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HEVC Motion Estimation Algorithm on Motion Homogeneity

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Abstract
In view of highly complicated calculation problems of inter-frame motion estimation of high efficiency video coding (HEVC), a fast termination algorithm of motion estimation on motion homogeneity was proposed. The motion homogeneity of the same object in video sequence was adopted to make a reasonable selection for the division method of current coding unit (CU) and end motion estimation of partly less likely complex division mode in advance. Under the current cursive depth, the CU motion difference was adopted to determine whether the current CU was the similar motion regions. For CU in the similar motion regions, after decomposition of next recursive depth small prediction unit (PU) splitting motion estimation was cut to reduce amount of calculation of motion estimation and lower calculation complexity. The results show that compared with the original HEVC encoding algorithm, the proposed algorithm can reduce en-coding time by 41.79% and 41.98% on average with peak signal-to-noise ratio(PSNR) loss of 0.052dB and 0.041dB in the low-delay and random-access cases.
Key words: HEVC, MOTION ESTIMATION, MOTION DIFFERENCE

1. Introduction

The standard of High Efficiency Video Coding (HEVC) has been set the new generation standard since Jan 2013 for the application of high definition and super high definition video [1]. HEVC has adopted commonly mixed block based coding framework since H.26X but made disruptive improvement for many coding technology. Recursive quad tree division structure of Coding unit (CU), motion fusion, high precision motion compensation and adaptive loop filter technology are among typical technologies[2]. Under the same coding quality condition, HEVC is as strong again as H.264/AVC for data compressed capability[3]. However, the improvement of coding efficiency causes high complexity of coding making HEVC go against real time video. Lowering coding complexity is the key point for the wide application of the coding standard of HEVC under the condition of not influencing coding efficiency.

Motion estimation probably occupies half of coding time in coding and how to find quick and high efficient motion estimation algorithm has always been the hot problem in the study of video coding. Han et al reduce times of motion estimation by using Motion Vector of upper Prediction Unit(PU) as current motion vector of PU[4]. Xiong et al determine the segmentation of CU as Optical Flow calculates eigenvalue of PMD and reduce the complexity to some extent[5]. The motion homogeneity has not been considered carefully, so coding Rate Distortion(RD) is not good. A quick algorithm of PU splitting is proposed in the reference of 6. This algorithm first examines flag bit of cbf and RD prices of current PU. If these two va- lues accord certain conditions, estimation of the next PU will be ended in advance[6]. Shen et al propose a method to decide whether CU needs to be divided by using the decision rules of Bayes and 41.4% of coding time will be saved[7]. It can been seen that a practical and effective method is based on current CU's characteristics such as RD prices, motion information, premature termination CU and further division of PU.

This paper proposes a quick ending algorithm on the motion homogeneity for the inter-frame motion estimation of HEVC. On current CU motion difference, reasonable selection is carried out on the current CU division method and part of low possibility motion estimation of complex division mode will be ended in advance. Amount of calculation of motion estimation will be reduced greatly. By calculating the average absolute deviation of current motion vector for CU motion difference, if the motion difference is smaller than threshold value, the current CU is considered in the region of motion similarity. Motion estimation of the division mode of non $2N\times 2N$ in the next recursive depth after decomposition probably will be cut to reduce division mode of motion estimation, end motion estimation in advance and reduce the complexity of encoder of HEVC.

2. Complexity analysis of inter-frame in HEVC

2.1. CU division method in HEVC

In the main profile (MP) of HEVC, every frame graph is divided into several coding tree units (CTU) and CTU in HEVC is similar to macro-block in H.264/AVC[8]. On the covered image region complexity, each CTU can be recursively adaptive division and be divided into several CUs to 4 layers[9]. This division method is called quad-tree partition as showed in figure 1.

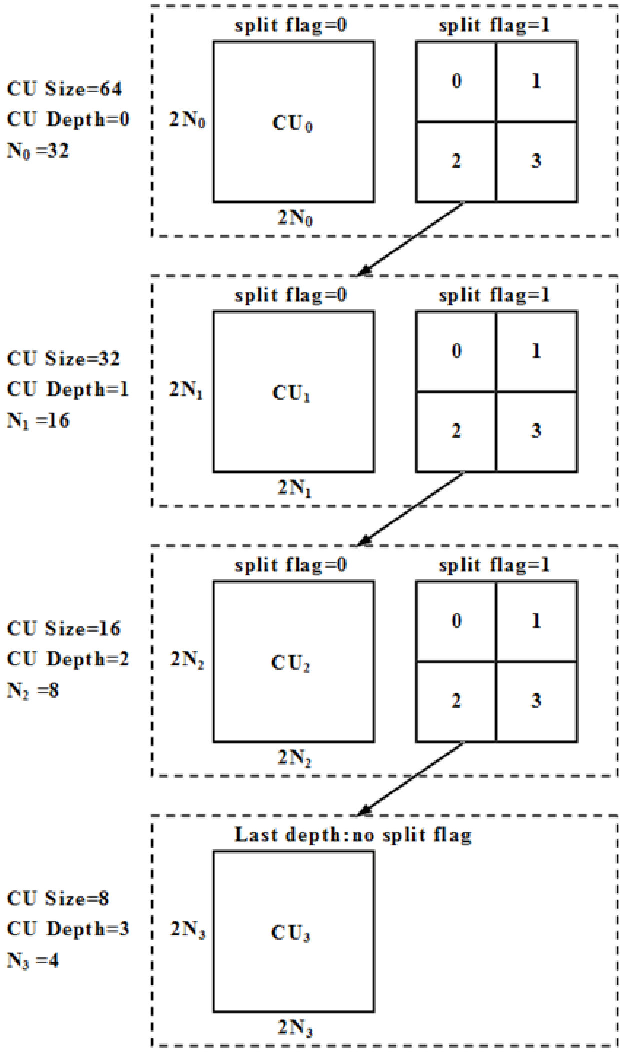


Figure 1. Quad-tree structure of CU

As showed in figure 1, if the depth of CU is 0, the size of CU is the same as CTU and it equals to 64×64[10]; if the depth of CU is 1, one CTU can be divided into 4 CU1 and each CU1 is 32×32; so if the depth is 2 or 3, CU2 or CU3 has the same condition. In the quad-tree structure of CU, the maximum depth is 3, the minimum CU3 is 8×8.

CU can be continuously divided into PU. Each PU has the same prediction information including prediction mode, motion vector, reference frame, etc[11,12]. the possible division method of PU is showed in figure 2 under the condition of intra-prediction and inter-prediction. Every CU may include 1 or 2 or 4 PUs on the division difference. For types of inter-frame, CU has 8 division methods. To residual transformation, transform unit (TU) can choose 4×4,8×8,16×16 or 32×32.

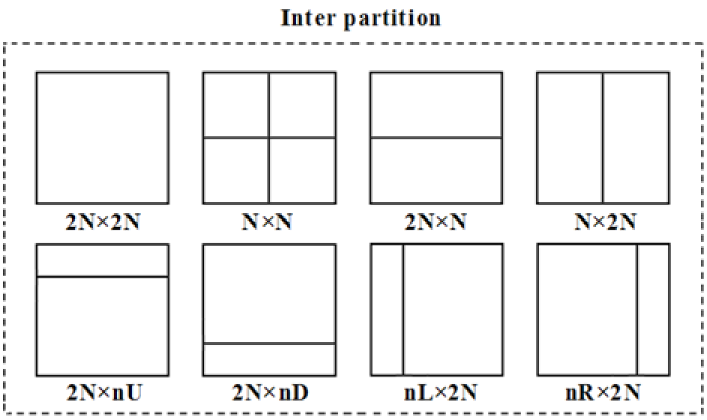


Figure 2. PU partition mode

2.2. Complexity analysis of inter-frame encoding

For every layer CU in depth, Skip, $2N\times 2N$, $N\times 2N$, $2N\times N$, $N\times N$ and other modes are used to make predictive encoding (asymmetrical prediction will be considered). Usually for one CU, there are 6 inter-frame encoding block including one skip, one $2N\times 2N$, two $N\times 2N$ and two $2N\times 2N$ to calculate cost value of rate distortion. For the biggest depth CU, additional four $N\times N$ encoding blocks need calculate.

For example, encoding size is 64×64, the biggest encoding depth is 3 in largest coding unit (LCU). The encoding process is as follows: when the encoding depth is zero, six predictive blocks need calculate; when the encoding depth is one, 4×6=24 blocks need calculate; when the encoding depth is two, 4×4×6=96 blocks need calculate; when the encoding depth is three, 4×4×4×6+256=640 blocks need calculate; The total times of calculation is 6+24+96+640=766. For example, if the encoding size of video frame is 1920×1080, inter-frame predictive times for cost value of rate distortion is about 766×1920×1080÷64÷64=387787. Therefore, the calculation times of inter-frame prediction of HEVC increases dramatically as CU/PU is introduced to make the complexity of encoders high and not to meet real-time application of encoders. Lowering the complexity of encoders is extremely important in application.

3. Motion estimation quick ending algorithm of HEVC inter-frame

3.1. Measurement of motion difference for CU

In video sequences motion vector for the same object is similar, hence CU has the same distribution of motion vector in regions for the same motion object. When these regions need not divide into small PU to make motion estimation, a relatively accurate motion vector can be acquired after motion estimation of big PU is made. However, motion changes are more intense for regions of CU, the divided smaller PU will be helpful to search for the right motion vector. If the similar regions of CU for motion characteristics are not divided, the times of motion estimation for the smaller size CU is reduced to end motion estimation s in advance.

When motion vector difference is analyzed, encoding blocks can be measured to decide whether they are in the same motion regions. 4×4 is the unit for motion vector storage in HM. For N 4×4 in some video region, in horizontal and vertical directions motion vector difference can be defined as:

$$MVH_x = \frac{1}{N}\sum_{i=0}^{N}\left|mvx_i - \frac{1}{N}\sum_{i=0}^{N} mvx_i\right| \qquad (1)$$

$$MVH_y = \frac{1}{N}\sum_{i=0}^{N}\left|mvy_i - \frac{1}{N}\sum_{i=0}^{N} mvy_i\right| \qquad (2)$$

mvx_i and mvy_i are motion vector of 4×4 in horizontal and vertical directions. When MVH_x and MVH_y are less than threshold, N 4×4 video regions in the same motion region are determined. The smaller MVH_x and MVH_y are, the more similar motion features are in this region. When adjacent CU in spatial domain and motion difference of current CU are calculated, the current CU is determined to whether it will be divided into smaller ones to make motion estimation.

3.2. Statistic analysis in accuracy for motion estimation quick ending

CU is made motion estimation in partition mode of PU, if the best estimation mode of the current CU is $2N \times 2N$, motion vector for all blocks of 4×4 is the same. If the best estimation mode is the small blocks of motion estimation of PU, motion vector for every PU will be different to cause motion vector difference for every storage of 4×4.According to formula (1) and (2), when motion estimation of the current CU is defined, the differences of motion vector in horizontal and vertical directions are:

$$Var_x = \frac{1}{N}\sum_{i=0}^{N}\left|Abs(mvx_i) - \frac{1}{N}\sum_{i=0}^{N}Abs(mvx_i)\right| \quad (3)$$

$$Var_y = \frac{1}{N}\sum_{i=0}^{N}\left|Abs(mvy_i) - \frac{1}{N}\sum_{i=0}^{N}Abs(mvy_i)\right| \quad (4)$$

N is the number of 4×4 in the current CU, the total differences in horizontal and vertical directions are both of them.

$$Var_{total} = Var_x + Var_y \quad (5)$$

The bigger the Var_{total}, the bigger the motion difference in every part of the current CU and the bigger possibility in the split of small PU. So when Var_{total} is small enough, and smaller than some threshold, the current CU in the similar motion region is determined. Motion vector of each part has the high similarity, as a result the possibility is small to make split to small PU. Var_{thresh} is 0.2 in the paper.

In order to analyze the accuracy of motion estimation when PU splitting is cut to small blocks by this threshold, in this paper many encoding experiments are made to analyze the distribution of Var_{total} and under the random access encoding CU best estimation mode in different Var_{total} is counted as the proportion of $2N \times 2N$ and non $2N \times 2N$ as showed in table1.

Table 1. Statistics of distribution of Var_{total}

Resolution	Sequence	$Var_{total} < Var_{thresh}$			$Var_{total} \geq Var_{thresh}$		
		CU /%	$2N \times 2N$ /%	non $2N \times 2N$ /%	CU /%	$2N \times 2N$ /%	non $2N \times 2N$ /%
416×240	BlowingBubbles	83.15	98.12	2.68	14.85	90.96	10.26
416×240	BasketballPass	87.93	97.37	1.73	11.01	91.97	9.03
416×240	BQSquare	91.95	99.87	1.23	8.05	88.98	10.82
832×480	BQMall	88.04	98.36	2.54	12.96	89.17	11.13
832×480	BasketballDrill	92.39	97.35	1.45	9.61	93.69	8.21
832×480	PartyScene	85.39	97.67	3.23	14.61	84.46	12.54
1280×720	Vidyo3	97.07	99.83	0.17	1.96	95.65	6.95
1280×720	Vidyo4	97.05	99.80	0.19	1.97	95.00	5.80
Average		90.37	98.55	1.65	9.38	91.24	9.34

In the table1.CU of $Var_{total} < Var_{thresh}$ accounts for big proportion and the average value reaches more than 90%. For 720p video with the high resolution, this part of CU even reaches 97%. In this part of CU, the best splitting mode of PU in sub-CU is high proportion of $2N \times 2N$ to reach 98.55% averagely but the best splitting mode in small part of CU is non $2N \times 2N$, and therefore the reduction of PU splitting for this part of CU can greatly reduce PU motion estimation and has little impact on video quality. In case of $Var_{total} \geq Var_{thresh}$, CU accounts for small proportion and the best PU splitting mode is that the proportion of non $2N \times 2N$ is next to 10%. The reduction of PU splitting for this part of CU can have great impact on video quality.

The right number of CU on proportion of the total number of CU is determined by counting small blocks of PU motion estimation. When the accuracy of small blocks of PU motion estimation is obtained, results of encoding statistics are showed in table 2.

Table 2. Accuracy statistics of motion estimation quick ending

Resolution	Sequence	Accuracy/%
416×240	BlowingBubbles	97.22
416×240	BasketballPass	98.89
416×240	BQSquare	99.19
832×480	BQMall	98.71
832×480	BasketballDrill	97.62
832×480	PartyScene	98.59
1280×720	Vidyo3	99.79
1280×720	Vidyo4	99.78
Average		98.72

In the table 2. in this paper accuracy of motion estimation quick ending is very high to 98.72% on average, which indicates that only small needed non $2N\times 2N$ mode motion estimation of CU is determined to have a motion estimation of $2N\times 2N$ mode. The part CU has little impact on overall effect to testify the reliability of this quick ending algorithm.

3.3 Flow chart of the algorithm in this paper

Steps of the algorithm in the paper are as follows:

Step1: When the current recursive depth $Depth_{cur}$ is 0, motion estimation of $2N\times 2N$ and non $2N\times 2N$ modes are calculated; if recursive depth is not 0, and $DeepME$ under the last $Depth_{cur}-1$ is true, motion estimation of non $2N\times 2N$ is calculated; otherwise, the calculation of motion estimation of non $2N\times 2N$ will be skipped;

Step2: If the current recursive depth is smaller than the biggest recursive depth, motion difference Var_{total} of all 4×4 motion vector for the current CU is calculated according to formula (3),(4)and(5).

Step3: If $Var_{total} < Var_{thresh}$, the mark of $DeepME$ under the $Depth_{cur}$ is set as true otherwise as false.

Step4: When the current CU is decomposed to 4 sub-CUs and 4 sub-CUs of recursive encoding, recursive depth will self-increase 1.

Step5When the best split of the current CU and RD query cost are determined, the current CU is ended to encode.

4. Experiment results and analysis

HEVC Reference software HM9.0 is adopted as a test platform to test the performance of the mentioned method. A total of 15 Video sequences with a resolution of 2560×1600, 1920×1080, 1280×720, 832×480 and 416×240 are tested. The experimental configuration is that size of CTU is 64×64, the maximum depth is 3. Low Delay(LD) and Random Access (RA) encoding structure were used and Quantizer Parameter(QP) 22, 27, 32 and 37 were adopted in the experiment to count noise ratio variation $\Delta PSNR$ in all frame and bitrate variation ΔBR and analyze the performance rate distortion for each algorithm. In order to measure changes of the algorithm complexity, encoding time variation rate ΔT of quick algorithm in the experiment is counted. When ΔT is negative, encoding time of the algorithm is reduced[13].

Calculation formulas are:

$$\Delta T = \frac{T_{pro} - T_{HM}}{T_{HM}} \times 100\% \quad (6)$$

$$\Delta BR = \frac{BR_{pro} - BR_{HM}}{BR_{HM}} \times 100\% \quad (7)$$

$$\Delta PSNR = PSNR_{pro} - PSNR_{HM} \quad (8)$$

Rate distortion and the whole performance of the quick algorithm in this paper are showed in table 3. This algorithm is horizontally compared with PMD algorithm of Xiong. Under LD and RA encoding configuration, the comparison results of PMD and HM algorithm are listed in table 4.

Table 3. Comparison between the algorithm in the paper and HM performance

Resolution	Sequence	LD			RA		
		$\Delta PSNR$ /dB	ΔBR /%	ΔT /%	$\Delta PSNR$ / dB	ΔBR /%	ΔT /%
2560×1600	Traffic	-0.069	2.9	-48.58	-0.047	1.4	-49.11
2560×1600	PeopleOnStreet	-0.034	1.1	-34.98	-0.038	0.9	-34.85
1920×1080	Kinomo	-0.021	0.9	-43.83	-0.032	0.8	-49.68
1920×1080	Cactus	-0.026	1.6	-45.46	-0.024	1.1	-44.58
1920×1080	ParkScene	-0.042	1.7	-48.58	-0.048	1.4	-53.12
1920×1080	BasketballDrive	-0.028	1.6	-49.01	-0.032	1.5	-48.26
1280×720	Vidyo1	-0.059	2.0	-58.21	-0.030	0.8	-57.98
1280×720	Vidyo3	-0.069	2.1	-57.78	-0.030	0.7	-56.81

1280×720	Vidyo4	-0.052	2.2	-55.86	-0.042	1.4	-54.62
832×480	PartyScene	-0.034	0.9	-26.98	-0.028	0.7	-28.14
832×480	RaceHorsesC	-0.027	0.8	-21.21	-0.031	0.8	-19.16
832×480	BasketballDrill	-0.110	2.7	-39.01	-0.078	1.9	-37.81
832×480	BQMall	-0.121	2.8	-38.51	-0.080	1.8	-38.15
416×240	BlowingBubbles	-0.024	0.9	-23.23	-0.026	0.6	-24.23
416×240	BasketballPass	-0.073	1.7	-34.56	-0.056	1.0	-33.17
	Average	-0.052	1.73	-41.79	-0.041	1.12	-41.98

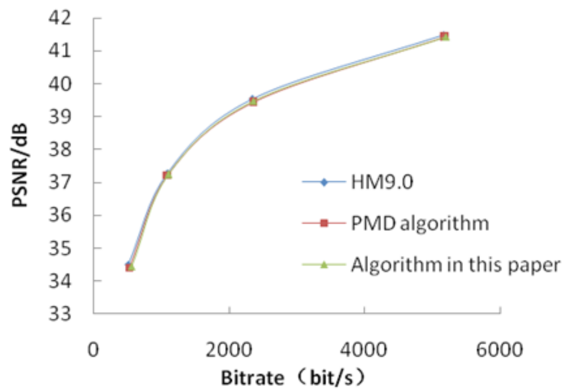
In table 3, compared with HM9.0 encoder, Encoding time of the algorithm in this paper was reduced by 41.79% and 41.98% respectively, ΔBR increased 1.73% and 1.12% and $\Delta PSNR$ decreased 0.052dB and 0.041dB on average under LD and RA encoding configuration. It is showed that the good rate distortion performance is guaranteed and encoding time is greatly reduced based on this algorithm. For some video sequences like Vidyo1 and Vidyo3, encoding time can be reduced up to 58.21% and 57.98% and acceleration effect of encoding is obvious under the different configuration. On the analysis of statistics of Var_{total} value distribution, for the high resolution of 720p video, 97% is accounted for CU of $Var_{total} < Var_{thresh}$ in which the best PU splitting of sub-CU is the proportion of $2N \times 2N$ to 99%. So, a large number of small pieces of PU motion estimation is reduced on the cut of small PU splitting for this CU to speed up encoding process. Under the condition of almost no quality loss, the algorithm can greatly reduce the time of the motion estimation and reduce the encoding complexity.

Table 4. Comparison between PMD algorithm and HM performance

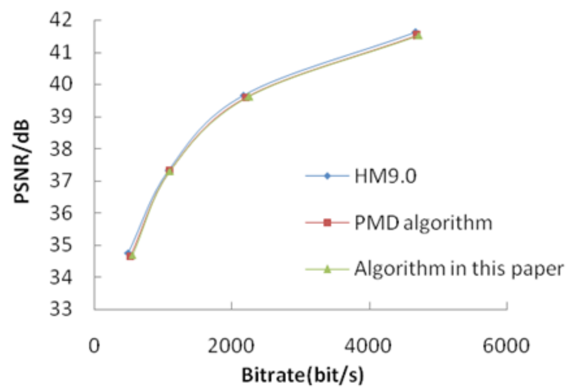
Resolution	Sequence	LD			RA		
		$\Delta PSNR$ /dB	ΔBR /%	ΔT /%	$\Delta PSNR$ /dB	ΔBR /%	ΔT /%
2560×1600	Traffic	-0.112	3.3	-49.70	-0.111	3.2	-48.61
2560×1600	PeopleOnStreet	-0.09	2.0	-37.67	-0.08	2.1	-35.76
1920×1080	Kinomo	-0.083	2.4	-34.66	-0.079	2.4	-33.17
1920×1080	Cactus	-0.064	2.5	-41.76	-0.056	2.4	-40.59
1920×1080	ParkScene	-0.078	2.5	-36.83	-0.081	2.5	-34.18
1920×1080	BasketballDrive	-0.102	4.6	-43.98	-0.102	4.5	-41.16
1280×720	Vidyo1	-0.079	2.3	-51.62	-0.081	2.2	-48.59
1280×720	Vidyo3	-0.077	2.1	-50.78	-0.078	1.9	-47.79
1280×720	Vidyo4	-0.077	2.6	-51.08	-0.078	2.5	-48.06
832×480	PartyScene	-0.072	1.5	-30.34	-0.069	1.6	-28.93
832×480	RaceHorsesC	-0.085	2.0	-30.91	-0.076	2.1	-28.19
832×480	BasketballDrill	-0.069	1.7	-42.19	-0.071	1.8	-41.01
832×480	BQMall	-0.085	2.0	-41.35	-0.079	1.9	-38.46
416×240	BlowingBubbles	-0.066	1.7	-23.60	-0.056	1.8	-21.97
416×240	BasketballPass	-0.056	1.2	-42.54	-0.051	1.1	-40.59
	Average	-0.079	2.29	-40.60	-0.077	2.27	-38.47

From table 4 and table 3, it can be seen that under LD and RA encoding configuration, ΔBR is reduced by 0.56% and 1.15% and $\Delta PSNR$ is improved 0.027dB and 0.036dB respectively, RD encoding performance is improved and encoding time is saved 1.19% and 3.51% for the algorithm in this paper compared with PMD.

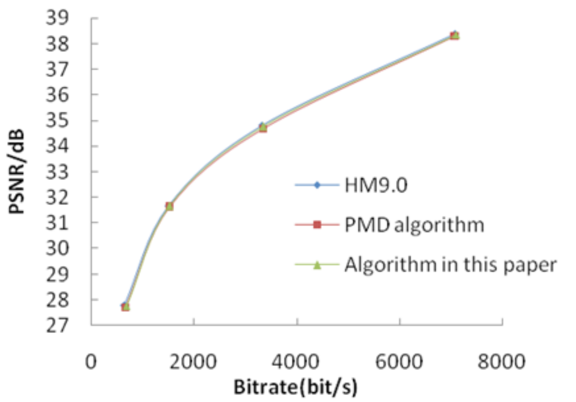
To more directly characterize encoding RD performance of fast termination algorithm proposed in this paper, taken Kinomo and PartyScene sequence as an example. Under the condition of different quantitative parameters, rate distortion of HM9.0, PMD algorithm and the algorithm in the paper are shown in figure. 3. PSNR is peak signal to noise ratio and bit rate is the size of bit stream for per second. From the figure 3 it can be seen that under the different encoding configuration, under different bit rates Kinomo and PartyScene sequence, RD performance is similar in each scheme compared with HM9.0.



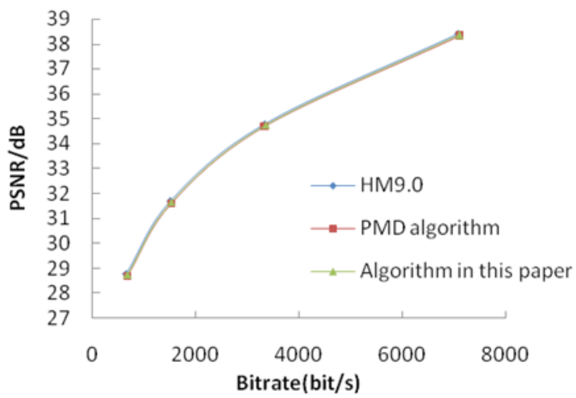
(a) Kinomo (LD)



(b) Kinomo (RA)



(c) PartyScene (LD)



(d) PartyScene (RA)

Figure 3. RD diagram of each scheme under LD and RA encoding configuration

5. Conclusions

In view of HEVC encoding process and highly complicated calculation problems of CU recursive division, this paper proposes a fast inter-prediction algorithm on motion homogeneity. The algorithm adopts motion homogeneity of the same object in video sequence to make a reasonable selection for the division method of current CU and end motion estimation of less likely complex division mode in advance. Based on the analysis of the current motion vector difference degree, algorithm measures whether the current coding blocks are in the similar motion regions. If in the similar motion regions, small PU splitting motion estimation is cut after decomposition of to end motion estimation in advance. The experimental results show that, compared with HM9.0 standard platform, in this paper under LD and RA encoding configuration, encoding time is reduced by 41.79% and 41.98% respectively, ΔBR is increased 1.73% and 1.12%, $\Delta PSNR$ is reduced by 0.052 dB and 0.041 dB on average according to the algorithm in this paper. On the premise of guaranteeing good rate distortion performance, this algorithm sharply reduces encoding time and lower encoding complexity.

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