EFFICIENT CODING STRATEGY FOR HEVC PERFORMANCE IMPROVEMENT BY EXPLOITING MOTION FEATURES

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ABSTRACT

The striking feature of High Efficiency Video Coding (HEVC) Standard is emphasized by 50% bit-rate reduction compared to its predecessor H.264/AVC while keeping the same perceptual image quality. The time complexity- a congenital issue of HEVC has also increased to intensify the compression ratio. However, it is really a demanding task for the researchers to reduce the encoding time while preserving expected quality of the video sequences. Our contribution is to trim down the computational time by efficient selection of appropriate block-partitioning modes in HEVC using motion features based on phase-correlation. In this paper, we use phase-correlation between current and reference blocks to extract three motion features and combine them to determine binary motion pattern of the current block. The motion pattern is then matched against a codebook of predefined pattern templates to determine a subset of the inter-modes. Only the selected modes are exhaustively motion estimated and compensated for a coding unit. The experimental outcomes demonstrate that the average computational time can be down scaled by 30% of the HEVC while providing improved rate-distortion performance.

***Index Terms*—** HEVC, Motion Estimation, Motion Features, Intermode Selection, Phase-Correlation.

1. INTRODUCTION

The latest emerging *High Efficiency Video Coding* (HEVC/H.265) standard is targeted for efficient transmission, excellent performance improvement and storage of next generation video [1][2]. To encode different resolutions and wide range of video contents for different display devices, HEVC introduces a number of innovative strategies and recommendations compared to its predecessor H.264/AVC such as (i) the size of *coding unit* (CU) extends from 16×16 up to 64×64; (ii) the size and quantity of *prediction unit* (PU) and *transform unit* (TU) and (iii) the more adaptive block-partitioning phenomenon. These result in distinct *rate-distortion* (RD) performance improvement compared to its predecessor [3][4]. HEVC also provides asymmetric partitioning such as 64×16, 64×48, 16×64, 48×64, 32×8, 32×24, 8×32, 24×32, 16×4, 16×12, 4×16 and 12×16. The algorithmic complexity and data structure of HEVC is much more than 4 times than its predecessor- which means HEVC based codec will require more computational resource and power than H.264/AVC [5]. Thus, a number of electronic devices with limited processing and battery power could not fully exploit HEVC encoding and decoding features. However, in order to select a particular motion prediction mode, HEVC checks the Lagrangian cost function exhaustively using all modes in selected coding depth level (i.e., level 0: 64×64, level 1: 32×32, level 2: 16×16 ,and level 3: 8×8). The Lagrangian cost function J for mode selection is defined by

$$J = D + \lambda \times R \tag{1}$$

where λ be the Lagrangian multiplier, D be the distortion, and R be the resultant bit which are determined by a mode for each CU. *Motion estimation* (ME) process in *HEVC model* (HM) is executed using all the possible depth levels and the best mode of any particular coding level is achieved by picking out the least cost J using Lagrange multiplier. To accomplish this task, HEVC necessitates at least 8 and at most 24 inter-prediction modes to turn inside out for the best mode form any CU. Therefore, only the role of Lagrangian cost function is not always adequate enough to select the best mode due to different partitioning patterns of PUs, complex parameter settings, operational bit-rate and diversified video contents in HEVC. For better performance some sort of preprocessing might provide an effective solution which we subscribe in section 2.

To alleviate the complexity problem (especially, due to mode decision in the RD-optimized way), several fast approaches have been proposed in the existing literature [6]-[11]. Shen *et al.* [12] propose an algorithm introducing an early termination method based on checking criteria e.g., homogeneity, RD cost and skip mode. They prosecuted their experiment on different games with human motion and the test results confirm that 36% and 14% of the tree blocks choose the depth level '0' and '3' respectively. Although their algorithm saves around 30% encoding time this process suffers from coding quality especially for sequences containing a large area with high motion activities such as *Basketball.* In order to terminate the exploring modes in lower level Hou *et al*. [13] recommend a threshold based on the RD cost to explore mode in higher level. Their tested results affirm the time savings approximately 30% with 0.5% quality loss. Leng *et al*. [14] propose a fast two level CU decision algorithm to accelerate encoding process where first and second level denote the frame level and CU level respectively. This method does not exploit coding information correlation among dissimilar depth levels of CU. The experimental results show that around 40% computing time can be reduced with some loss in bit rate and PSNR. Apart from the above mentioned mode selection algorithms based on HEVC video coding standard, there also exist other fast mode selection algorithms based on H.264 video coding standard [15][16]. Paul *et al*. [17] fully exploit the direct intermode selection process for H.264 video coding using phase correlation where they minimize the number of candidate modes based on motion prediction using the low frequency energy concentration of the phase-matched error.

Podder *et al.* [19] propose a fast inter-mode selection technique using energy concentration ratio technique used in [17][18] to reduce computational time of HEVC. The experimental results show that they can reduce computational time; however, they sacrifice 0.24dB PSNR on average compared to the exhaustive mode selection of HEVC. The energy concentration ratio only indicates the residual

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error between the current block and the motion-compensated reference block. Thus, any decision on block-partitioning using energy concentration ratio does not provide very good compression results as it unnecessarily uses smaller block-partitions while a block does not have any translational motion or the block provides high accurate predicted motion. Besides energy concentration ratio, we can get predicted motion (i.e., an approximated translational movement between the current block and the reference block) and phase-correlation peak (i.e., the magnitude of the motion accuracy) from phase-correlation. In this paper we use three motion features: energy concentration ratio, predicted motion vector, and the phase-correlation peak for determining the motion type of the current block using weighted motion features. Then we select a subset of inter-modes by comparing the motion type against a codebook of predefined binary motion pattern templates. The final mode is selected based on the minimum Lagrangian cost function among the modes of the selected sub-set. The proposed method not only reduces the computational time significantly by selecting a sub-set of inter-modes but also improves the rate-distortion performance by exploiting appropriate block-partitioning modes based on the motion type and object-shape compared to the exhaustive mode selection of HEVC standard.

The remainder of this paper is organized as follows. Section 2 explicitly presents the key steps of the proposed method; Experimental results and discussion are evaluated in section 3 while section 4 is the conclusion of the paper.

2. PROPOSED MODE SELECTION METHOD

The phase-correlation renders relative displacement between correlated images by *fast Fourier transformation* (FFT) [20][21]. In this paper we extract three motion features namely (i) energy concentration ratio (α), (ii) phase-correlation peak (β), and (iii) motion vector (dx, dy) based on the phase-correlation between the current block and the reference block with 8×8 pixels size. We calculate a cost function using weighted average of the normalized motion features to determine a unified motion feature of the current block with respect to the reference block. The unified motion feature is then converted to binary motion type using a predefined threshold. In this process, we get a $n \times n$ binary matrix for a given CU (for example, 4×4 matrix for a CU of 32×32 size). Then, the binary matrix is matched against a codebook of predefined binary pattern templates and selects the best-matched pattern template using a similarity metric where the template corresponds to a subset of inter-modes. The final mode from the selected subset is obtained using the minimum Lagrangian cost function. The whole procedure is shown as a block diagram in Fig. 1.

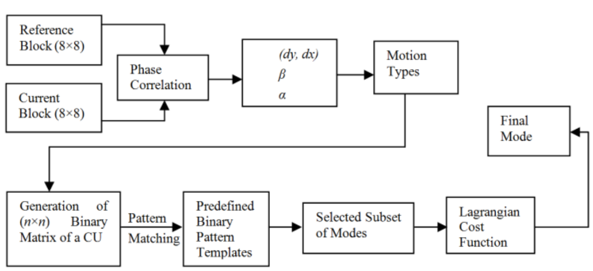


Fig. 1. Block diagram of the proposed mode selection process.

2.1. Motion Features and Motion Type

Phase-correlation is calculated from the FFT of the current and reference blocks using *inverse* FFT(IFFT) and FFTSHIFT as follows:

$$\Omega = fftshift\left(\left|ifft\left(e^{j(\angle F_r - \angle F_c)}\right)\right|\right) \tag{2}$$

where F_r and F_c are the FFTs of the reference and current blocks respectively. The predicted motion vector is calculated is as follows:

$$(dx, dy) = \max_{\arg}(\Omega) - blocksize/2 - 1 \tag{3}$$

where blocksize is 8 if 8×8 block is used for phase-correlation. The phase-correlation peak is determined as follows:

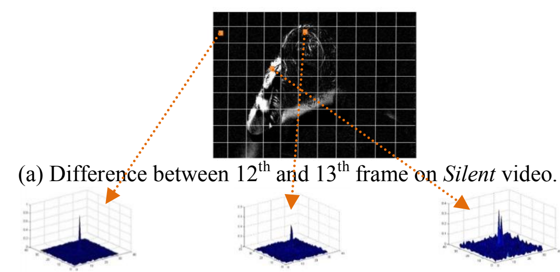
$$\beta = \Omega(dx + blocksize/2 + 1, dy + blocksize/2 + 1) \tag{4}$$

We can get a phase-matched block by applying IFFT on the magnitude of the motion-compensated reference block and the phase of the current block. A phase-matched error block is determined by the difference between the phase-matched block and the current block. The energy concentration ratio, α, is calculated using the ratio between the energy of the low frequency and all coefficients extracted from the *discrete-cosine transformed* phase-matched error block (details are in [21]-[23]).

Then we calculate a cost function $\Theta(i,j)$ for $(i,j)th\ block$ by:

$$\Theta(i,j) = \omega_1\alpha(i,j) + \omega_2(1-\beta) + \omega_3\left(\frac{|dx|}{\delta} + \frac{|dy|}{\delta}\right) \tag{5}$$

where δ be the maximum block size and ω is the weight where $\sum_{i=1}^{3}\omega_i = 1$. If the value of the cost function is higher than a predefined threshold the motion type is tagged by '1' otherwise the motion type is tagged by '0' ('1' as motion and '0' as no motion).

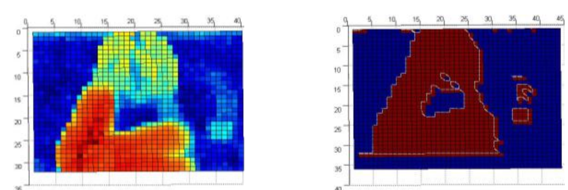


(a) Difference between 12th and 13th frame on *Silent* video.

(b) No motion (c) Simple motion (d) Multiple motions

Fig. 2. Illustration of phase-correlation (Ω) generated at different CUs of 13th frame on *silent* video; (b)-(d) are the phase shifted plots of different types of motion (no motion, simple/single motion and multiple/complex motion found in CU at (2, 1), (2, 6) and (4, 4) positions respectively).

The resultant magnitude of motion accuracy will have a peak signal at coordinates corresponding to the shift between current block and its reference block. The cost function generated motion indication map and respective motion representation map ('1' as motion and '0' as no motion) between 12th and 13th frame on *Silent* video are displayed in (a) and (b) of Fig. 3 (generated based on Fig. 2) in which reddish and bluish blocks are marked as motion and non-motion blocks respectively.



(a) An example of the cost function (Θ) values between 12th and 13th frame on *Silent* video.

(b) An example of generated motion type (1 or 0) by threshold, originated between 12th and 13th frame on *Silent*.

Fig. 3. Motion type identification by combined motion features and its justification through motion representation map.

2.2. Selection of Interprediction Modes

In the current experiment we use 8×8 pixel blocks for binary matrix generation through the phase-correlation process in each of the CUs i.e., a 32×32, thus, a CU has a matrix of 4×4 binary values. A 4×4 binary matrix is generated based on the extracted motion features (1/0) which then compared to a codebook of predefined binary motion pattern templates (see Fig. 4) at 32×32, 16×16 and 8×8 block level to select a subset of modes as depicted in Fig. 1. For instance, Template-7 should be adopted for the approximation of an object with motion in upper-half and no-motion in lower half, Template-8 is the inverse of Template-7. Based on the similarity metric we explore a best-matched binary pattern template for a binary motion block of a CU. From the explored subset of modes at 32×32, 16×16 and 8×8 level the final mode is selected by estimating their lowest Lagrangian cost function after full search motion estimation and compensation. We use a similarity metric using the *sum of absolute difference* (SAD) between the binary matrix of a CU generated by phase correlation and the *binary pattern templates* (BPTs) in Fig. 4. The best-matched BPT is selected for a CU which provides the minimum SAD. The SAD, D_n is determined as follows where M is the binary motion prediction matrix of a CU comprising 4×4 '1' or '0' combination and P_n is the n-th BPT:

$$D_n(x,y) = \sum_{x=0}^{4}\sum_{y=0}^{4}\left|M(x,y) - P_n(x,y)\right|. \quad (6)$$

The best-matched j-th BPT is selected from all BPTs as follows

$$P_j = \arg\min_{\forall P_n \in BPT}(D_n). \quad (7)$$

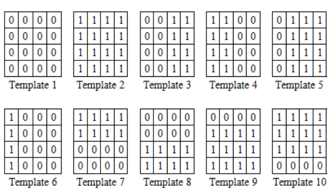


Fig. 4. Proposed templates for a subset of mode selection.

The intuitive mode selection process from the BPT at 32×32 and 16×16 levels are illustrated in Table I and Table II respectively. Once a particular template selects a subset of candidate modes at 32×32 level we decide the final mode by calculating their lowest Lagrangian cost function. If 16×16 mode is selected at 32×32 level, we again explore smaller modes using the motion pattern at 16×16 block level. The mode selection process for a block will be terminated by selecting the final mode from the generated subset of modes having the lowest value using the Lagrangian cost function. Finally we verify the result by comparing the rate-distortion performance of the proposed method against the performance of HEVC using all inter-modes exhaustively.

Table I. Mode selection at 32×32 block level using pre-defined binary motion pattern templates.

Motion Pattern at 32×32 block level and corresponding Template number	Subset of Mode Selection at 32×32 block level
Template 1	Skip or 32×32
Template 2	Intra 16×16 or Inter 6×16
Template 3 & 4	32×16 or Inter 16×16
Template 5	32×8 or Inter 16×16
Template 6	32×24 or Inter 16×16
Template 7 & 8	16×32 or Inter 16×16
Template 9	8×32 or Inter 16×16
Template 10	24×32 or Inter 16×16

Table II. Selected subset of modes at 16×16 block level.

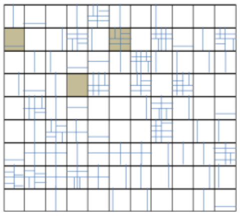
Motion Pattern at 16×16 block	Selected Subset of Modes
[1 1; 1 1], [1 1; 0 1], [0 1; 1 1], [1 0; 1 1], [1 1; 1 0]	16×8, 8×16 or 8×8
[1 0; 1 0], [0 1; 0 1], [1 1; 0 0], [0 0; 1 1], [1 0; 0 0], [0 1; 0 0], [0 0; 0 1], [0 0; 1 0], [0 0; 0 0]	16×8 and 8×16.
[0 1; 1 0], [1 0; 0 1]	16×12, 16×4, 12×16 or 4×16.

2.3. Fixed Threshold for Different Bitrates

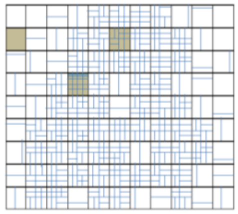
Instead of employing dynamic threshold, we apply fixed threshold (Th) and set to 0.20 in order to diminish the threshold selection complexity. Paul *et al*. [17] use thresholds ranging from 0.27 to 0.91 for different QP values which could not perform well in our algorithm because of extended number of modes in HEVC compared to H.264 as well as the problem mentioned above about the limitation of the energy concentration ratio for some blocks. Podder *et al*. [19] also use dynamic thresholds ranging from 0.37 to 0.52 for a wide range of bit rates. However, in our experiment we observe that the proposed method with a fixed threshold for different bit rates performs better compared to the HEVC with exhaustive mode selection strategy. The distribution of the proposed cost function values is more compact compared to the distribution of energy concentration ratio, thus, a fixed threshold works better in a wide range of bit rates for all types of videos. As a result, in the proposed method both for high and low bit rates we use the same value of Th for motion type determination in various video sequences.

3. EXPERIMENTAL OUTCOMES

To verify the performance of the proposed algorithm experimental outcomes are presented with six *standard definition* (SD), two *high definition* (HD-*Pedestrian & Bluesky*) and two *multiview* (MV-*Exit & Ballroom*) video sequences. Each of the sequences is encoded with search length ± 15 (for SD), ± 31 (for HD and MV), and frame rate 25 per second. The proposed scheme and the HEVC exhaustive mode selection scheme are developed based on HEVC *test model* (HM) version 8.0. In the experiment, we fix each of the CU blocks as 32×32 pixels and calculate phase-correlation using blocks of 8×8 pixels. We use the equal weight for three motion features to combine into a unique motion feature. Fig. 5 exhibits that for no motion and simple motion block (CU at (2,1) & (2,6) position respectively) we find an identical partitioning pattern by both schemes although the proposed scheme grasps the complex motion more efficiently as marked in CU at (4, 4) position (justified by CU at (4, 4) of Fig. 2). HEVC exhaustive mode selection scheme treats this block as a no motion region whereas, the proposed method picks the block as a high motion region and partition it ideally for accurate motion estimation (verified by reddish block at (16, 16) position in Fig. 3).



(a) block partitioning by HEVC



(b) block partitioning by the proposed method

Fig. 5. Block partitioning on 13th frame of the *silent* video at QP=24.

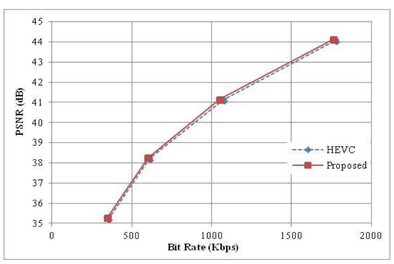
Table III provides an evidence of overall percentage of mode selection in which we find that for a wide range of bit rates the proposed algorithm selects smaller modes i.e., 16×16 level for moving regions and larger modes in smooth or background regions. This phenomenon reflects on the rate-distortion performance by providing better image quality. Fig. 6 (a-d) reveals improved RD performance for all types (SD, HD and MV) of videos. As comprehensive performance test, Table IV demonstrates the results for six additional sequences and in all cases (except *Bluesky*) the proposed scheme reveals improved image quality compared to HEVC. To produce the results in Table IV we first generate the RD performance curve (for instance Fig. 6 (a-d)) and from the curve we just mention a number of bit-rates from different QPs to compare the PSNR results of both schemes. Note that we do not use fixed bit-rate in either cases. Fig. 6 (e) is an example of bit-rate reduction by the proposed method for four sequences. Over ten different sequences the proposed method also reduces on average 30% encoding time (ranging 18%-40%) shown in Fig. 6 (f). Thus, considering overall performance including bit rate reduction, PSNR gain [24] and time savings the proposed approach eradicates many complexities in the existing literature.

Table III. Percentage of modes selected by HEVC and the proposed method based on different coding depth levels.

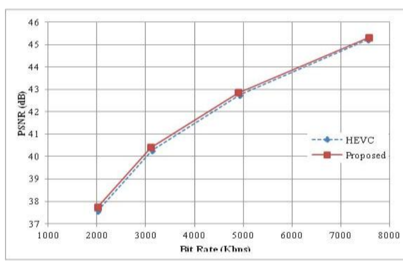
Overall Selected Percentage (%) of Modes					
QP	**HEVC**			**Proposed Method**	
	Depth Level 1 (32×32)	Depth Level 2 (16×16)		Depth Level 1 (32×32)	Depth Level 2 (16×16)
32	66.25	33.74		29.58	70.41
28	61.73	38.25		28.72	71.28
24	56.40	43.59		26.36	73.62
20	53.62	46.37		21.73	78.26

4. CONCLUSION

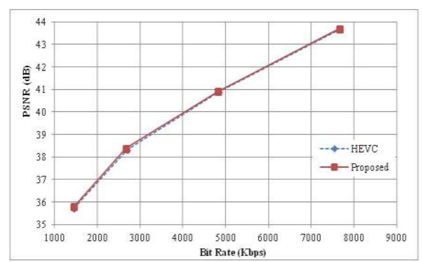
This paper utilises phase-correlation between the current block and the reference block to extract three different motion features focusing on three different aspects of motions in each of the CUs. A cost function is formulated to determine motion type and eventually to select a subset of inter-modes using pre-defined binary pattern templates. The final mode is selected using Lagrangian optimization criteria among the modes from the selected subset. Unlike any other fast inter-mode selection strategy, the proposed method does not sacrifice rate-distortion performance compared to HEVC. More specifically, the proposed method saves 1% bit rate or improving 0.15dB PSNR on average for a wide range of bit rates and also reducing on average 30% encoding time. Other existing strategies can be combined with the proposed method for further computational time reduction.



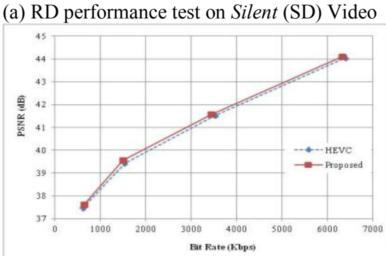
(a) RD performance test on *Silent* (SD) Video



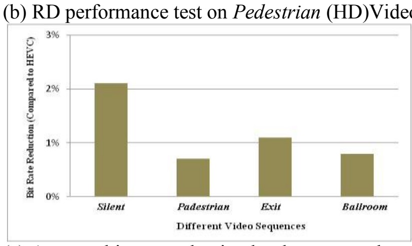
(b) RD performance test on *Pedestrian* (HD)Video



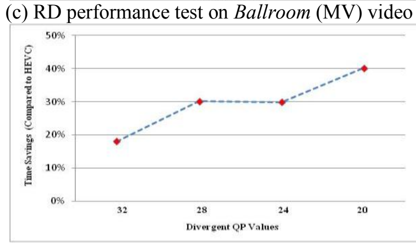
(c) RD performance test on *Ballroom* (MV) video



(d) RD performance test on *Exit* (MV) Video



(e) Average bit-rate reduction by the proposed method against HEVC



(f) Average time savings by the proposed method against HEVC over ten video sequences.

Fig. 6. Comparative study on RD performance, Time and Bit-rate savings by HEVC and the Proposed method on divergent video sequences.

Table IV. Additional results of HEVC and the proposed scheme on six other video sequences.

Name of the Sequences	Bit Rates	PSNR		Average. BD-(PSNR) Gain	Name of the Sequences	Bit Rates	PSNR		Average. BD-(PSNR) Gain
		HEVC	**Proposed**				**HEVC**	**Proposed**	
Paris	800	35.03	**35.32**	0.275	*Waterfall*	1000	32.81	**32.92**	0.087
	1200	38.12	**38.43**			1550	36.36	**36.51**	
	1800	40.74	**41.07**			2500	39.63	**39.70**	
	2600	43.39	**43.56**			3500	42.94	**42.96**	
Bridgeclose	700	34.67	**34.73**	0.10	*Bluesky*	3300	**35.93**	35.84	-0.072
	1400	37.34	**37.48**			4800	**39.25**	39.25	
	2400	40.26	**40.32**			7000	**42.39**	42.28	
	3700	43.51	**43.65**			9800	**45.25**	45.16	
Tempete	1700	33.16	**33.47**	0.25	*Tennis*	550	36.63	**36.81**	0.225
	2500	36.43	**36.72**			850	39.23	**39.55**	
	3800	40.21	**40.45**			1300	41.85	**42.17**	
	4800	43.16	**43.32**			1900	44.28	**44.36**	

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