also explicitly identifies the reference picture list and reference picture index; whereas the direct mode assumes that these have some pre-defined values [2].

Merge mode includes a set of possible candidates consisting of spatial neighboring candidates, a temporal candidate and generated candidates. Figure 3.7 shows the position of spatial candidates and for each candidate, the availability is checked in the order a_1, b_1, b_0, a_0, b_2 [2].

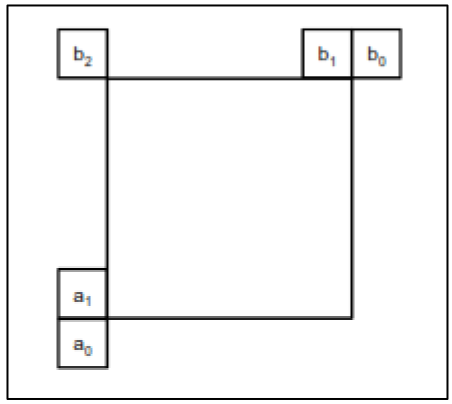


Figure 3.7 Positions of spatial candidates [2]

There are two kinds of redundancies which are removed after the validation of the spatial candidates. The first is if the candidate position for the current PU refers to the first PU within the same CU, it means that the same merge could be achieved by a CU without splitting it into prediction partitions. Hence it is removed. The second is when the candidates have the same motion information.

For the temporal candidate, the right bottom position just outside of the collocated PU of the reference picture is used if it is available. Otherwise, the center position is used instead [2]. The HEVC standard provides more flexibility than H.264 by transmitting the index of the reference picture list used for the collocated reference picture. Since temporal candidates use more memory, the granularity for storing the temporal motion candidates is restricted to a resolution of 16x16 luma grid, even when smaller PB structures are used at the corresponding location in the reference picture.

The total number of merge candidates is provided in the slice header. If it goes above the specified number, only the first candidates equal to the number specified are considered. If it is less than the specified number, additional candidates are generated to match the specified number.

3.4 Motion vector prediction

If the merge mode is not used, then a motion vector predictor is used to differentially code the motion vector. This mode is called the non-merge mode. Like merge mode, it also consists of multiple predictor candidates. The difference between the actual motion vector and the predictor is calculated and is sent to the decoder along with the index of the predicted motion vector candidate. Only two of the five spatial candidates is used in the non-merge mode according to the availability. So if the merge and non-merge modes are compared, HEVC allows a much lower number of candidates for the non-merge mode. This is because if the number of candidates is low, the encoder can send the coded difference and hence can change the motion vector. The reason for sending a fewer number of candidates is that the encoder needs to perform motion estimation which is a computationally complex process and the complexity is reduced if the number of candidates is low. When the reference index of the neighboring PU is not equal to that of the current PU, a scaled version of the motion vector is used [2]. The neighboring motion vector is scaled according to the temporal distances between the current picture and the reference pictures indicated by the reference indices of the neighboring PU and the current PU, respectively. When two spatial candidates have the same motion vector components, one redundant spatial candidate is excluded. The temporal motion vector prediction candidate is only included when the number of motion vector candidates is not equal to two and the use of temporal motion vector prediction is not disabled.

3.5 Proposed method

The existing algorithm of the motion estimation uses the block given by the predicted motion vector as the starting point to code the actual motion vectors. Once the starting point is decided, a search algorithm such as square search, diamond search or full search are used to calculate the sum of absolute differences (SAD) between the neighboring blocks in the reference frame and the current block which is to be encoded. Each time a block is checked and SAD is calculated it is compared with the best SAD. If the current SAD is less than the best SAD, it is declared as the best SAD. The total time taken by the search algorithm constitutes longest part of the motion estimation process. However, it is observed that if the SAD of the block given by the predicted motion vector value is precise, then the search pattern can be terminated if the SAD of any search point goes below a threshold [21]. The threshold can be calculated using the sum of absolute differences of the predicted motion vector and if a search point meets this requirement it can be declared as the winning point. The current step of the search process can be ended and hence the time taken for unnecessary calculations of the remaining search points in that step can be reduced. As the number of steps increase and the number of search points increase, the early termination can produce a lot of time saving.

3.6 Summary

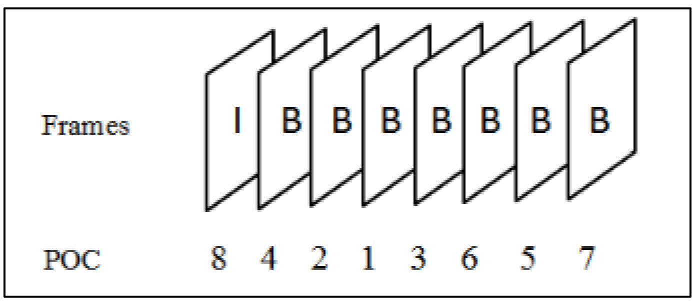
Chapter 3 describes the motion estimation process and the existing search algorithm along with a method to optimize and reduce the encoding time. Chapter 4 gives the results and graphs of the comparison of the existing algorithm and the proposed algorithm by testing it on various test sequences for different quantization parameters.

Chapter 4

Results

4.1 Test conditions

To test the performance of the proposed motion merge encoding technique the HEVC reference software HM 13.0 [38] was used. The encoder random access profile was used for testing purposes with a Group of Pictures (GOP) of length 8. The 'encoder random access profile' encodes the first frame as an intra-frame (I frame) and the following 7 frames are inter frames with bi-directional prediction (B-frames) .It follows a non-sequential approach towards selecting the next frame for encoding as shown in Figure 4.1. POC is the Picture Order Count.



4.1 GOP structure of encoder random access profile

The proposed algorithm was tested for 5 different test sequences [40] with resolutions going from WQVGA (416 x 240) up to high definition (1920 x 1080). Each test sequence was then run with 4 different quantization parameters of 22, 27, 32 and 37 which are commonly used for comparison/evaluation of various techniques. The list of test sequences is given in the table 4.1:

Table 4.1 List of test sequences [40] (all sequences at 30 fps)

No	Sequence	Resolution	Type	No of frames
1	Race Horses	416x240	WQVGA	30
2	BQ Mall	832x480	WVGA	30
3	BasketBallDrillText	832x480	WVGA	30
4	Kristen and Sara	1280x1080	SD	30
5	Parkscene	1920x1080	HD	30

4.2 Reduction in encoding time

The proposed algorithm has reduced the encoding time of the test sequences by about 5 to 17% as compared to the existing algorithm in the HEVC reference software HM 13.0 [38] for different quantization parameters. The PSNR change is less than 1 dB compared to the existing algorithm in the HEVC reference software HM13.0. Figures 4.2 through 4.6 show comparison graphs of the time taken by the existing algorithm against the proposed algorithm for 4 quantization parameters 22, 27, 32 and 37. The total number of frames considered for all the test sequences is 30.

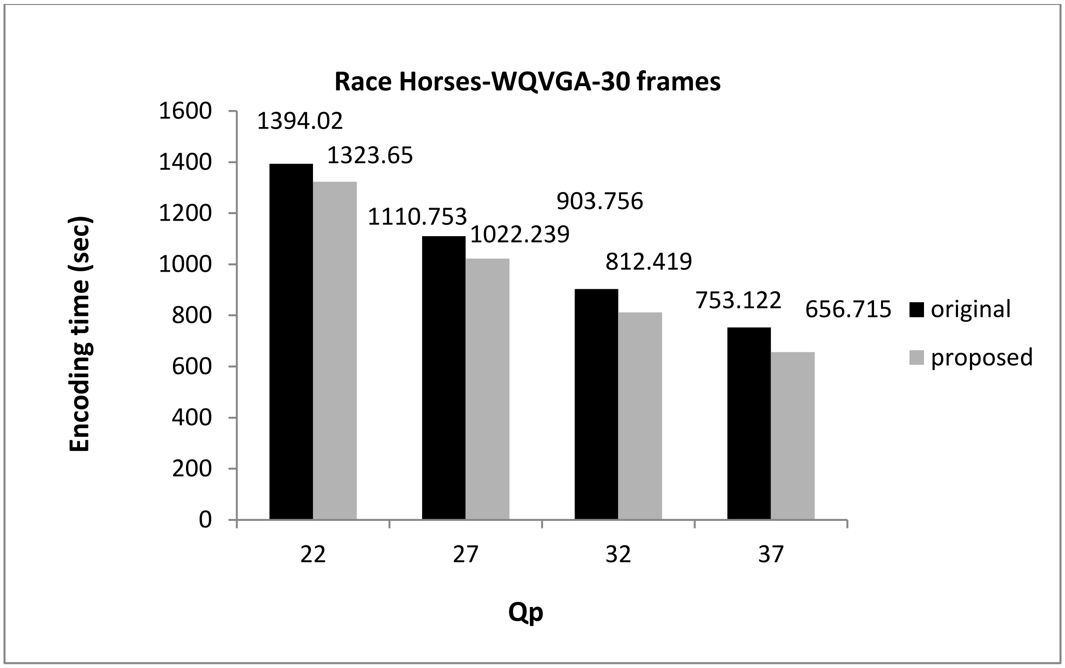


Figure 4.2 Encoding time versus QP for Race Horses (416x240)

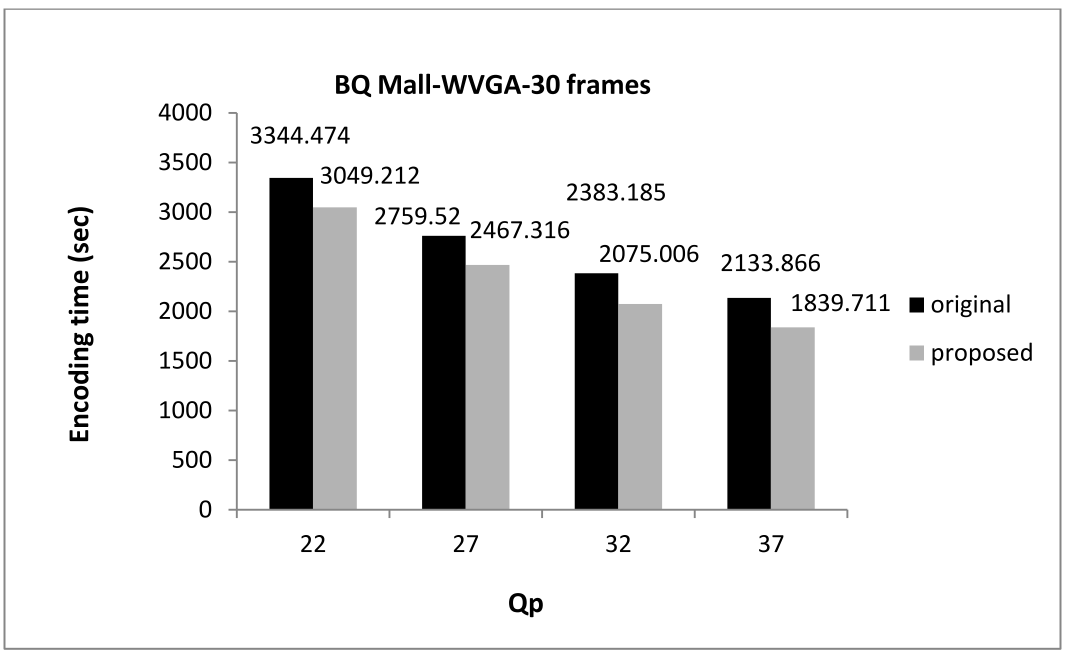


Figure 4.3 Encoding time versus QP for BQ Mall (832x480)

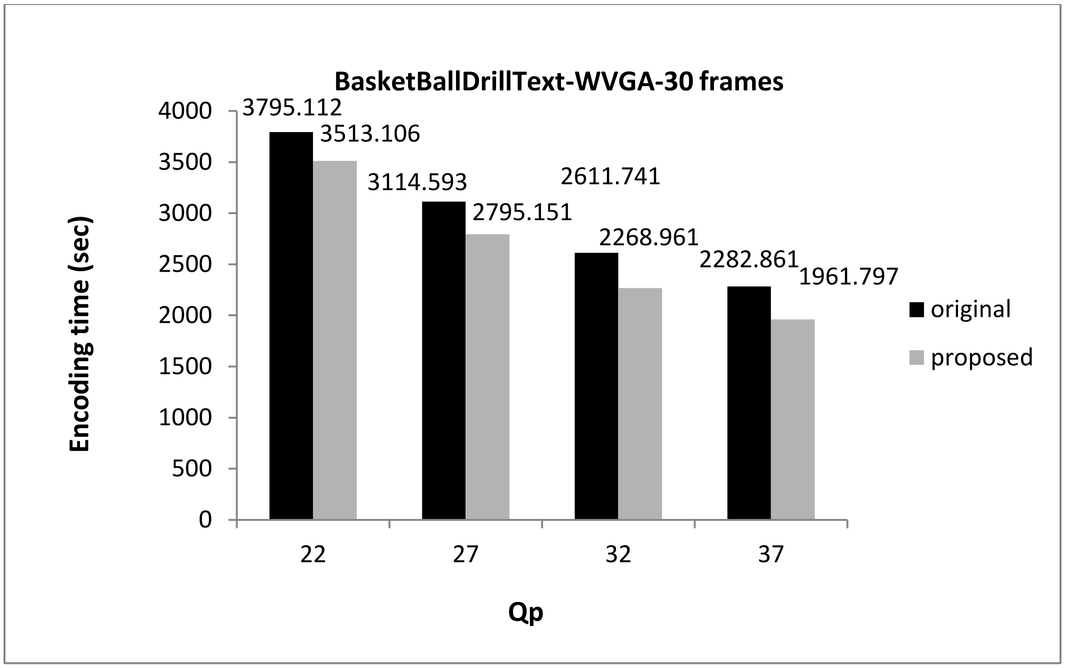


Figure 4.4 Encoding time versus for BasketBallDrillText (832x480)

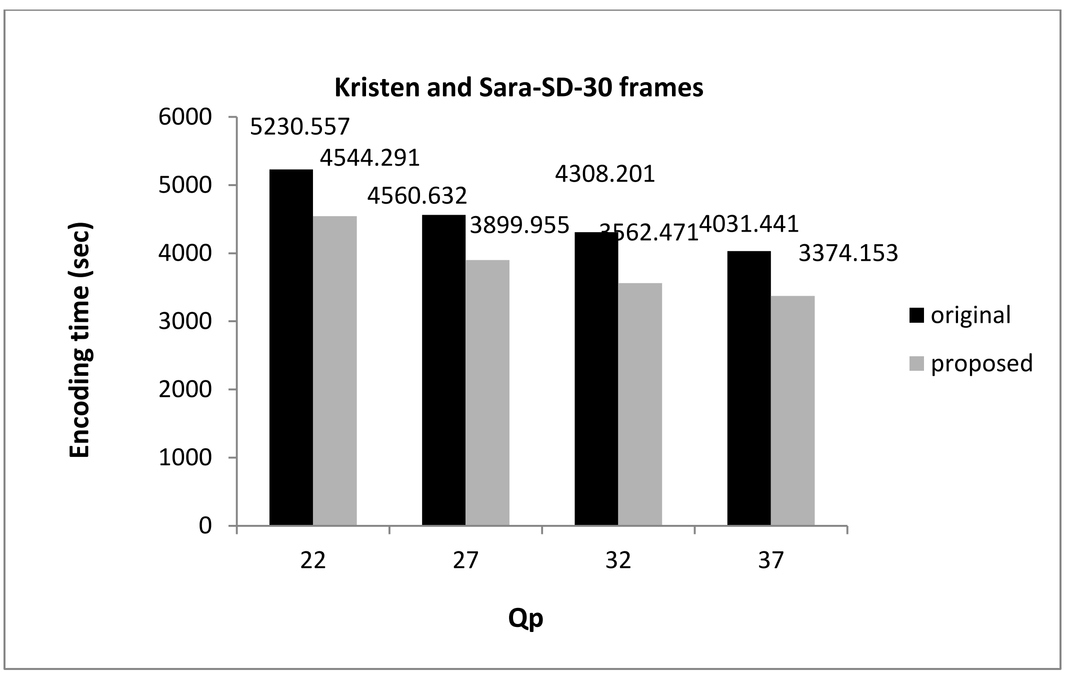


Figure 4.5 Encoding time versus QP for Kristen and Sara (1280x720)

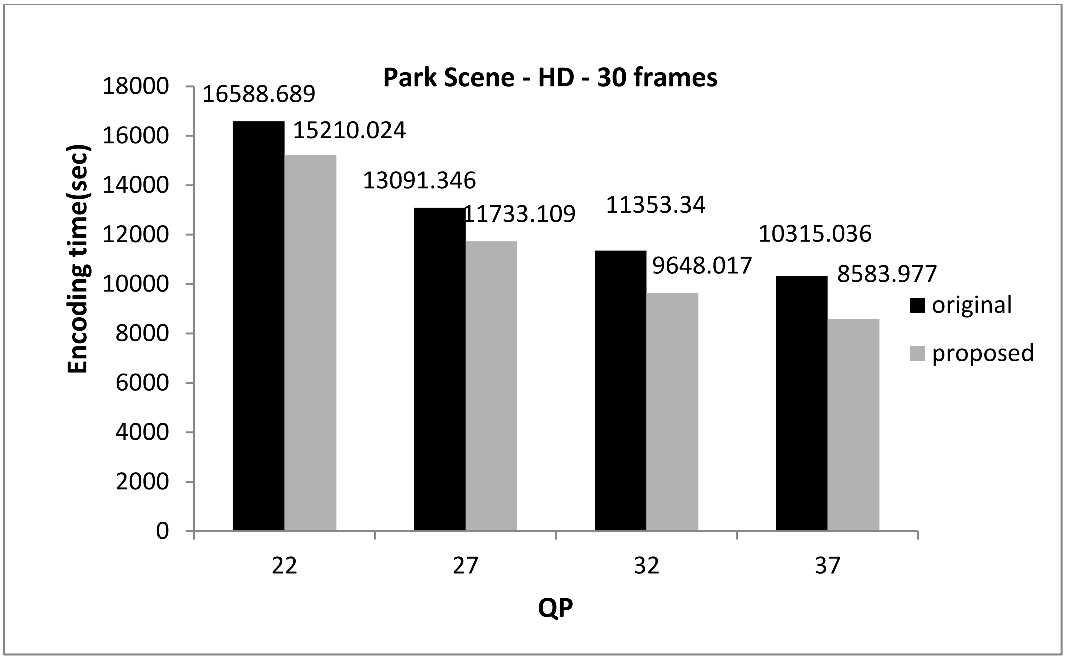


Figure 4.6 Encoding time versus QP for Park Scene (1920x1080)

Figures 4.7 through 4.11 show the comparison graphs of the bit-rate increase between the existing algorithm and the proposed algorithm.

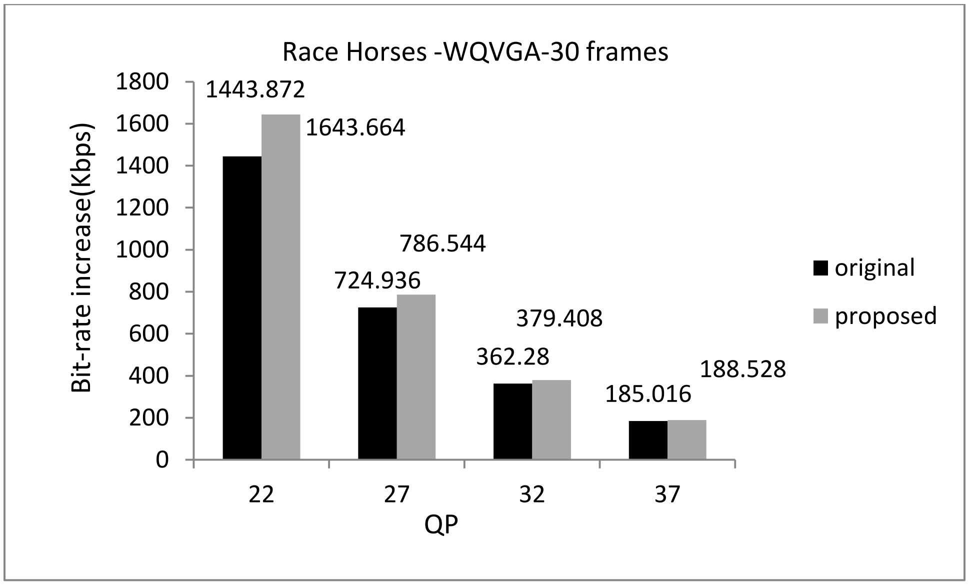


Figure 4.7 Bit-rate versus QP for Race Horses (416x240)

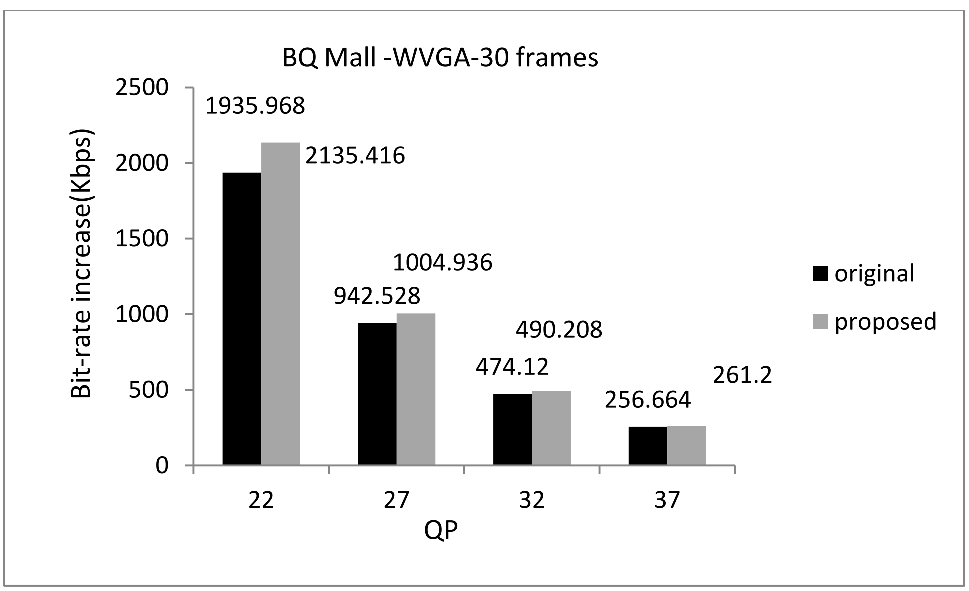


Figure 4.8 Bit-rate versus QP for BQ Mall (832x480)

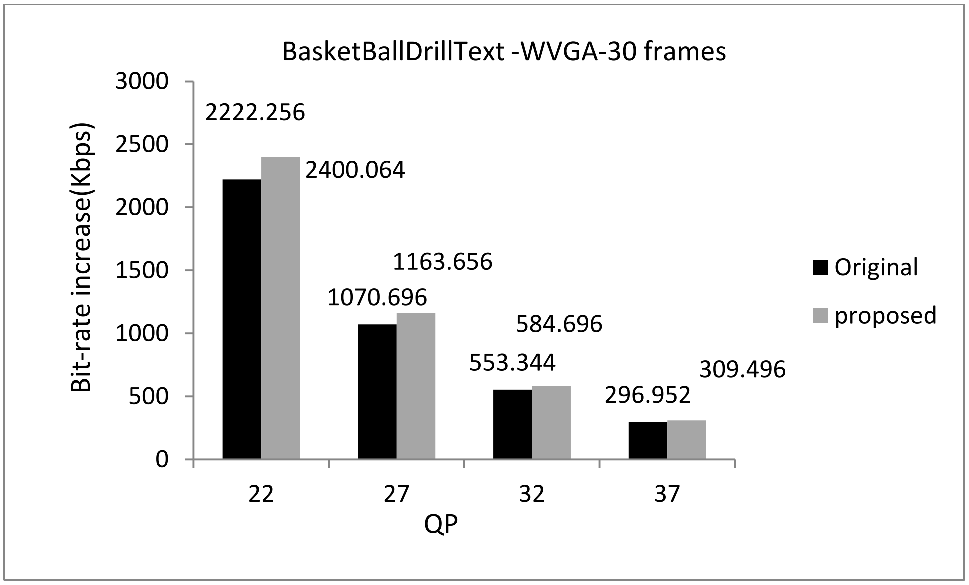


Figure 4.9 Bit-rate versus QP for BasketBallDrillText (832x480)

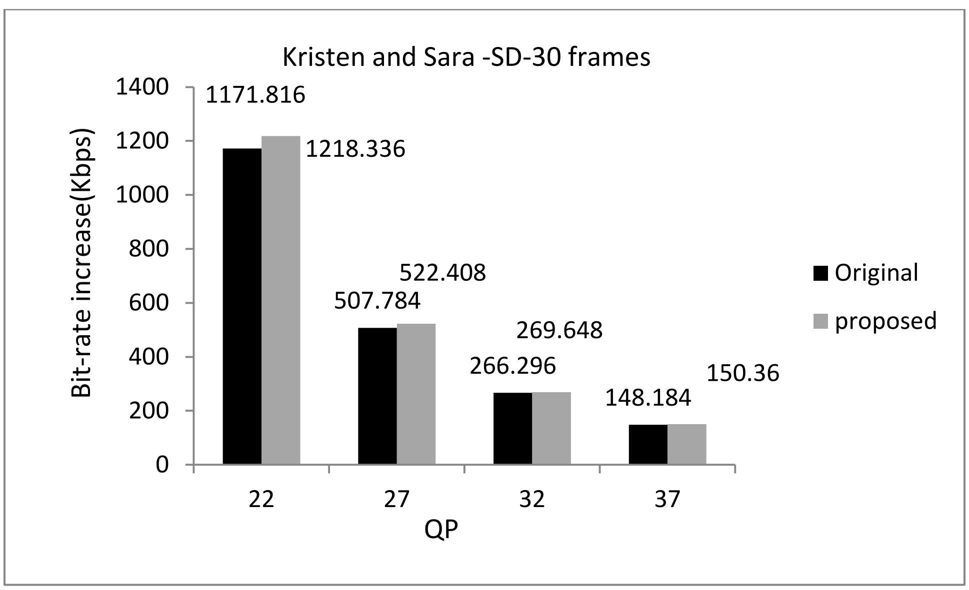


Figure 4.10 Bit-rate versus QP for Kristen and Sara (1280x720)

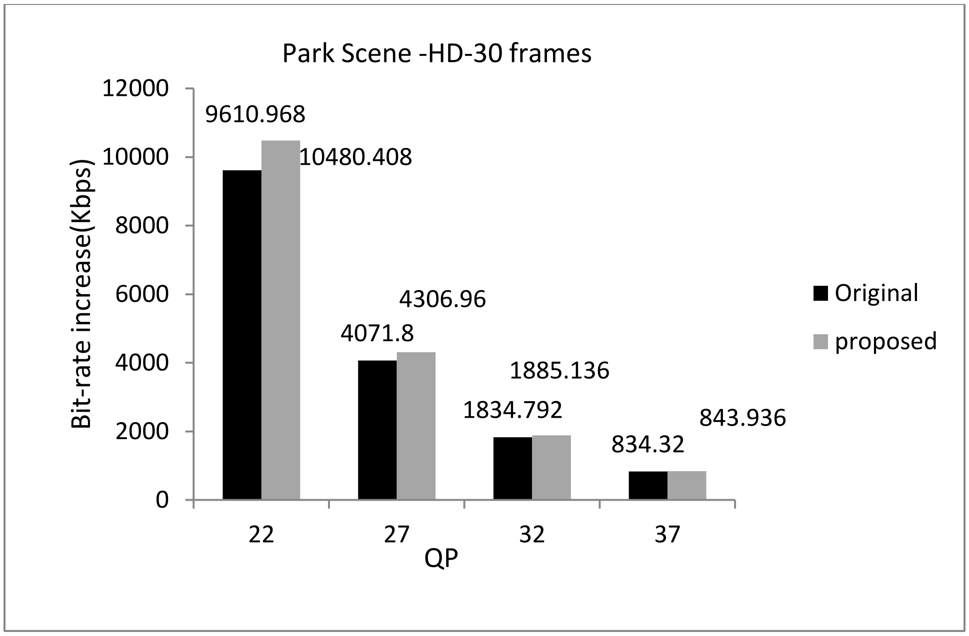


Figure 4.11 Bit-rate versus QP for Kristen and Sara (1920x1080)

4.3 BD-PSNR and BD-Bitrate

Bjøntegaard Delta PSNR (BD-PSNR) was proposed to objectively evaluate the coding efficiency of video codecs [39]. BD-PSNR is able to provide a good evaluation of the R-D performance based on the Rate-Distortion(R-D) curve fitting but with one critical drawback [39]. It does not consider the complexity of the coding while evaluating, yet it indicates the quality of the video [38][40]. It suggests that to improve the video codec, the BD-PSNR value should increase and the BD-Bitrate should decrease. The following figures are a plot of BD-PSNR and BD-Bitrate versus the quantization parameters for the test sequences.

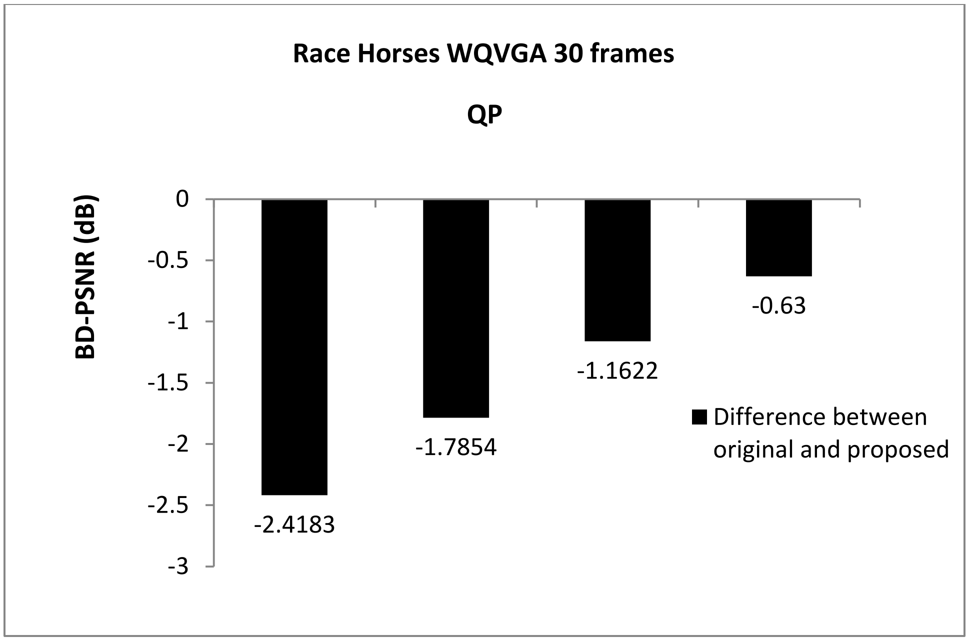


Figure 4.12 BD-PSNR versus QP for Race Horses (416x240)

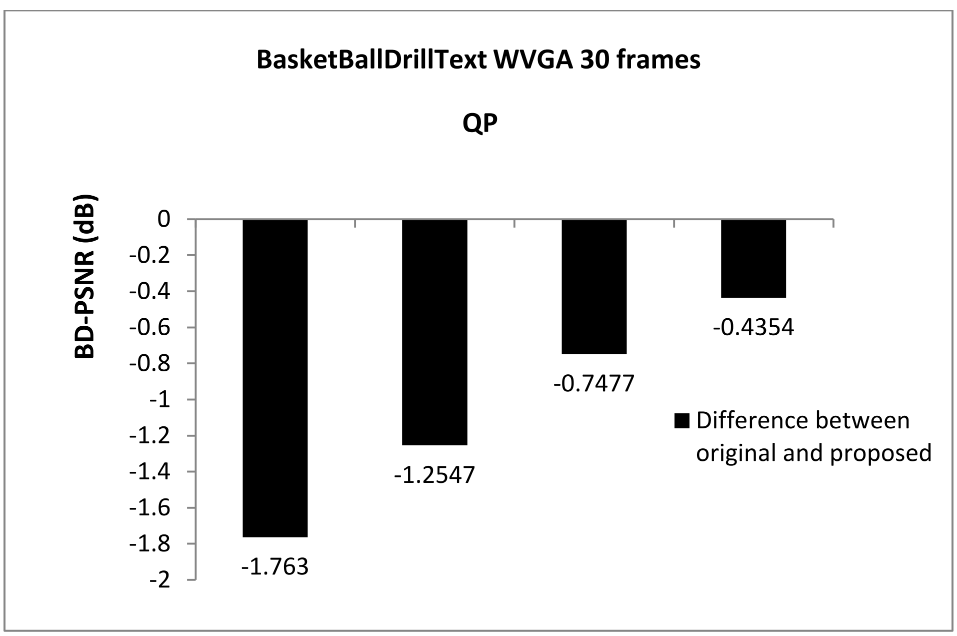


Figure 4.13 BD-PSNR versus QP for BasketBallDrillText (832x480)

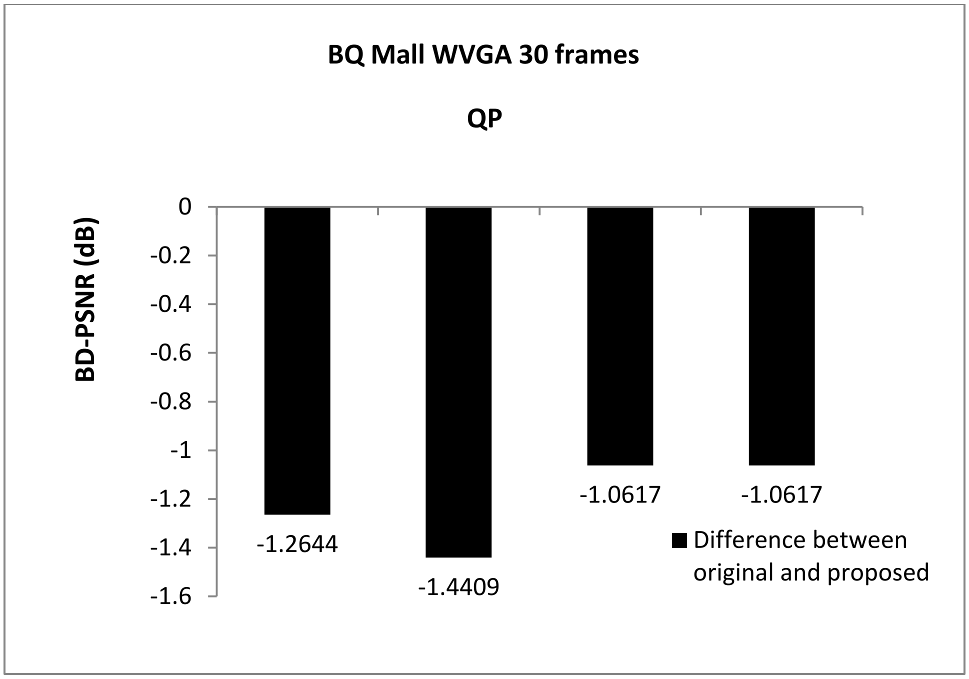


Figure 4.14 BD-PSNR versus QP for BQ Mall (832x480)

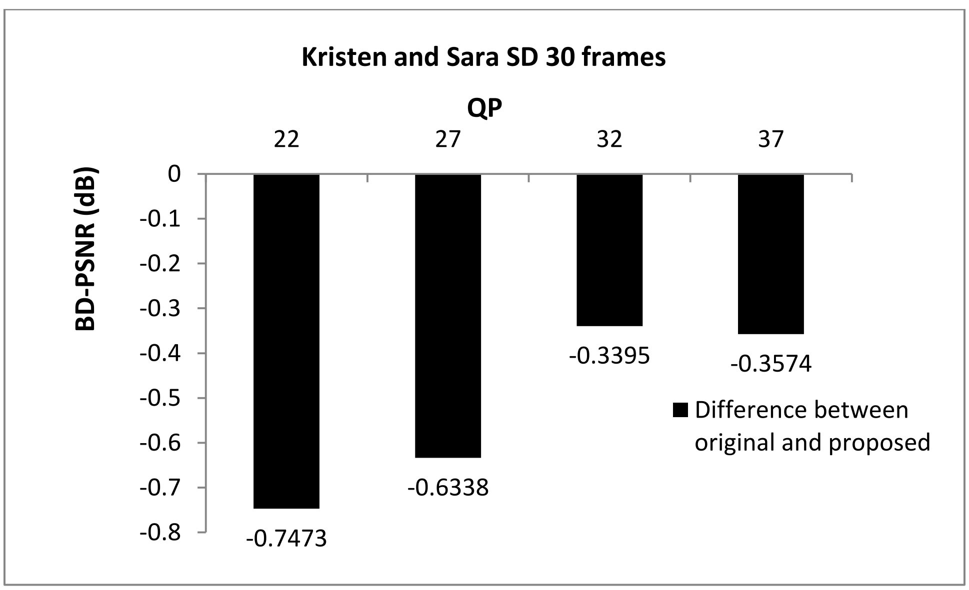


Figure 4.15 BD-PSNR versus QP for Kristen and Sara (1280x720)

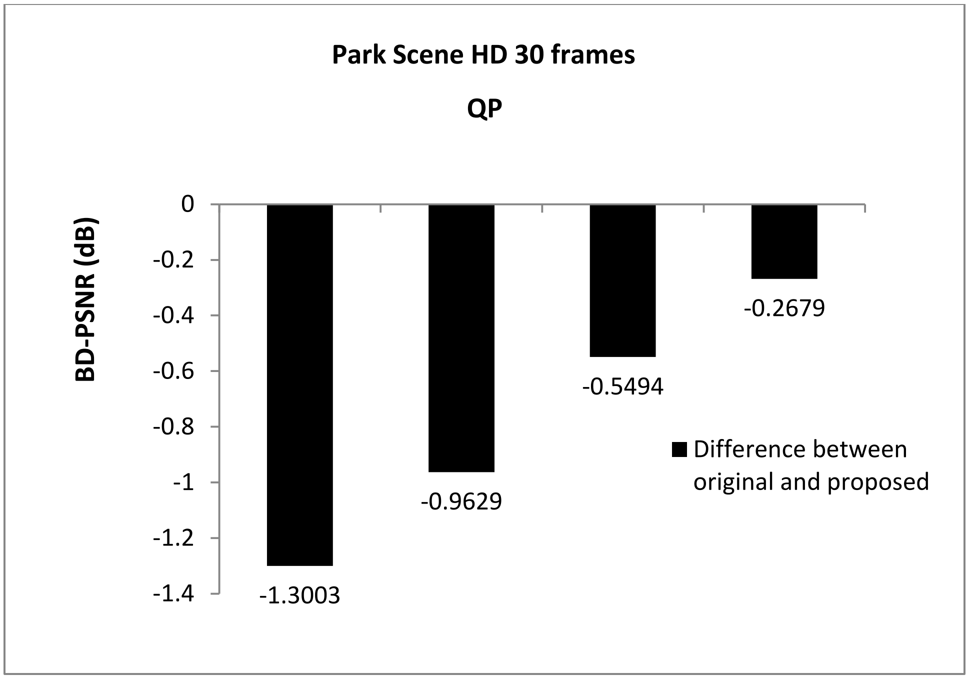


Figure 4.16 BD-PSNR versus QP for Park scene (1920x1080)

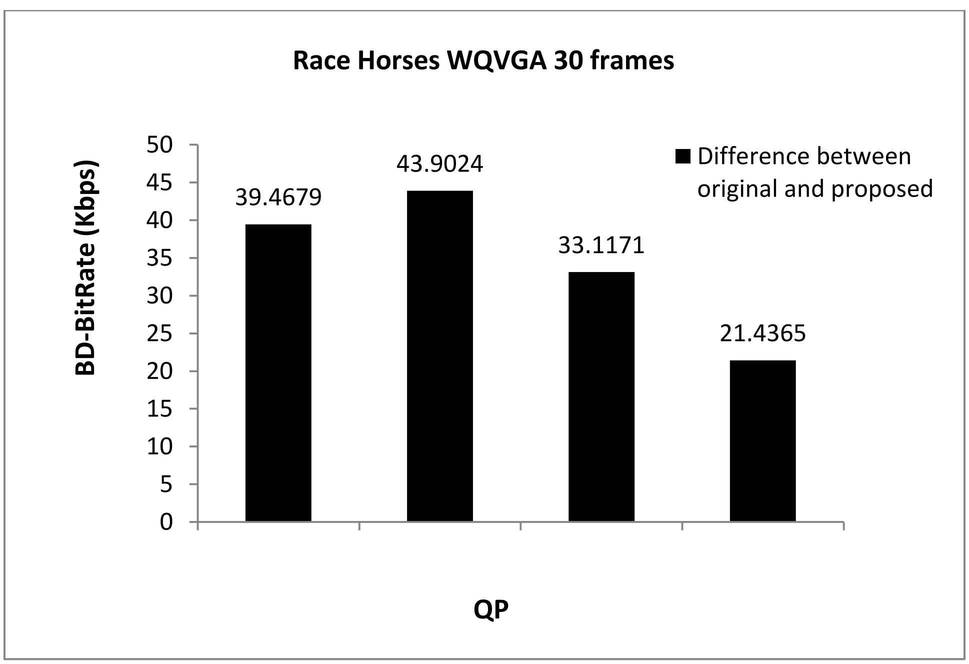


Figure 4.17 BD-Bitrate versus QP for Race Horses (416x240)

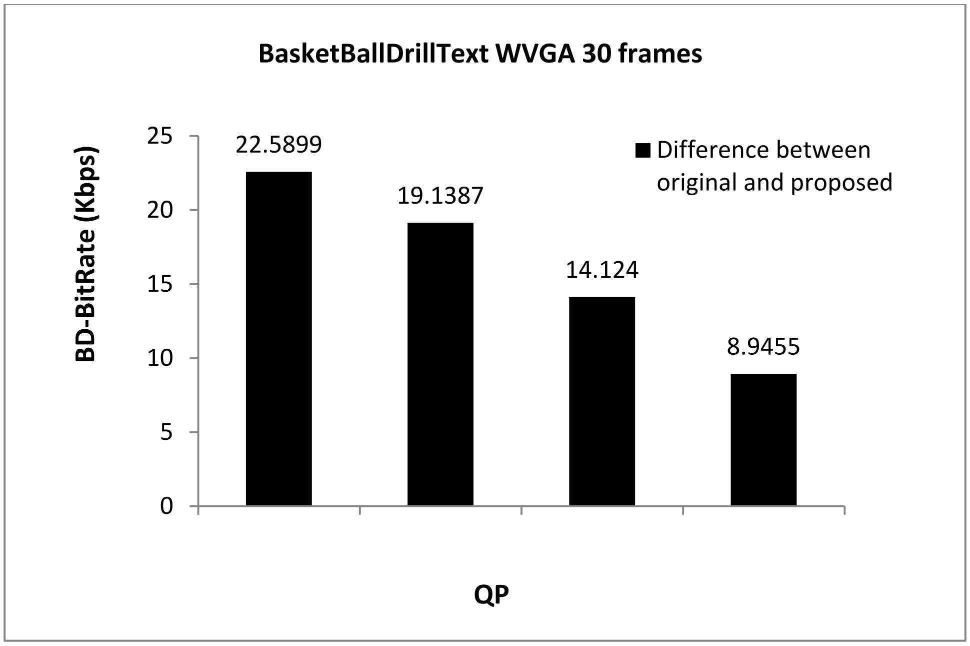


Figure 4.18 BD-Bitrate versus QP for BasketBallDrillText (832x480)

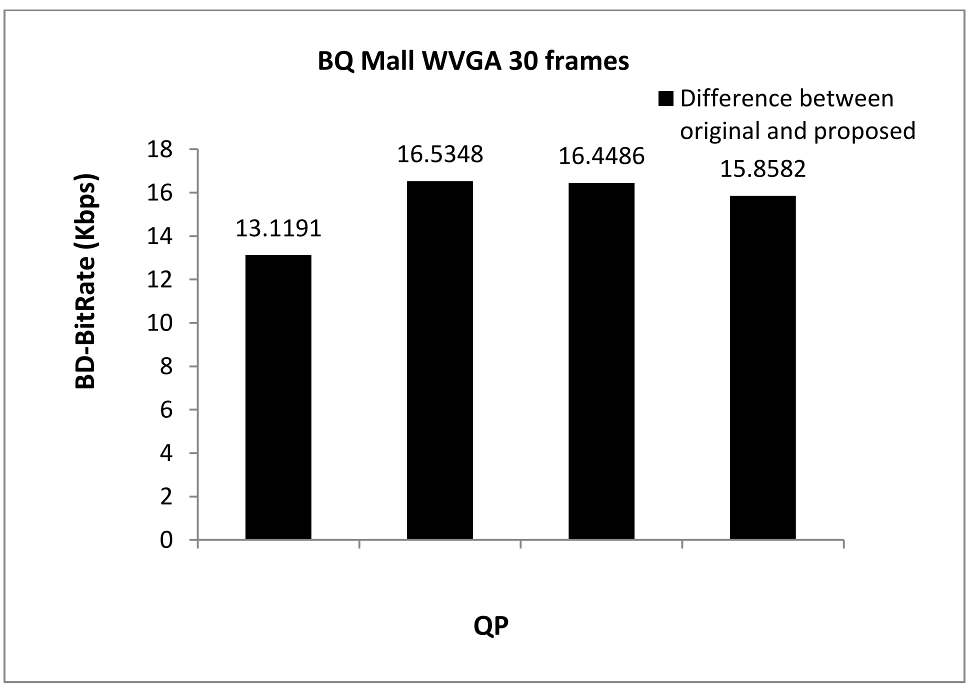


Figure 4.19 BD-Bitrate versus QP for sequence BQ Mall (832x480)

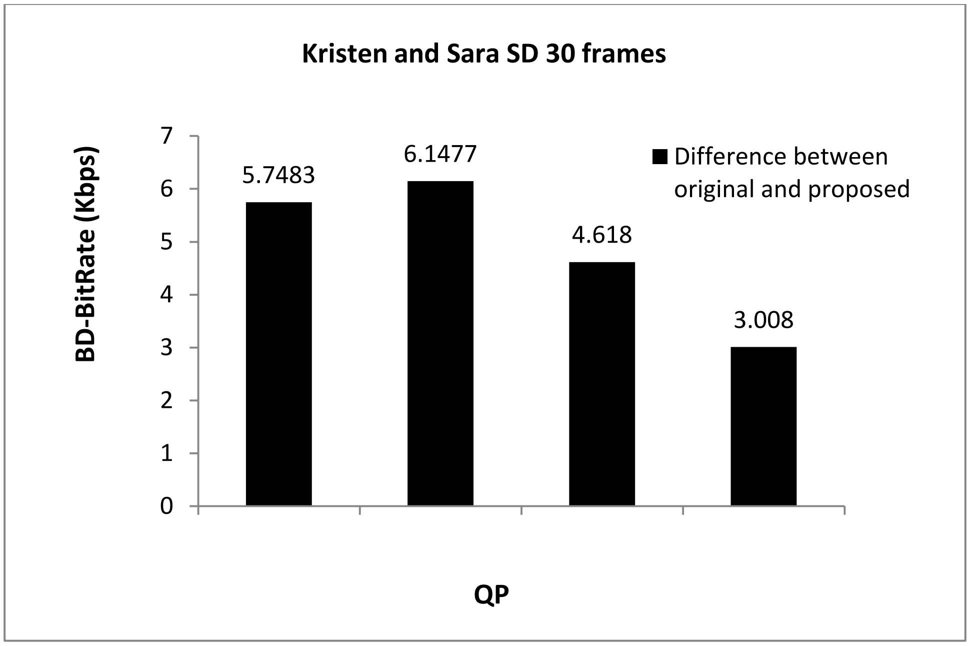


Figure 4.20 BD-Bitrate versus QP for Kristen and Sara (1280x720)

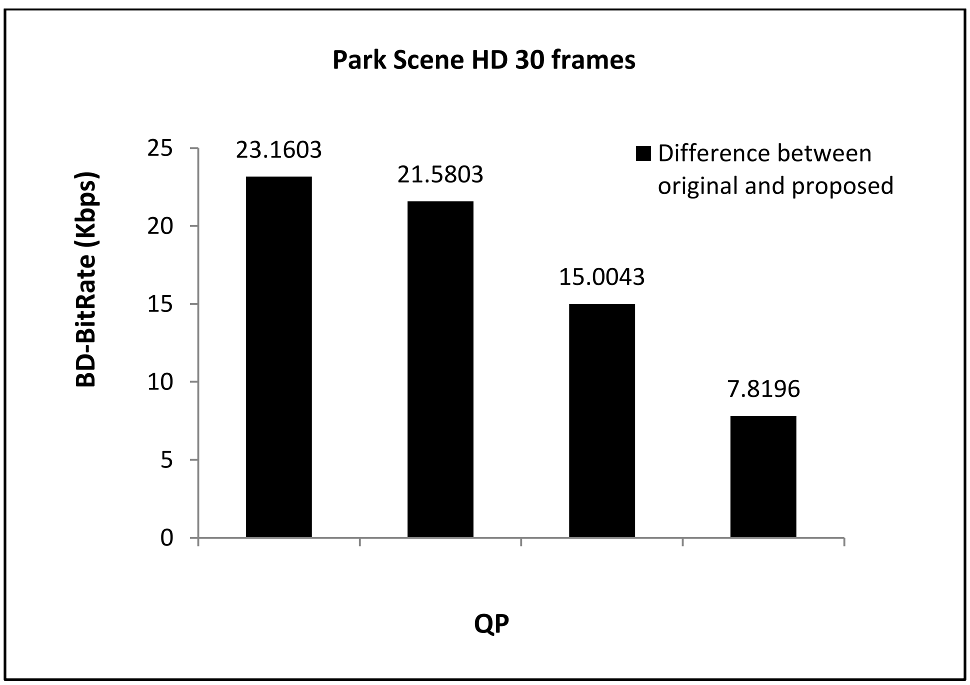


Figure 4.21 BD-Bitrate versus QP for Park Scene (1920x1080)

4.4 Rate Distortion Plot

The proposed algorithm has a negligible reduction in PSNR with a slight increase in the bit-rate for low resolution sequences. Figures 4.16 through 4.20 show the graphs of the PSNR vs bitrate for the test sequences.

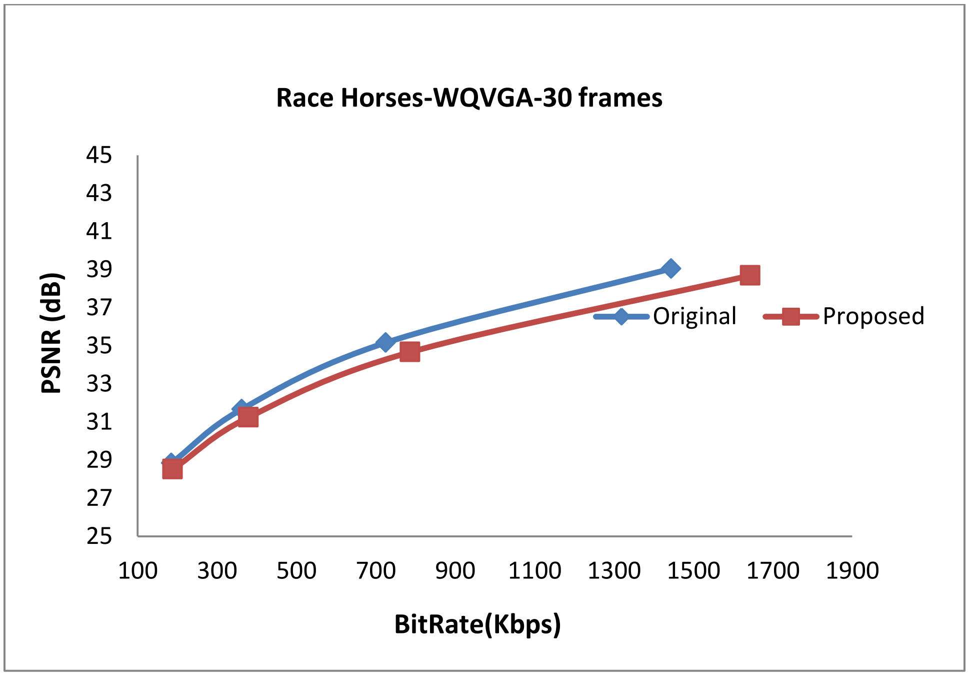


Figure 4.22 PSNR versus Bitrate for sequence Race Horses (416x240)

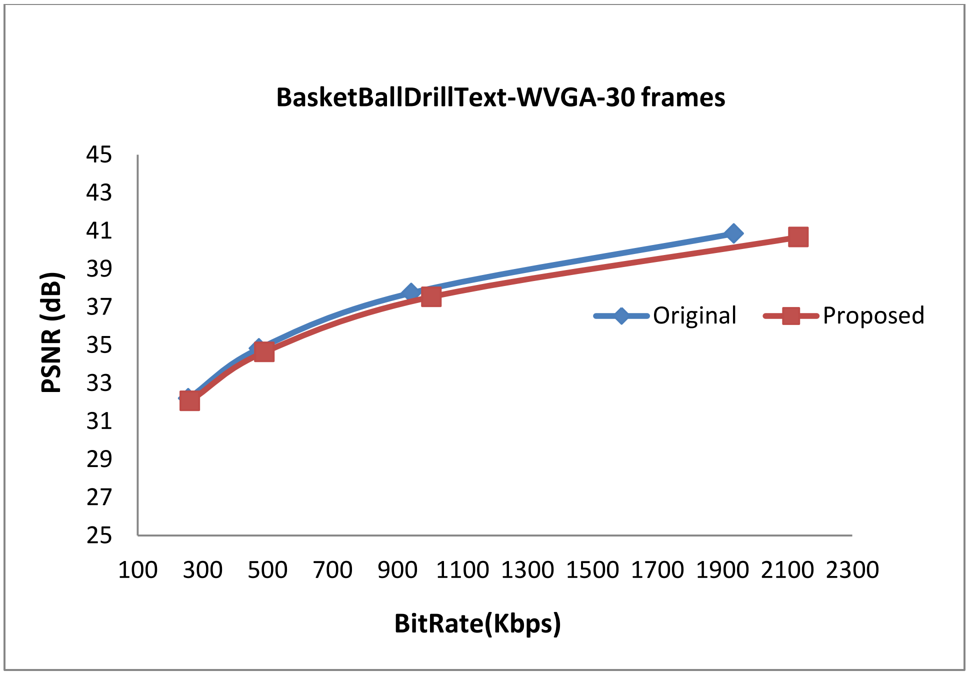


Figure 4.23 PSNR versus Bitrate for sequence BasketBallDrillText (832x480)

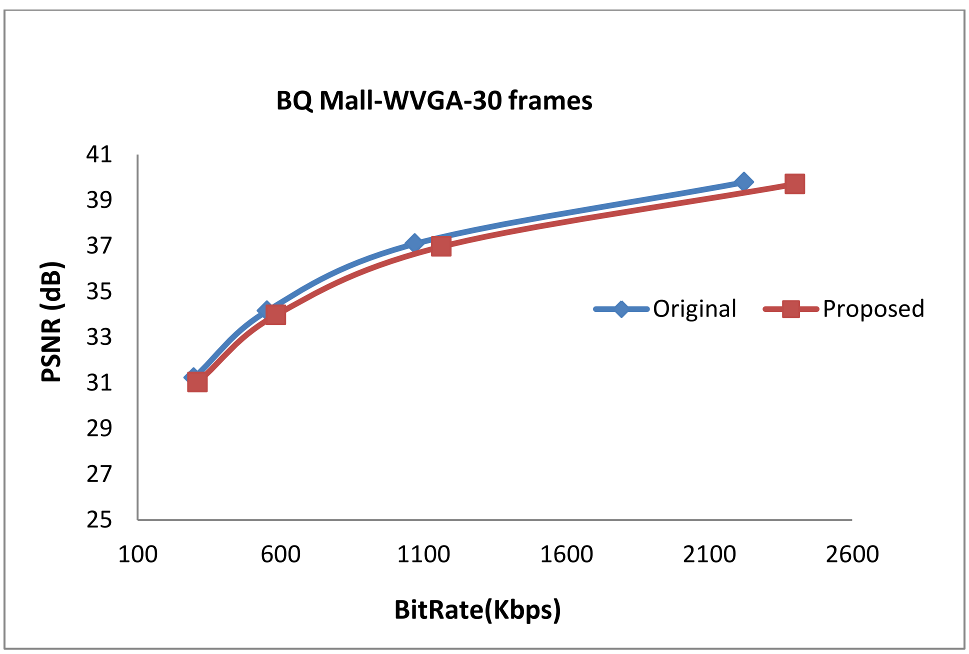


Figure 4.24 PSNR versus Bitrate for sequence BQ Mall (832x480)

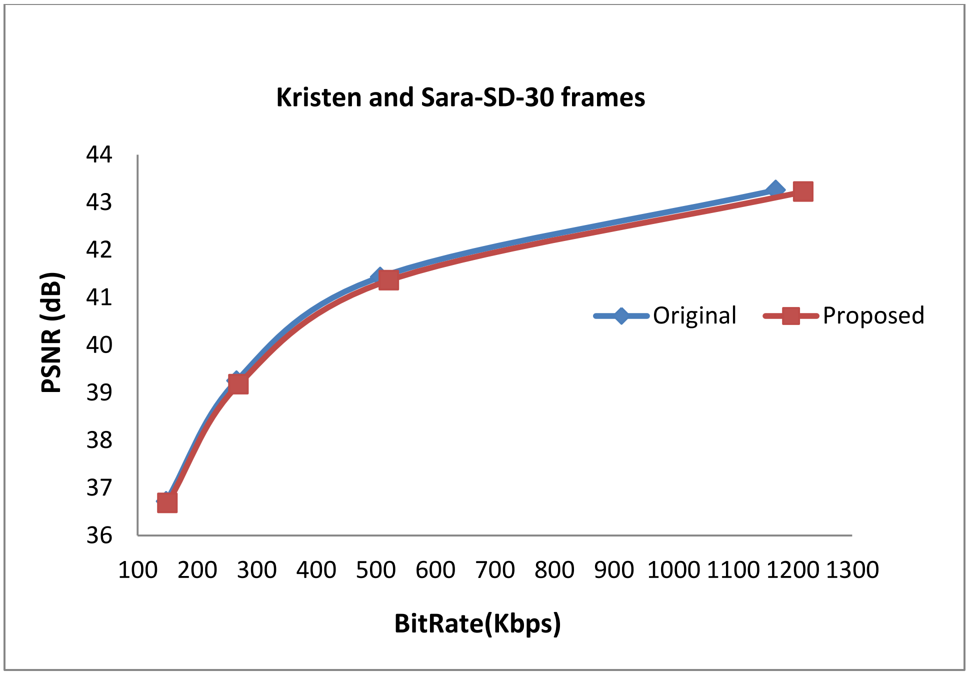


Figure 4.25 PSNR versus Bitrate for sequence Kristen and Sara (1280x720)

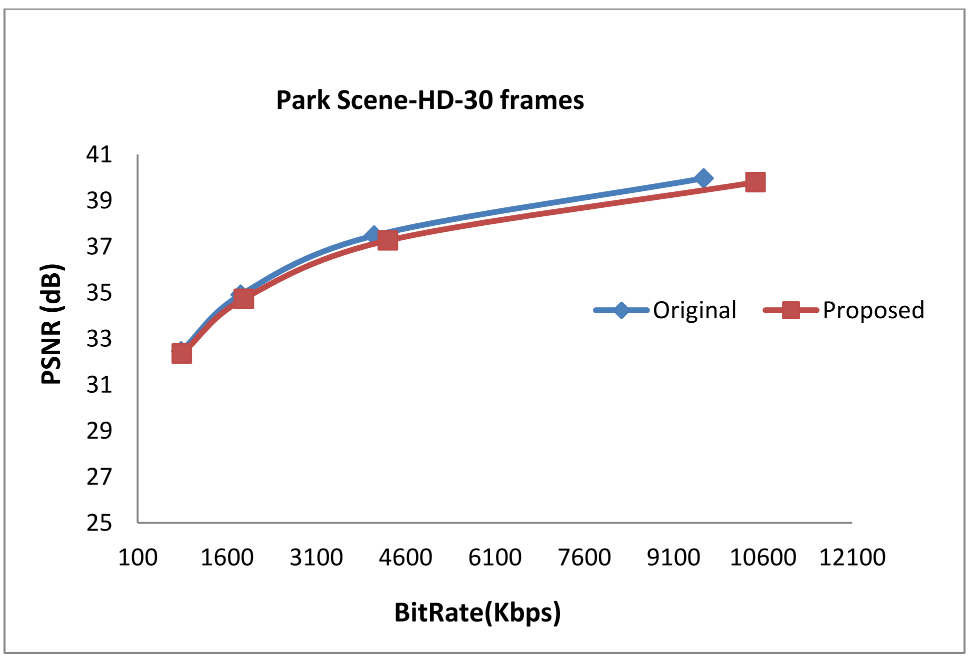


Figure 4.26 PSNR versus Bitrate for sequence Park Scene (1920x1080)

4.5 Summary

In this chapter, results and graphs for different test sequences and quantization parameters have been plotted which compare the original HEVC algorithm to the one proposed. Different factors like BD-PSNR, BD-bit-rate and encoding time have been considered while getting the results. Chapter 5 gives the conclusions and describes the topics that can be explored in the future.

Chapter 5

Conclusions and Future work

5.1 Conclusions

An early termination of the search algorithm is proposed to reduce the total time taken by the motion estimation process in the HEVC encoder. The search algorithm which is used to calculate motion vectors takes most of the time. Any reduction of time in this process, results in reduction of the overall encoding time. The proposed method uses the predicted motion vectors to calculate a threshold and terminate the search process if the SAD value falls below this threshold. Comparison of the proposed algorithm with the existing algorithm shows that the encoding time has been reduced by 5% to 17% with a negligible PSNR loss of less than 1 dB. The results also show an increase in the bitrate by 1% to 13%, however it increases by 13% only for 1 case out of 20 (5 test sequences x 4 quantization parameters). Otherwise, the bit-rate increase is typically in the range of 2% to 7%. The BD-PSNR decreased only by 0.3 dB to 2.4 dB and BD-Bitrate increased only by 7 to 43 Kbps.

5.2 Future work

The proposed early termination algorithm can be used with different search patterns such as hexagon or octagon patterns [41] or adaptive patterns. The HEVC standard also supports parallel processing which if used can result in a lot of reduction of the time taken. There are many blocks in the HEVC standard (fig.2.1) which can be parallelized like getting motion information of different PUs, CUs or search points. The use of GPUs can considerably increase the processing speed and reduce the encoding time due to the availability of a greater number of threads. GPU implementation can be done using

CUDA [7][8] or OpenGL. However, the dependency needs to be considered while using the parallel processing technique.

Complexity can also be reduced using hardware implementations at various encoder levels and optimizing parallel processing features. It can be implemented in a FPGA for evaluation purposes and the performance can be compared with the existing one.

Appendix A

Test Sequences [40]

A1. Race Horses

A2. BQ Mall

A3. BasketBallDrillText

A4. Kristen and Sara

A.5 Park Scene

Appendix B

Test Conditions

The code revision used for this work is HM 13 [38].The work was done using intel core i-7 processor with Microsoft windows 7 64 bit version running with 8GB RAM and 2.2 GHz speed.

Appendix C

BD-PSNR and BD-Bitrate [52][53]

Introduction

VCEG-L38 defines "Recommended Simulation Conditions for H.26L". One of the outcomes is supposed to be RD-plots where PSNR and bitrate differences between two simulation conditions may be read. The present document describes a method for calculating the average difference between two such curves. The basic elements are:

Fit a curve through 4 data points (PSNR/bitrate are assumed to be obtained for QP = 16,20,24,28)

Based on this, find an expression for the integral of the curve

The average difference is the difference between the integrals divided by the integration interval

IPR

“The contributor(s) are not aware of any issued, pending, or planned patents associated with the technical content of this proposal.”

Fitting a curve

A good interpolation curve through 4 data points of a "normal" RD-curve (see figure 1) can be obtained by:

SNR = (a + b*bit + c*bit^2)/(bit + d)

where a,b,c,d are determined such that the curve passes through all 4 data points.

This type of curve is well suited to make interpolation in "normal" luma curves. However, the division may cause problems. For certain data (Jani pointed out some typical chroma data) the obtained function may have a singular point in the range of integration - and it fails.

Use of logarithmic scale of bitrate

When we look at figure 1, the difference between the curves is dominated by the high bitrates.

The range (1500-2000) gets 4 times the weight of the range (375-500) even if they both represent a bitrate variation of 33%

Hence it was considered to be more appropriate to do the integration based on logarithmic scale of bitrate. Figure 2 shows a plot where "Logarithmic x-axes" is used in the graph function of Excel. However, this function has no flexibility and only allows factors of 10 as units.

In figure 3 I first took the logarithm of bitrates and the plot has units of "dB" along both axes. The factor between two vertical gridlines in the plot is: $10^{0.05} = 1.122$ (or 12.2%). Could this be an alternative way of presenting RD-plots?

Interpolation with logarithmic bitrate scale

With logarithmic bitrate scale the interpolation can also be made more straight forward with a third order polynomial of the form:

$SNR = a + b*bit + c*bit^2 + d*bit^3$

This result in good fit and there is no problems with singular points. This is therefore the function I have used for the calculations in VCEG-M34. *However, for integration of luma curves the results are practically the same as with the first integration method which was used for the software distributed by Michael regarding the complexity experiment.*

In the same way we can do the interpolation to find Bit as a function of SNR:

$SNR = a + b*SNR + c*SNR^2 + d*SNR^3$

In this way we can find both:

Average PSNR difference in dB over the whole range of bitrates

Average bitrate difference in % over the whole range of PSNR

On request from Michael average differences are found over the whole simulation range (see integration limits in figure 3) as well as in the middle section - called mid range.

As a result VCEG-M34 shows 4 separate data tables.

Conclusions

It is proposed to include this method of finding numerical averages between RD-curves as part of the presentation of results. This is a more compact and in some sense more accurate way to present the data and comes in addition to the RD-plots.

The distinction between "total range" and "mid range" does not seem to add much and it is therefore proposed to use "total range" only.

From the data it is seen that relation between ∆SNR and ∆bitrate is well represented by **0.5 dB = 10%** or **0.05 dB = 1%** It is therefore proposed to calculate either change in bitrate or change in PSNR.

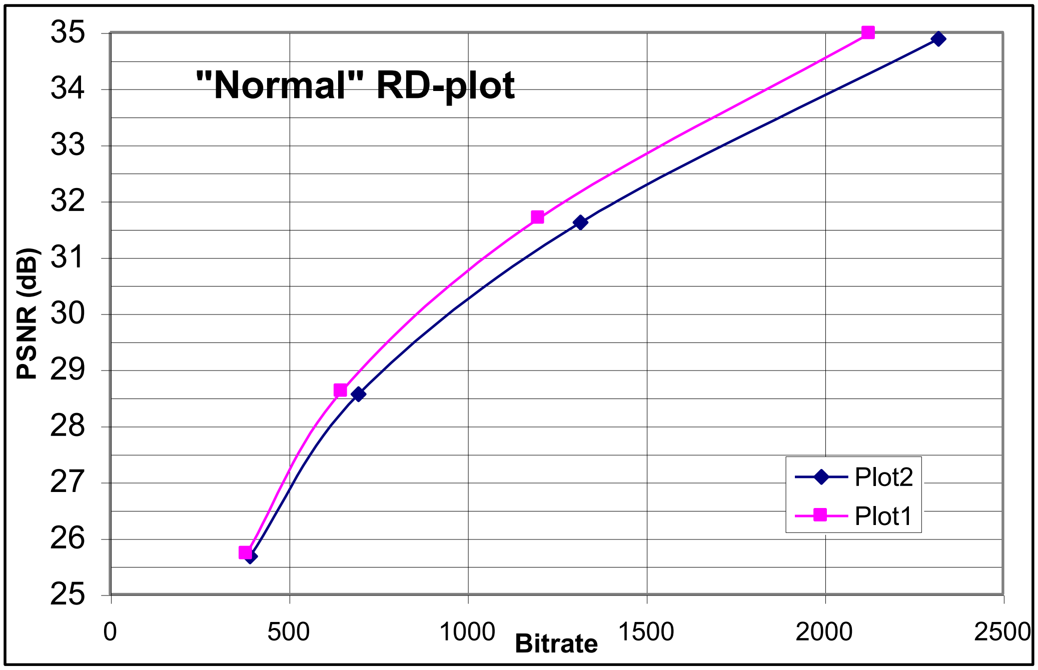

"Normal" RD-plot
PSNR (dB)
35
34
33
32
31
30
29
28
27
26
25
0
500
1000
1500
2000
2500
Bitrate
Plot2
Plot1

Figure 1

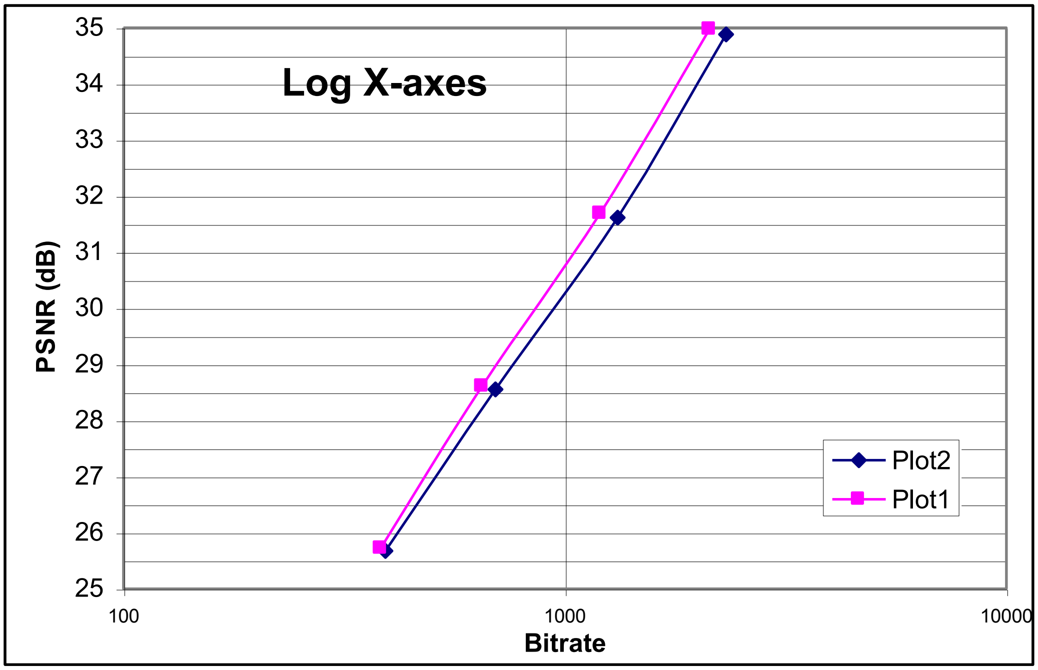

Log X-axes
PSNR (dB)
35
34
33
32
31
30
29
28
27
26
25
100
1000
10000
Bitrate
Plot2
Plot1

Figure 2

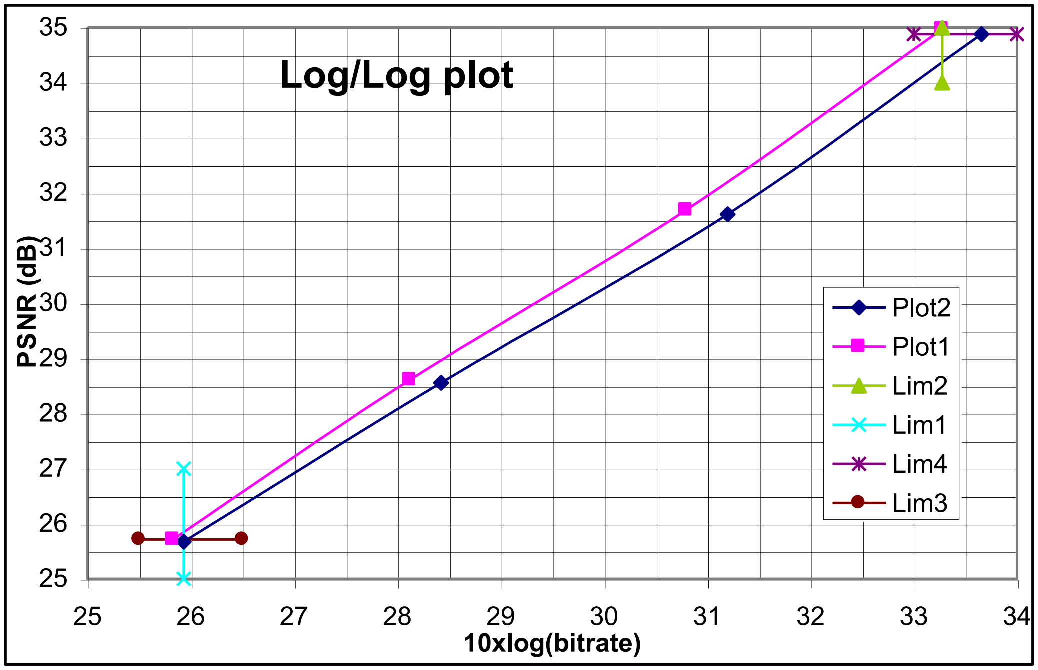


Figure 3

Here is a document about BD-PSNR which has been referenced by many Video Engineers. You can download it at http://wftp3.itu.int/av-arch/video-site/

The matlab code for computing BD-Bitrate and BD-PSNR is found in this link: http://www.mathworks.com/matlabcentral/fileexchange/27798-bjontegaardmetric/content/bjontegaard.m

```
function avg_diff = bjontegaard(R1,PSNR1,R2,PSNR2,mode)

%BJONTEGAARD    Bjontegaard metric calculation
%   Bjontegaard's metric allows to compute the average gain in PSNR or the
%   average per cent saving in bitrate between two rate-distortion
%   curves [1].
%   Differently from the avsnr software package or VCEG Excel [2] plugin this
%   tool enables Bjontegaard's metric computation also with more than 4 RD
%   points.
%
%   R1,PSNR1 - RD points for curve 1
```

```
%   R2,PSNR2 - RD points for curve 2
%   mode -
%       'dsnr' - average PSNR difference
%       'rate' - percentage of bitrate saving between data set 1 and
%               data set 2
%
%   avg_diff - the calculated Bjontegaard metric ('dsnr' or 'rate')
%
%   (c) 2010 Giuseppe Valenzise
%
%   References:
%
%   [1] G. Bjontegaard, Calculation of average PSNR differences between
%       RD-curves (VCEG-M33)
%   [2] S. Pateux, J. Jung, An excel add-in for computing Bjontegaard metric and
%       its evolution

% convert rates in logarithmic units
lR1 = log(R1);
lR2 = log(R2);

switch lower(mode)
    case 'dsnr'
        % PSNR method
        p1 = polyfit(lR1,PSNR1,3);
        p2 = polyfit(lR2,PSNR2,3);

        % integration interval
        min_int = min([lR1; lR2]);
        max_int = max([lR1; lR2]);

        % find integral
        p_int1 = polyint(p1);
        p_int2 = polyint(p2);

        int1 = polyval(p_int1, max_int) - polyval(p_int1, min_int);
        int2 = polyval(p_int2, max_int) - polyval(p_int2, min_int);

        % find avg diff
        avg_diff = (int2-int1)/(max_int-min_int);

    case 'rate'
        % rate method
        p1 = polyfit(PSNR1,lR1,3);
        p2 = polyfit(PSNR2,lR2,3);

        % integration interval
        min_int = min([PSNR1; PSNR2]);
        max_int = max([PSNR1; PSNR2]);
```

```
    % find integral
    p_int1 = polyint(p1);
    p_int2 = polyint(p2);

    int1 = polyval(p_int1, max_int) - polyval(p_int1, min_int);
    int2 = polyval(p_int2, max_int) - polyval(p_int2, min_int);

    % find avg diff
    avg_exp_diff = (int2-int1)/(max_int-min_int);
    avg_diff = (exp(avg_exp_diff)-1)*100;
end
```

Appendix D

Acronyms

AVC - Advanced Video Coding

AMVP – Advanced Motion Vector Prediction

BBME- Block Based Motion estimation

BD - Bjontegaard Delta

BDM-

CABAC – Context Adaptive Binary Arithmetic Coding

CB – Coding Block

CBF – Coding Block Flag

CFM – CBF Fast Mode

CTU – Coding Tree Unit

CTB – Coding Tree Block

CU – Coding Unit

CUDA- Compute unified device architecture

DCT – Discrete Cosine Transform

DST – Discrete Sine Transform

GOP-Group of pictures

FPGA- Field programmable gate arrays

HDTV - High Definition Tele Vision

HDR - High Dynamic Range

HDRI - High Dynamic Range Imaging

HEVC – High Efficiency Video Coding

HM – HEVC Test Model

HVS – Human Visual System

ISO – International Standards Organization

ITU – International Telecommunication Union

JCT-VC - Joint Collaborative Team on Video Coding

JVT- Joint video team

KTA- Key technical areas

MB – Macroblock

MC – Motion Compensation14

ME – Motion Estimation

MPEG – Moving Picture Experts Group

NAL – Network Abstraction Layer

PB – Prediction Block

POC-Picture order count

PSNR – Peak Signal to Noise Ratio

PU – Prediction Unit

QP – Quantization Parameter

RDOQ – Rate Distortion Optimization Quantization

RGB – Red Green Blue

RMD – Rough Mode Decision

SAD-Sum of absolute differences

SATD – Sum of Absolute Transform Differences

SD – Standard Definition

SSIM – Structural Similarity

TB – Transform Block

TU – Transform Unit

URQ – Uniform Reconstruction Quantization

VCEG – Video Coding Experts Group

VPS – Video Parameter Set

WQVGA – Wide Quarter Video Graphics Array

WVGA – Wide Video Graphics Array

Appendix E

Code for the proposed algorithm

The following section of the HEVC code has been modified to implement the proposed algorithm

```
__inline Void TEncSearch::xTZ8PointDiamondSearch( TComPattern*
pcPatternKey, IntTZSearchStruct& rcStruct, TComMv* pcMvSrchRngLT, TComMv*
pcMvSrchRngRB, const Int iStartX, const Int iStartY, const Int iDist )
{
  Int   iSrchRngHorLeft   = pcMvSrchRngLT->getHor();
  Int   iSrchRngHorRight  = pcMvSrchRngRB->getHor();
  Int   iSrchRngVerTop    = pcMvSrchRngLT->getVer();
  Int   iSrchRngVerBottom = pcMvSrchRngRB->getVer();
  UInt cost=rcStruct.min_cost;
  // 8 point search,                   //   1 2 3
  // search around the start point     //   4 0 5
  // with the required  distance       //   6 7 8
  assert ( iDist != 0 );
  const Int iTop        = iStartY - iDist;
  const Int iBottom     = iStartY + iDist;
  const Int iLeft       = iStartX - iDist;
  const Int iRight      = iStartX + iDist;
  rcStruct.uiBestRound += 1;
  UInt c=rcStruct.uiBestSad;
  if ( iDist == 1 ) // iDist == 1
  {
        //if (c > cost)
        //{
    if ( iTop >= iSrchRngVerTop && c > cost) // check top
    {
      xTZSearchHelp( pcPatternKey, rcStruct, iStartX, iTop, 2, iDist );
    }
      //if(c < cost)
             //goto label;
      if ( iLeft >= iSrchRngHorLeft && c > cost ) // check middle left
    {
      xTZSearchHelp( pcPatternKey, rcStruct, iLeft, iStartY, 4, iDist );
    }
      //if(rcStruct.uiBestSad < rcStruct.min_cost)
      //     goto label;
    if ( iRight <= iSrchRngHorRight  && c > cost ) // check middle right
    {
      xTZSearchHelp( pcPatternKey, rcStruct, iRight, iStartY, 5, iDist );
    }
      //if(rcStruct.uiBestSad < rcStruct.min_cost)
      //     goto label;
      if ( iBottom <= iSrchRngVerBottom  && c > cost) // check bottom
    {
      xTZSearchHelp( pcPatternKey, rcStruct, iStartX, iBottom, 7, iDist );
    }
        //}
  }
//label:
  else
```

```
  //if (iDist != 1)
  {
    if ( iDist <= 8 )
    {


      const Int iTop_2      = iStartY - (iDist>>1);
      const Int iBottom_2   = iStartY + (iDist>>1);
      const Int iLeft_2     = iStartX - (iDist>>1);
      const Int iRight_2    = iStartX + (iDist>>1);

      if (  iTop >= iSrchRngVerTop && iLeft >= iSrchRngHorLeft &&
          iRight <= iSrchRngHorRight && iBottom <= iSrchRngVerBottom && c >
cost) // check border
      {
        xTZSearchHelp( pcPatternKey, rcStruct, iStartX,  iTop,      2,
iDist    );
        xTZSearchHelp( pcPatternKey, rcStruct, iLeft_2,  iTop_2,    1,
iDist>>1 );
        xTZSearchHelp( pcPatternKey, rcStruct, iRight_2, iTop_2,    3,
iDist>>1 );
        xTZSearchHelp( pcPatternKey, rcStruct, iLeft,    iStartY,   4,
iDist    );
        xTZSearchHelp( pcPatternKey, rcStruct, iRight,   iStartY,   5,
iDist    );
        xTZSearchHelp( pcPatternKey, rcStruct, iLeft_2,  iBottom_2, 6,
iDist>>1 );
        xTZSearchHelp( pcPatternKey, rcStruct, iRight_2, iBottom_2, 8,
iDist>>1 );
        xTZSearchHelp( pcPatternKey, rcStruct, iStartX,  iBottom,   7,
iDist    );
      }
      else // check border
      {


                //if(rcStruct.uiBestSad < rcStruct.min_cost)
              //goto label1;
                if ( iTop >= iSrchRngVerTop  && c > cost) // check top
        {
          xTZSearchHelp( pcPatternKey, rcStruct, iStartX, iTop, 2, iDist );
        }
                //if(c < cost)
              //goto label1;
        if ( iTop_2 >= iSrchRngVerTop && c > cost) // check half top
        {
                      if ( iLeft_2 >= iSrchRngHorLeft ) // check half left
          {
            xTZSearchHelp( pcPatternKey, rcStruct, iLeft_2, iTop_2, 1,
(iDist>>1) );
          }
```

```
                    // if(rcStruct.uiBestSad < rcStruct.min_cost)
              //goto label1;
                    if ( iRight_2 <= iSrchRngHorRight && c > cost) // check
half right
          {
            xTZSearchHelp( pcPatternKey, rcStruct, iRight_2, iTop_2, 3,
(iDist>>1) );
          }
        } // check half top
               //if(rcStruct.uiBestSad < rcStruct.min_cost)
              //goto label1;
              if ( iLeft >= iSrchRngHorLeft  && c > cost) // check left
        {
          xTZSearchHelp( pcPatternKey, rcStruct, iLeft, iStartY, 4, iDist
);
        }
               //if(rcStruct.uiBestSad < rcStruct.min_cost)
              //goto label1;
              if ( iRight <= iSrchRngHorRight && c > cost) // check right
        {
          xTZSearchHelp( pcPatternKey, rcStruct, iRight, iStartY, 5, iDist
);
        }
               //if(rcStruct.uiBestSad < rcStruct.min_cost)
              //goto label1;
              if ( iBottom_2 <= iSrchRngVerBottom && c > cost) // check half
bottom
        {
                    if ( iLeft_2 >= iSrchRngHorLeft ) // check half left
          {
            xTZSearchHelp( pcPatternKey, rcStruct, iLeft_2, iBottom_2, 6,
(iDist>>1) );
          }
                    // if(rcStruct.uiBestSad < rcStruct.min_cost)
              //goto label1;
                    if ( iRight_2 <= iSrchRngHorRight && c > cost)// check
half right
          {
            xTZSearchHelp( pcPatternKey, rcStruct, iRight_2, iBottom_2, 8,
(iDist>>1) );
          }
        } // check half bottom
               //if(rcStruct.uiBestSad < rcStruct.min_cost)
              //goto label1;
              if ( iBottom <= iSrchRngVerBottom && c > cost) // check bottom
        {
          xTZSearchHelp( pcPatternKey, rcStruct, iStartX, iBottom, 7, iDist
);
        }

         } // check border
```

```
    }
       //label1:
    else // iDist > 8
    //if(iDist>8)
       {
      if ( iTop >= iSrchRngVerTop && iLeft >= iSrchRngHorLeft &&
          iRight <= iSrchRngHorRight && iBottom <= iSrchRngVerBottom && c >
cost) // check border
      {
        xTZSearchHelp( pcPatternKey, rcStruct, iStartX, iTop,    0, iDist
);
        xTZSearchHelp( pcPatternKey, rcStruct, iLeft,   iStartY, 0, iDist
);
        xTZSearchHelp( pcPatternKey, rcStruct, iRight,  iStartY, 0, iDist
);
        xTZSearchHelp( pcPatternKey, rcStruct, iStartX, iBottom, 0, iDist
);
        for ( Int index = 1; index < 4; index++ )
        {
          Int iPosYT = iTop    + ((iDist>>2) * index);
          Int iPosYB = iBottom - ((iDist>>2) * index);
          Int iPosXL = iStartX - ((iDist>>2) * index);
          Int iPosXR = iStartX + ((iDist>>2) * index);
          xTZSearchHelp( pcPatternKey, rcStruct, iPosXL, iPosYT, 0, iDist
);
          xTZSearchHelp( pcPatternKey, rcStruct, iPosXR, iPosYT, 0, iDist
);
          xTZSearchHelp( pcPatternKey, rcStruct, iPosXL, iPosYB, 0, iDist
);
          xTZSearchHelp( pcPatternKey, rcStruct, iPosXR, iPosYB, 0, iDist
);
        }
      }
      else // check border
      {
        if ( iTop >= iSrchRngVerTop && c > cost) // check top
        {
          xTZSearchHelp( pcPatternKey, rcStruct, iStartX, iTop, 0, iDist );
        }
        if ( iLeft >= iSrchRngHorLeft && c > cost) // check left
        {
          xTZSearchHelp( pcPatternKey, rcStruct, iLeft, iStartY, 0, iDist
);
        }
        if ( iRight <= iSrchRngHorRight && c > cost) // check right
        {
          xTZSearchHelp( pcPatternKey, rcStruct, iRight, iStartY, 0, iDist
);
        }
        if ( iBottom <= iSrchRngVerBottom && c > cost) // check bottom
        {
```

```
          xTZSearchHelp( pcPatternKey, rcStruct, iStartX, iBottom, 0, iDist
);
        }
        for ( Int index = 1; index < 4; index++ )
        {
          Int iPosYT = iTop    + ((iDist>>2) * index);
          Int iPosYB = iBottom - ((iDist>>2) * index);
          Int iPosXL = iStartX - ((iDist>>2) * index);
          Int iPosXR = iStartX + ((iDist>>2) * index);

          if ( iPosYT >= iSrchRngVerTop && c > cost) // check top
          {
            if ( iPosXL >= iSrchRngHorLeft ) // check left
            {
              xTZSearchHelp( pcPatternKey, rcStruct, iPosXL, iPosYT, 0,
iDist );
            }
            if ( iPosXR <= iSrchRngHorRight ) // check right
            {
              xTZSearchHelp( pcPatternKey, rcStruct, iPosXR, iPosYT, 0,
iDist );
            }
          } // check top
          if ( iPosYB <= iSrchRngVerBottom && c > cost) // check bottom
          {
            if ( iPosXL >= iSrchRngHorLeft ) // check left
            {
              xTZSearchHelp( pcPatternKey, rcStruct, iPosXL, iPosYB, 0,
iDist );
            }
            if ( iPosXR <= iSrchRngHorRight && c > cost) // check right
            {
              xTZSearchHelp( pcPatternKey, rcStruct, iPosXR, iPosYB, 0,
iDist );
            }
          } // check bottom
        } // for ...
      } // check border
    } // iDist <= 8
  } // iDist == 1
}


Void TEncSearch::xCheckBestMVP ( TComDataCU* pcCU, RefPicList eRefPicList,
TComMv cMv, TComMv& rcMvPred, Int& riMVPIdx, UInt& ruiBits, UInt& ruiCost )
{


  AMVPInfo* pcAMVPInfo = pcCU->getCUMvField(eRefPicList)->getAMVPInfo();

  assert(pcAMVPInfo->m_acMvCand[riMVPIdx] == rcMvPred);
```

```
  if (pcAMVPInfo->iN < 2) return;

  m_pcRdCost->getMotionCost( 1, 0 );
  m_pcRdCost->setCostScale ( 0    );

  Int iBestMVPIdx = riMVPIdx;

  m_pcRdCost->setPredictor( rcMvPred );
  Int iOrgMvBits  = m_pcRdCost->getBits(cMv.getHor(), cMv.getVer());
  iOrgMvBits += m_auiMVPIdxCost[riMVPIdx][AMVP_MAX_NUM_CANDS];
  //x+=m_auiMVPIdxCost[riMVPIdx][AMVP_MAX_NUM_CANDS];
  Int iBestMvBits = iOrgMvBits;

  for (Int iMVPIdx = 0; iMVPIdx < pcAMVPInfo->iN; iMVPIdx++)
  {
    if (iMVPIdx == riMVPIdx) continue;

    m_pcRdCost->setPredictor( pcAMVPInfo->m_acMvCand[iMVPIdx] );
       //x=AMVPInfo->m_acMvCand[iMVPIdx];
       Int iMvBits = m_pcRdCost->getBits(cMv.getHor(), cMv.getVer());
       //x=m_pcRdCost->getCost(1);
       //x=x<<4;
       //min_cost=m_pcRdCost->getCost(1);
       //min_cost=(min_cost/2);
       //Int iMvBits = m_pcRdCost->getBits(cMv.getHor(),
cMv.getVer())/AMVP_MAX_NUM_CANDS;
       //x=m_pcRdCost->getCost(cMv.getHor(), cMv.getVer());
    //iMvBits +=
m_auiMVPIdxCost[iMVPIdx][AMVP_MAX_NUM_CANDS]/AMVP_MAX_NUM_CANDS;
    iMvBits += m_auiMVPIdxCost[iMVPIdx][AMVP_MAX_NUM_CANDS];
    //x=m_auiMVPIdxCost[iMVPIdx][AMVP_MAX_NUM_CANDS];
       float b_stop;
       b_stop= ((width*height))/x*x;
       b_stop= b_stop-alpha;
       min_cost=b_stop*x;
    if (iMvBits < iBestMvBits)
    {
      iBestMvBits = iMvBits;
      iBestMVPIdx = iMVPIdx;
    }
  }
```

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