Efficient Inter Prediction Mode Decision Method for Fast Motion Estimation in High Efficiency Video Coding

Alex Lee, Dongsan Jun, Jongho Kim, Jin Soo Choi, and Jinwoong Kim

High Efficiency Video Coding (HEVC) is the most recent video coding standard to achieve a higher coding performance than the previous H.264/AVC. In order to accomplish this improved coding performance, HEVC adopted several advanced coding tools; however, these cause heavy computational complexity. Similar to previous video coding standards, motion estimation (ME) of HEVC requires the most computational complexity; this is because ME is conducted for three inter prediction modes — namely, uniprediction in list 0, uniprediction in list 1, and biprediction. In this paper, we propose an efficient inter prediction mode (EIPM) decision method to reduce the complexity of ME. The proposed EIPM method computes the priority of all inter prediction modes and performs ME only on a selected inter prediction mode. Experimental results show that the proposed method reduces computational complexity arising from ME by up to 51.76% and achieves near similar coding performance compared to HEVC test model version 10.1.

Keywords: Inter prediction mode, fast motion estimation, HEVC, video coding.

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I. Introduction

As demands for high-quality video services (such as ultra high definition) increase and high data bandwidth (caused by video applications on mobile devices) imposes severe traffic on today's network, a new video compression standard with higher coding performance than H.264/AVC [1] is desired. High Efficiency Video Coding (HEVC) [2] was recently developed by the Joint Collaborative Team on Video Coding (JCT-VC), which comprises the ITU-T Video Coding Experts Group and the ISO/IEC Moving Pictures Experts Group. The main goal of HEVC [3] is to achieve a bitrate reduction of 50% with similar video quality compared to H.264/AVC. To achieve this, HEVC deploys the advanced coding tools listed in Table 1; in particular, these tools evaluated the powerful coding performance in the compression of video with increased picture resolution, such as high definition and beyond [4].

As the basic coding unit (CU), the block structure of H.264/AVC supports the macroblock (MB) containing one 16×16 luma sample and two corresponding 8×8 chroma samples in the case of 4:2:0 sampling. The block structure of HEVC supports coding tree units (CTUs), varying in size from 16×16 to 64×64, to enable better compression. A CTU consists of one luma coding tree block (CTB), two corresponding chroma CTBs, and syntax elements. It can also be split into a quad-tree structure consisting of four CUs that include one luma coding block (CB), two corresponding chroma CBs, and syntax elements.

Within the CU level, a prediction unit (PU) decides whether a current CU is coding in intra or inter predicted mode. The predicted residual is transformed using a block-based discrete cosine transform (DCT), where the size of a transform unit (TU) ranges from 4×4 to 32×32. For the 4×4 transform of luma different concepts (CU, PU, and TU) allow each to be

Table 1. Comparison of coding tools between H.264/AVC and HEVC.

	H.264/AVC	HEVC
Block structure	• MB	• CU • PU • TU
Inter prediction	• Spatial motion vector prediction (median) • Direct mode	• AMVP • MERGE mode
Interpolation	• 6-tap FIR filter • Bi-linear interpolation	• DCT-based interpolation (7-tap, 8-tap filter)
Intra prediction	• 9 modes (4 × 4, 8 × 8 luma blocks) • 4 modes (16 × 16 luma and chroma blocks)	• 35 modes (planar, dc, 33 angular modes)
In-loop filtering	• Deblocking filter	• Simplified deblocking filter
Entropy coding	• CABAC • CAVLC	• Simplified CABAC

optimized according to its role.

In addition, HEVC adopted a new motion vector (MV) signaling method called advanced motion vector prediction (AMVP). To reduce the MV signaling bit, AMVP derives two MV predictors from spatio-temporal neighboring blocks instead of derivation from only spatial neighboring blocks. HEVC uses DCT-based 7-tap or 8-tap interpolation filters to generate fractional-pel samples. To improve the accuracy of intra prediction, HEVC increases the number of angular intra prediction modes by up to 35 in the luma CB.

Although HEVC focuses on achieving high coding performance with those tools (block structure, inter prediction, interpolation, and intra prediction), its heavy computational complexity causes difficulty in developing the real-time encoder. While many fast algorithms [5]–[13] for inter or intra prediction were proposed in H.264/AVC, there are currently few fast algorithms [14]–[19] to reduce the encoding complexity of HEVC. Most of all, it is important to develop a fast inter prediction mode decision method since inter prediction has the most computational complexity in HEVC. Therefore, we propose an efficient inter prediction mode (EIPM) decision method to significantly reduce the complexity of an HEVC encoder.

The remainder of this paper is organized as follows. In section II, we introduce the inter prediction process of HEVC, evaluate the encoding complexity, and address the motivation of the proposed method. The proposed method is described in section III. Finally, experimental results and conclusions are given in sections IV and V, respectively.

II. Analysis and Motivation

1. Overview of Inter Prediction

Figure 1 depicts the procedures of the inter prediction process in HEVC when a PU is encoded. If a current PU is 2N × 2N, then ME is sequentially conducted on uniprediction in list 0 (Uni-L0), uniprediction in list 1 (Uni-L1), and biprediction (Bi) after SKIP/MERGE prediction. Otherwise, motion estimation (ME) is preferentially performed on Uni-L0, Uni-L1, and Bi before MERGE prediction. The best inter prediction mode for the PU is finally decided among Uni-L0, Uni-L1, and Bi modes by rate-distortion optimization (RDO) [20]. In the case of Uni-L0 and Uni-L1 in ME, the AMVP construction process finds the two initial MVs from spatio-temporal neighboring PUs and selects an RDO-based initial

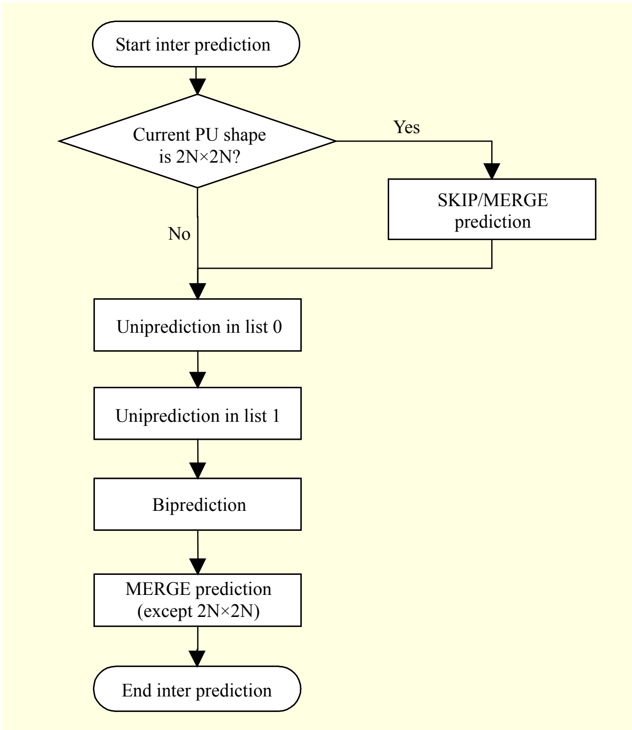

Fig. 1. Flowchart of inter prediction process in HEVC.

MV. Starting from the initial MV, integer-pel MV is searched using a sum of absolute differences (SAD)-based motion cost, which is calculated from

$$J_{\text{Motion}} = SAD(s, c(MV, ref\_idx)) + \lambda_{\text{Motion}} \cdot R(MVD, ref\_idx). \quad (1)$$

In (1), $SAD(s, c(MV, ref\_idx))$ is the sum of absolute differences between the current PU(s) and its reference PU(c) whose motion vector is *MV* and reference frame index is "*ref_idx*." The difference between the current MV and the initial MV, obtained from AMVP, is denoted by *MVD*. In (1), λ_{Motion} is a Lagrangian multiplier [20] and $R(MVD, ref\_idx)$ is the required bitrate to encode *MVD* and *ref_idx*. Then, fractional-pel ME is searched using the sum of absolute Hadamard transformed differences–based motion cost to find the best MV.

Bi should find the two best motion vectors from the reference frames of list 0 and list 1. Since the two best MVs are already computed from Uni-L0 and Uni-L1 prediction, one of them is fixed by RDO, and the MV of the other list is newly searched to find the optimally predicted block for Bi.

2. Complexity Analysis of Inter Prediction

To analyze the complexity of inter prediction, we used the sequences of Class A and Class B under the main profile–random access (MP–RA) configuration [21] recommended by JCT-VC. As shown in Figs. 2 and 3, inter prediction has the most computational complexity, which consumes about 70% of total encoding time (TET). In particular, ME of inter prediction accounts for the most complexity because SKIP/MERGE prediction omits the ME process and obtains the motion information, including MV, reference index, and IPM, from spatio-temporal neighboring PUs.

We evaluated the computational complexity for each inter prediction mode (IPM). Figure 4 shows that uniprediction has higher complexity than that of Bi. Also, the complexity of Uni-L0 is higher than that of Uni-L1 between unipredictions. It means that if the reference frame of Uni-L1 is the same as that of Uni-L0, then the MV of Uni-L1 is only copied from Uni-L0 to avoid redundant ME on the same reference frame. The reason why Bi is less complex than unipredictions is because it reuses the MV information from Uni-L0 or Uni-L1 without the AMVP process and because the integer ME is simply performed with a small search range of four.

3. Motivation of Proposed Method

According to complexity analysis, the inter prediction process imposes a heavy complexity burden of up to 70% on the entire encoding process. Regardless of the complexity

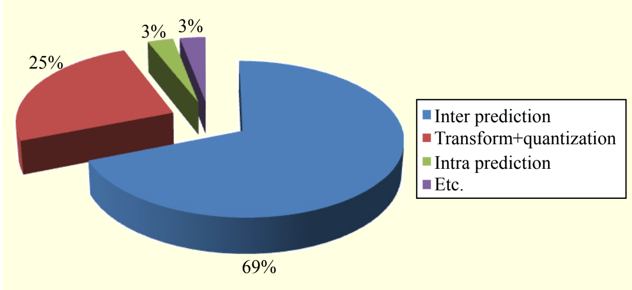

Fig. 2. Complexity distribution of total encoding time.

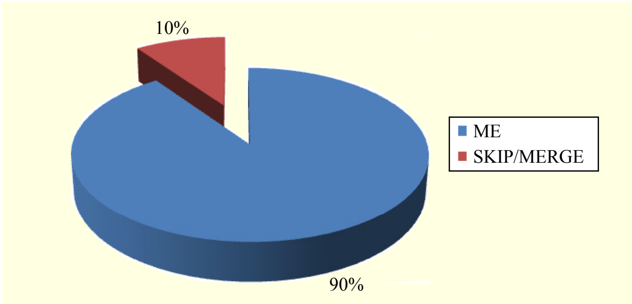

Fig. 3. Complexity distribution of inter prediction.

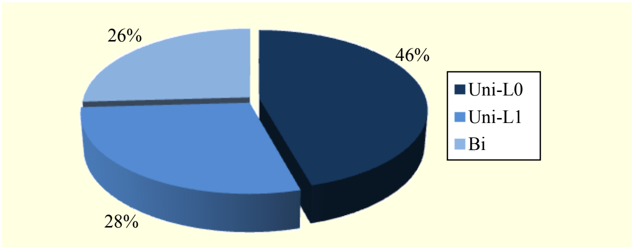

Fig. 4. Complexity distribution according to inter prediction.

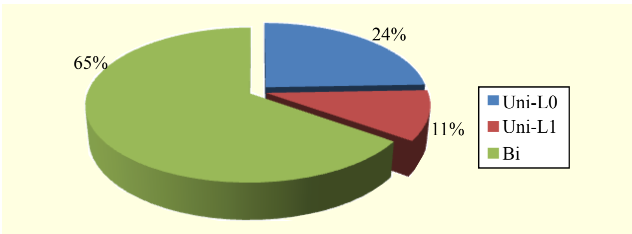

Fig. 5. Distribution of best IPM.

distribution of IPMs, Bi is more likely to be selected than Uni-L0 or Uni-L1, as shown in Fig. 5. Therefore, if accurate IPM is predetermined among Uni-L0, Uni-L1, and Bi, then the ME complexity incurred by unnecessary IPM can be significantly removed. Although Kim [19] proposed a fast algorithm related to inter prediction mode decision, it still has heavy computational complexity because [19] always performed ME in Uni-L0 and Uni-L1. Therefore, we define the priority for each IPM using spatial and upper-PU correlation such that ME

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can be performed on the selected IPM along a descending order of priority unless the priority of each IPM is lower than the threshold value.

III. Proposed EIPM Decision Method

In HEVC, PU shape is differently partitioned within a current CU, as shown in Table 2. A total of seven PU partition shapes are defined for inter prediction as follows: one square (2N × 2N), two rectangular (2N × N, N × 2N), and four asymmetric (2N × nU, 2N × nD, nL × 2N, and nR × 2N). The four asymmetric shapes are disabled for both ME and MERGE prediction at 8 × 8 CU and are just enabled for MERGE prediction at 64 × 64 CU in HEVC [2].

As demonstrated in [8] and [9], a current block tends to have similar motion information. It means that the correlation relative to motion information between a current PU and a spatially neighboring PU is very high. Also, the motion information of the upper-layer block has a strong correlation to those of lower-layer blocks [13]. Figure 6 demonstrates that the correlation of IPM between a current PU and spatial/upper PUs is as high as 82% on average. Therefore, we define the upper PU of current PU partitions to be those shown in Table 3 and exploit the correlation between the spatial neighboring PU and the upper PU to calculate the priority for the IPM decision.

Table 2. Illustration of PU partition type and shape in HEVC.

PU partition type	Square	Rectangular		Asymmetric			
PU partition shape	2N×2N	2N×N	N×2N	2N×nU	2N×nD	nL×2N	nR×2N

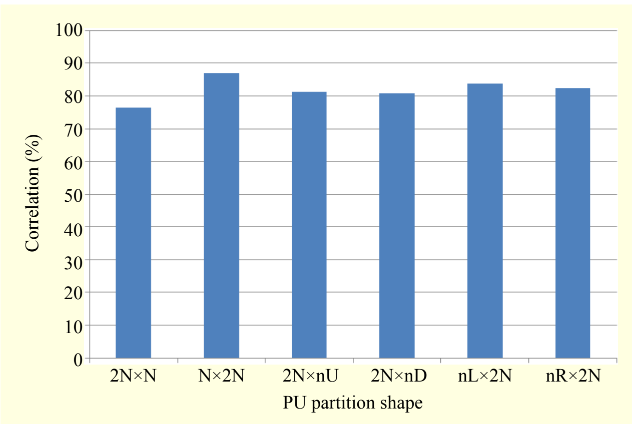

Fig. 6. Correlation of IPM between current PU and spatial/upper PUs.

Table 3. Definition of upper PU.

PU partition shape	Current PU	Upper PU
2N×2N		N/A
2N×N		2N×2N
N×2N		
1st partition of nL×2N or nR×2N		1st of N×2N
2nd partition of nL×2N or nR×2N		2nd of N×2N
1st partition of 2N×nU or 2N×nD		1st of 2N×N
2nd partition of 2N×nU or 2N×nD		2nd of 2N×N

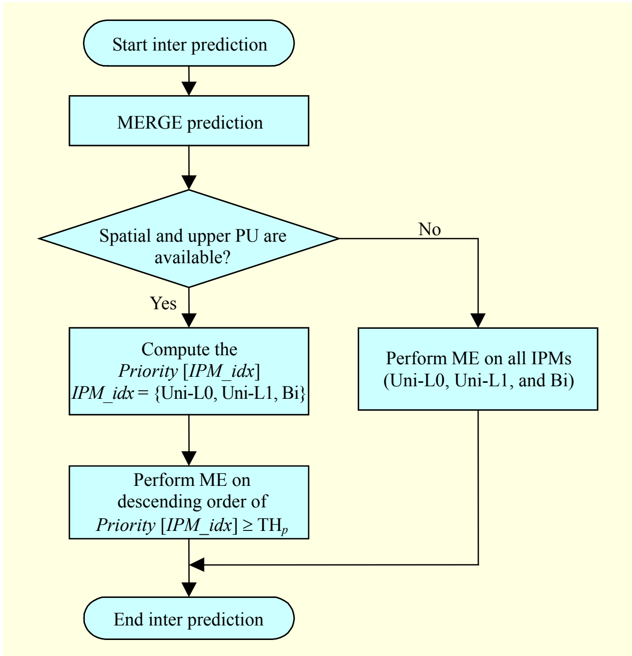

Fig. 7. Flowchart of proposed EIPM method.

The overall flowchart of the proposed EIPM method is depicted in Fig. 7. The proposed EIPM method is applicable to all PU shapes except a 2N × 2N PU — as there is no upper PU for a 2N × 2N PU. Before performing ME on the three IPMs, the priority of each IPM is computed for a current PU by the following:

$$Priority[IPM\_idx] = \frac{SPU[IPM\_idx] + UPU[IPM\_idx]}{\underset{k}{Max}\{SPU[k] + UPU[k]\}}, \quad (2)$$

where $IPM\_idx,\ k \in$ {Uni-L0, Uni-L1, Bi}.

The priority of each IPM is the quantitative IPM correlation obtained from the previously coded spatial and upper PU. In (2), *SPU[IPM_idx]* and *UPU[IPM_idx]* are the number of PU blocks with optimal inter prediction mode *IPM_idx* among all available spatial and upper PU blocks, respectively. The denominator of (2) is used for the normalization of the IPM priority by taking the maximum IPM priority whose range is from zero to one.

The proposed EIPM method performs ME only on the selected IPM along a descending order of priority, unless the priority of each IPM is lower than the threshold value TH_p. According to the designed decision rule, as the threshold is increased encoding complexity is reduced (by skipping ME), while coding loss is increased; and vice versa. Therefore, it is important to choose the optimal threshold of priority because it has an effect on the trade-off between complexity reduction and coding loss. To determine the optimal TH_p we define the cost function (CF) to be

$$CF(TH_p) = ANM + \alpha \cdot BD\text{-}Bitrate, \quad (3)$$

where *ANM* is the average number of MEs performed by a PU block and a positive *BD-Bitrate* [22] represents coding loss. Since *BD-Bitrate* is calculated from the various QPs (QP = 22, 27, 32, 37) recommended by JCT-VC common conditions [21], CF reflects the various QPs from low bitrate to high bitrate through the terms of *BD-Bitrate* in (3). Figure 8 shows the distribution of the average CF obtained from the training sequences "PeopleOnStreet" and "BasketballDrive". When a specific threshold is given, we plotted the corresponding CF values obtained from the training sequences; these procedures were conducted on offline experiments because both *ANM* and *BD-Bitrate* cannot be computed in the middle of an encoding process. In addition, we set the weighting factor α as 0.25 to emphasize more on the side of computational complexity (*ANM*) than coding loss (*BD-Bitrate*); this was after analyzing the distribution of CF corresponding to various values of weighting factor α. In accordance with the results from Fig. 8,

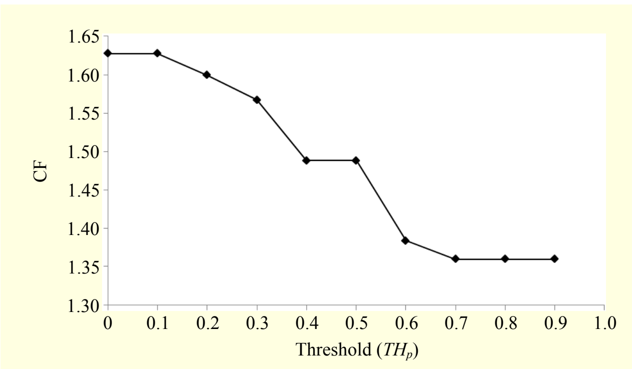

Fig. 8. Distribution of average CF for "PeopleOnStreet" and "BasketballDrive" sequences.

we set TH_p to 0.7 in all experiments.

IV. Experimental Results

The proposed method was implemented in HEVC test model (HM) 10.1 and evaluated under the JCT-VC common conditions [21] listed in Table 4. We compared the proposed method with HM 10.1 [2] and Kim's method [19] under the MP–RA configuration.

For comparison of computational complexity, we measured the time reduction using both TET and motion estimation time (MET) as follows:

$$\Delta T = \frac{Time_{\mathrm{HM10.1}} - Time_{\mathrm{Proposed}}}{Time_{\mathrm{HM10.1}}} \times 100. \quad (4)$$

As shown in Table 5, the proposed method reduces MET and TET by 51.76% and 31.29%, respectively. Also, it is about 5.6 times faster than Kim's method. In addition, since the time reduction may not truly reflect computational complexity, due to different programming skills or use of a different hardware platform, we examined how many times ME was performed. In (5), we measured the speed-up ratio using $Number_{\mathrm{HM10.1}}$ and $Number_{\mathrm{Proposed}}$, which are the number of MEs with or without the proposed method, respectively.

$$\Delta Number = \frac{Number_{\mathrm{HM10.1}} - Number_{\mathrm{Proposed}}}{Number_{\mathrm{HM10.1}}} \times 100. \quad (5)$$

Table 6 shows that the proposed method reduced the number of ME processes by 61.23% on average. To evaluate coding

Table 4. Encoder parameters used in experiment.

Test sequences	Class A (2,560 × 1,600)	Traffic	150 frames	30 fps
		Nebuta	300 frames	60 fps
		SteamLocomotive	300 frames	60 fps
	Class B (1,920 × 1,080)	Kimono	240 frames	24 fps
		ParkScene	240 frames	24 fps
		Cactus	500 frames	50 fps
		BQTerrace	600 frames	60 fps
Coding options	Intra period		24 for 24 fps, 32 for 30 fps, 48 for 50 fps, and 64 for 60 fps.	
	GOP size		8	
	Search range		64	
	CTU Size		64 × 64	
	Asymmetric motion partitioning		On	
	RDOQ		On	

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Table 5. Comparison of complexity reduction between Kim's method [19] and proposed method.

Test sequences		QP	Kim's method		Proposed method	
			MET (%)	TET (%)	MET (%)	TET (%)
Class A (2,560 × 1,600)	Traffic	22	7.24	2.17	50.60	25.09
		27	11.26	6.74	52.25	31.04
		32	10.60	6.76	53.02	34.14
		37	13.69	9.49	54.81	37.00
	Nebuta	22	3.50	2.70	43.57	18.05
		27	5.90	4.34	46.54	20.30
		32	4.30	1.82	52.95	27.89
		37	7.32	4.11	52.29	32.78
	StreamLocomotive	22	10.29	6.98	39.62	23.74
		27	12.91	9.47	46.64	31.06
		32	11.01	7.29	47.18	31.39
		37	12.05	8.23	49.13	33.61
Class B (1,920 × 1,080)	Kimono	22	3.79	0.33	52.25	28.47
		27	5.28	1.92	54.25	33.49
		32	11.19	7.60	56.05	36.95
		37	14.11	10.61	56.73	38.63
	ParkScene	22	6.30	1.94	53.45	28.00
		27	5.60	1.89	54.37	32.30
		32	11.45	7.80	56.99	37.83
		37	12.69	8.99	56.95	38.74
	Cactus	22	7.35	3.31	47.94	25.31
		27	8.53	5.02	51.19	32.15
		32	9.47	5.43	50.31	31.79
		37	8.49	4.66	51.98	34.62
	BQTerrace	22	10.36	6.90	52.24	25.20
		27	9.16	5.43	54.30	31.94
		32	10.70	7.34	55.49	36.40
		37	10.90	6.82	56.27	38.23
Average			9.12	5.57	51.76	31.29

Table 6. Speed-up ratio of proposed method compared to HM 10.1.

Test sequences		Δ*Number* (%)			
		QP 22	QP 27	QP 32	QP 37
Class A (2,560 × 1,600)	Traffic	61.31	59.42	58.13	57.41
	Nebuta	65.21	64.25	63.69	57.84
	SteamLocomotive	59.23	57.52	56.66	56.24
Class B (1,920 × 1,080)	Kimono	61.28	59.99	58.93	58.18
	ParkScene	61.19	59.48	58.31	57.54
	Cactus	59.65	59.00	58.53	58.05
	BQTerrace	60.77	60.41	58.56	57.48
Average		61.23	60.01	58.97	57.53

Table 7. Coding performance comparison.

Test sequences		*BD-Bitrate* (%)	
		Kim's method	Proposed method
Class A (2,560 × 1,600)	Traffic	0.09	1.22
	Nebuta	0.09	0.68
	SteamLocomotive	0.07	0.54
Class B (1,920 × 1,080)	Kimono	0.29	0.79
	ParkScene	0.09	1.05
	Cactus	0.09	1.11
	BQTerrace	0.23	2.00
Average		0.14	1.06

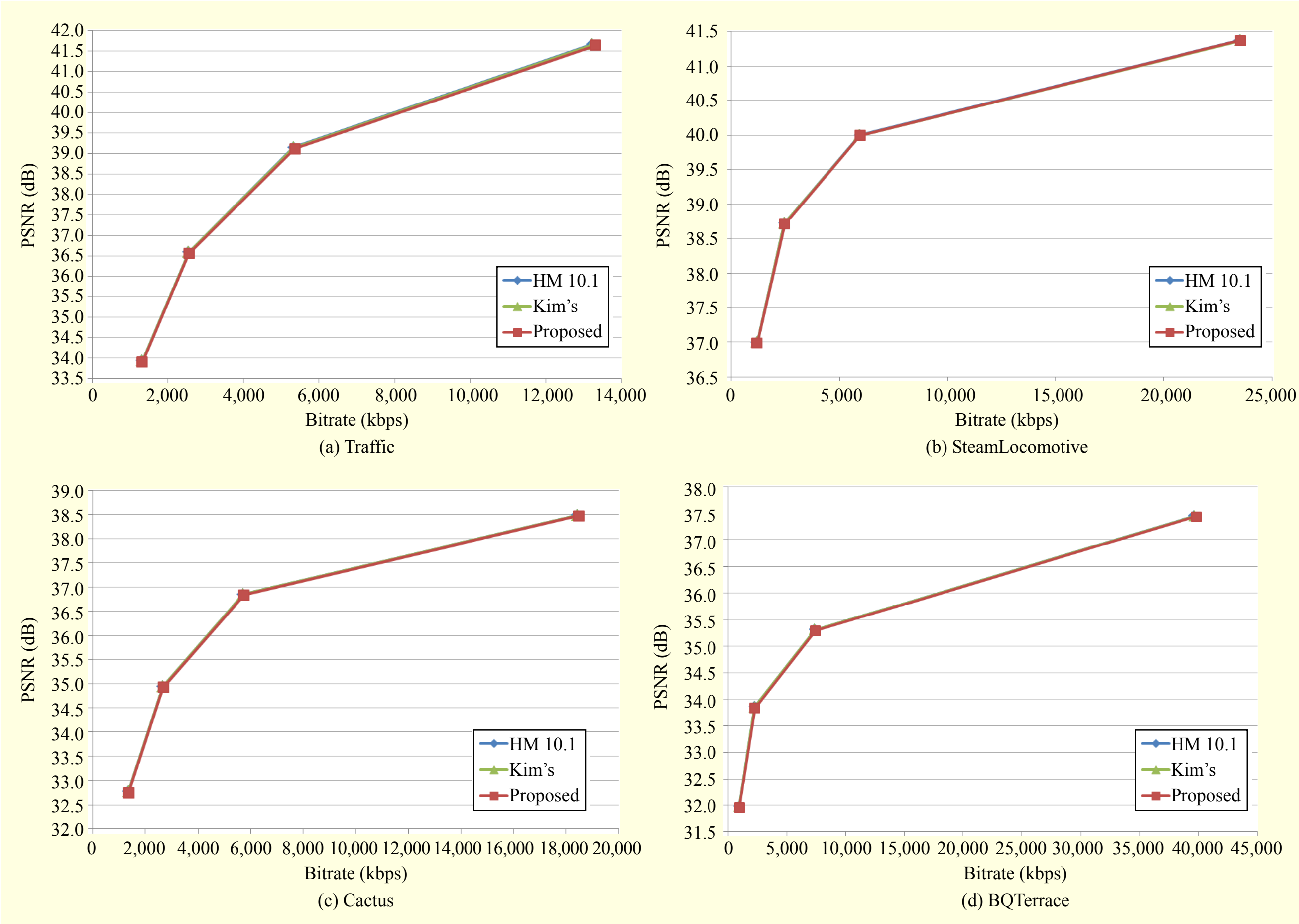

Fig. 9. RD curves of HM, Kim's method [19], and proposed method.

Table 8. Hit rate of proposed EIPM method.

CU size (2N × 2N)	PU shape	Hit rate (%)
64 × 64	2N × N	84.50
	N × 2N	83.97
32 × 32	2N × N	80.24
	N × 2N	78.05
	2N × nU	88.80
	2N × nD	89.42
	nL × 2N	88.89
	nR × 2N	89.08
16 × 16	2N × N	80.87
	N × 2N	75.93
	2N × nU	88.62
	2N × nD	89.10
	nL × 2N	88.77
	nR × 2N	88.84
8 × 8	2N × N	82.52
	N × 2N	76.28
Average		84.62

performance we used the *BD-Bitrate* recommended by JCT-VC [22]. Table 7 shows that the proposed method increased the *BD-Bitrate* by 1.06% on average. Although Kim's method [19] increased the *BD-Bitrate* by 0.14%, it still has heavy computational complexity because uniprediction (Uni-L0, Uni-L1) should always be performed. In contrast to [19], the difference in *BD-Bitrate* increments is 0.92% for EIPM; such insignificant degradation does not manifest in any noticeable visual quality.

As in Fig. 9, the rate distortion (RD) performance of the proposed EIPM maintains nearly the same coding performance as [19] and HM 10.1.

In addition, we measured the hit rate to verify the accuracy of the priority. It is the probability that the IPM selected from the proposed EIPM is equal to that obtained from the HM 10.1. Table 8 shows the hit rate to be as high as 85% on average for the given test sequences.

V. Conclusion

The proposed EIPM method is to perform ME on the

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selected IPM, based on the priority computed from spatial and upper PU blocks. Experimental results demonstrated that the proposed method significantly reduced the computational complexity of ME, while maintaining the coding efficiency to be almost the same RD performance for various bitrates and test sequences.

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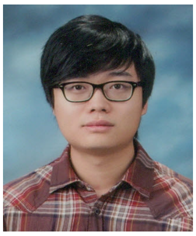

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