Fast Inter-Mode Decision Algorithm for High-Efficiency Video Coding Based on Textural Features

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Abstract —Due to the problems of the new generation of video coding standard HEVC (High-Efficiency Video Coding), such as high computational complexity and the large computation, This paper proposes a fast inter-mode decision algorithm based on image texture features and by using Sobel operator the edge features are extracted from CU which is partitioned by simulation, and then the final partitioning size of CU is determined by the texture features contained in the current CU block of simulation partitioning. By using this method, both of the traverse layers of CU depth and the times of inter predictive coding are reduced. Thus the computational complexity of coding terminal is lowered effectively. The experimental results showed that, compared with inter-mode decision algorithm in HEVC standard, the time of this method is saved 45.35% on average with little loss of coding efficiency and *PSNR* (peak signal-noise ratio).

Index Terms—HEVC, inter frame, texture feature, coding depth

I. Introduction

The new generation of the video compression standard HEVC (High Efficiency Video Coding) was JCT-VC (Joint Collaborative Team on Video Coding) jointly established by ISO/IEC (MPEG) and Video Coding Experts Group (VCEG) of ITU-T, and it was determined in the first JCT-VT meeting convened in April, 2010 in Germany along with the test software HM(HEVC Model) [1]. HEVC was formally determined as the international standard in the 12th JCT-VT meeting convened in January of 2013 in Switzerland. It mainly serves high-definition video which is gradually promoted now [2].

Compared with the H.264/AVC, the aspects improved by HEVC mainly are: (1) the size of macroblock extends from 16×16 of H.264/AVC to 64×64 so as to the compress for video of high resolution, at the same time, the luminance component has 35 defined prediction modes and the chrominance component has 6 in intra prediction technology; (2) flexible coding structure includes CU (Coding Unit), PU (Prediction Unit) and TU (Transform unit), and the CU of largest size is called as LCU (Largest Coding Unit); (3) sample adaptive offset (SAO), adaptive loop filter and parallel structure [3].

Many advanced coding techniques make the HEVC compression performance more efficient. Compared with H.264/AVC, at the objective performance, the quality of the reconstructed image with the same *PSNR* , the encoding rate of HEVC can be saved by 40%; at the subjective performance, the quality of reconstructed image with the same subjective quality, encoding rate of HEVC can be saved by more than 50%. It explains the advantages of HEVC standard [4]. However, HEVC efficiency is at the cost of huge computational complexity. So the problem of fast coding optimization of HEVC encoder has been the research hotspot in academic circle.

In the H.264/AVC research, fast inter algorithm can generally be summarized as follows.

By using temporal/spatial correlation of a sequence of images, the prediction encoding mode can be selected correctly [5]. The excess calculation time of full search rate distortion cost function can be reduced through the method of hierarchical structure decision [6]. The candidate list of the final calculation of the rate-distortion is reduced through early mode determination [7]. By using statistical methods, the calculation speed of determining inter mode is accelerated [8]. Based on Sobel operator, the optimal prediction mode is obtained through detecting the continuity of the moving edge of the macroblock [9]. Based on the pixel information contained in the macroblock, the computational complexity of inter frame predictive coding is reduced [10].

Above-mentioned methods obtain better results, but all of them take improvements for H.264/AVC. Therefore, it is not applicable to HEVC to a great extent.

In the research of HEVC, the coding depth range of CU can be better determined by estimating the optical flow of the sample frame [11] and the temporal/spatial correlation of video sequences [12]. Bayesian decision algorithm can reduce the computational complexity [13]. During the encoding process, the efficiency of inter-coding can be well improved by sharing movement information through the merger patterns [14].

HEVC inter-mode coding processes and existing judgment techniques of fast inter-mode PU mode are mainly introduced in the following Part Two of this paper. The algorithm based on Sobel operator is proposed in Part Three. Experiment results and data analysis are

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obtained in Part Four. The conclusion of this paper is listed in the last part.

II. Introduction of HEVC Inter-Mode Coding Processes and Existing Judgment Techniques of Fast Inter-Mode PU Mode

A. The Procedures of HEVC Inter-Mode Coding

In the test model of HEVC, the default setting of HM code supports four CUs, i.e. 64×64, 32×32, 16×16, 8×8, and the corresponding coding depths are 0, 1, 2, 3. The size of PU varies from 64×64 to 4×4, and in accordance with the predicted types, symmetric mode similar with H.264/AVC ($2N\times 2N$, $2N\times N$, $N\times 2N$, $N\times N$) and new asymmetric mode ($2N\times nU$, $2N\times nD$, $nL\times 2N$, $nR\times 2N$) AMP (asymmetric motion partitions) are provided.

During the process of HEVC inter-mode prediction, single frame picture is separated from non-overlapping LCUs. In LCU quad-tree recursive partition is being carried out until it reaches the maximum depth of coding, as shown in Fig. 1. For CU under different coding depth , all the PU modes of that size will be traversed, and ultimately CU size and PU mode shall be determined by comparing RD-cost (Rate Distortion-cost). Specific processes are shown in Fig. 2.

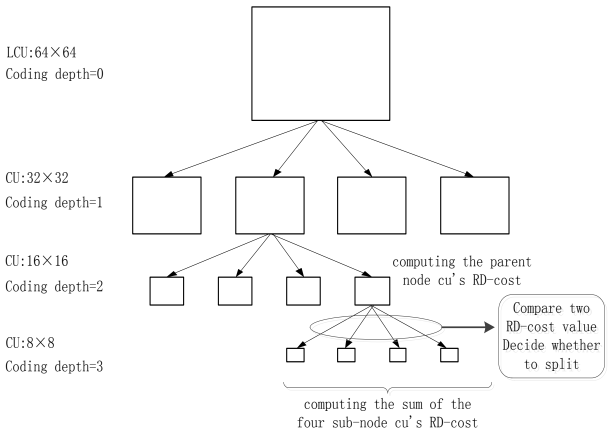

Fig. 1. CU quad-tree recursive partitioning process

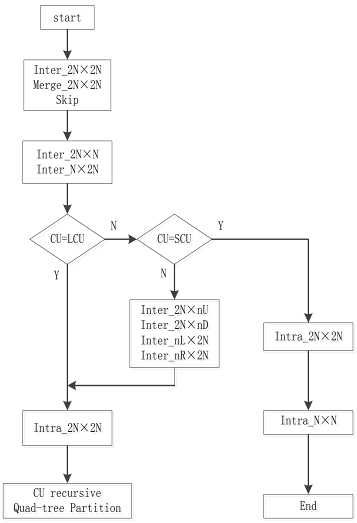

Fig. 2. HEVC inter-mode prediction process

It is known from the analysis above that without considering non-symmetric mode, for CU of each depth, during its inter prediction mode, the RD-cost of one skip mode, one merge mode, one $2N\times 2N$ inter-mode, two $2N\times N$ inter-mode, two $N\times 2N$ inter-mode and one $2N\times 2N$ intra-mode (eight in total) need to be calculated, and for the circumstance of CU with maximum coding depth as well as the size of 8×8, another four RD-cost of $N\times N$ intra-mode need to be calculated. In the case of taking no account of asymmetric mode, RD-cost shall be calculated for 8 times, 4×8=32 times, 4×4×8=128 times and 4×4×4×(8+4) =768 times when the coding depth is respectively 0, 1, 2 and 3. Take one LCU as an example, even without considering asymmetric mode, RD-cost still need to be calculated for 8+32+128+768=936 times. Thus although HEVC used coding mode which combines CU and PU to make more accurate forecasts and achieve better prediction results, it increased the computational complexity greatly.

B. Introduction of Existing Judgment Techniques of Fast Inter-Mode PU Mode

In the research on HEVC, two algorithms proposed in ref. [15], [16] reduce the computational complexity greatly in the premise of ensuring the coding performance, and these two algorithms have been recorded in HEVC test model (HM) code. And they are be used as optional configuration in accelerating HEVC coding. They are closed in HEVC default configuration reference.

Ref. [15] is defined as ESD (Early SKIP Detection setting) in HEVC configuration code, and a method of stopping PU mode in advance is proposed in this reference. In this method, it will check the values of DMV (differential motion vector) and CBF (coded block flag) to determine whether early termination should be taken to traverse to other PU mode. Ref. [16] is defined as CFM (CBF Fast Mode setting) in HEVC configuration code. In the reference the PU mode to be calculated is determined by judging the CBF value. If CBF is equal to 0, it shows that all coefficients of residual after changing quantization is 0 means and that current predictive accuracy is very high. Therefore, other PU modes under current depth shall be stopped traversing.

At present, these two algorithms have been treated as the optional configuration of accelerating HEVC coding. In order to calculate the time saved by these two algorithms, this paper has a statistics to various QP values of nine series, as shown in Table I. Time can be saved by 31.31% averagely at starting these two algorithms at the same time, which can be seen from Table I. Above-mentioned two algorithms reduce PU modes through judging conditions to achieve reducing the process of computational complexity. However, the algorithm proposed in this paper determines CU size through textual features of image to reduce the coding depth needed to be traversed to finally reach to the goal of further saving coding time on the basis of ref. [15], [16].

TABLE I: THE TIME SAVED BY USING FAST ALGORITHM IN THE REFERENCE [15], [16]

Sequence	QP=22 (%)	QP=27 (%)	QP=32 (%)	QP=37 (%)	Average value (%)
BQSquare (416×240)	-8.73	-23.96	-35.48	-44.03	-28.05
BlowingBubbles (416×240)	-11.33	-22.82	-32.72	-37.83	-26.18
PartyScene (832×480)	-5.74	-14.71	-23.04	-31.12	-18.65
RaceHorses (832×480)	-4.54	-13.94	-22.15	-29.04	-17.42
Johnny (1280×720)	-29.00	-43.10	-47.70	-51.60	-42.85
KristenAndSara (1280×720)	-33.08	-43.90	-49.46	-52.25	-44.67
BQTerrace (1920×1080)	-10.01	-30.42	-43.78	-49.87	-33.52
Cactus (1920×1080)	-15.53	-25.84	-40.83	-43.91	-31.53
PartyScene (1920×1080)	-39.97	-30.65	-39.60	-45.56	-38.94
average value	-17.55	-27.70	-37.20	-42.80	-31.31

III. PROPOSED ALGORITHM BASED ON SOBEL OPERATOR

For regions of each inter-mode image having smooth and similar textures in video sequence, after comparing RD-cost value, these regions usually select CUs of larger size to code; while regions of each inter-mode image having rich and complex textures details and regions of strong motions etc. in video, after selecting RD-cost, these regions usually select CUs of smaller size to code. Based on this characteristic we can conclude that textural features of each frame in video are closely related to CU size finally determined.

A. Inspection Method of Image Edge

Image gradient operator can better adapt to the changing trend of an image. Edge inspection usually uses various differential operators to extract image borders. The commonly used for edge detection operators are Sobel, Roberts, Prewitt and Canny. Wherein, Sobel operator weighs the effects of pixel positions, so the result is good. It has smooth effect on noise and provides more precise information of edge direction. This paper shall take Sobel operator as the basis of judging textures to finally determine the size of coding block through improvement.

Sobel operator of convolution factor as follows, presumed $f(x,y)$ is the image function. G_x, G_y represent transversal and longitudinal gray value of image for edge inspection, respectively.

$$\begin{aligned} G_x = &\{f(x-1,y+1)+2f(x,y+1)+ \\ &f(x+1,y+1)\}-\{f(x-1,y-1)+ \\ &2f(x,y-1)+f(x+1,y-1)\} \end{aligned} \quad (1)$$

$$\begin{aligned} G_y = &\{f(x+1,y-1)+2f(x+1,y)+ \\ &f(x+1,y+1)\}-\{f(x+1,y+1)- \\ &2f(x-1,y)+f(x-1,y+1)\} \end{aligned} \quad (2)$$

B. LCU Partition Algorithm Based on Sobel Operator

Sobel value of single pixel can be calculated from previous section, and for coding block of various sizes, the definition formula is:

$$G_{sum} = \sum_{x=1}^{x<width} \sum_{y=1}^{y<height} \sqrt{(G_x)^2 + (G_y)^2} \quad (3)$$

Wherein, width refers to the width of current CU size, height refers to the height of current CU size.

In order to distinct G_{sum} of different sizes, for G_{sum_ab} is concerned, wherein, a refers to the coding depth, b refers to serial number, as shown in Fig. 3.

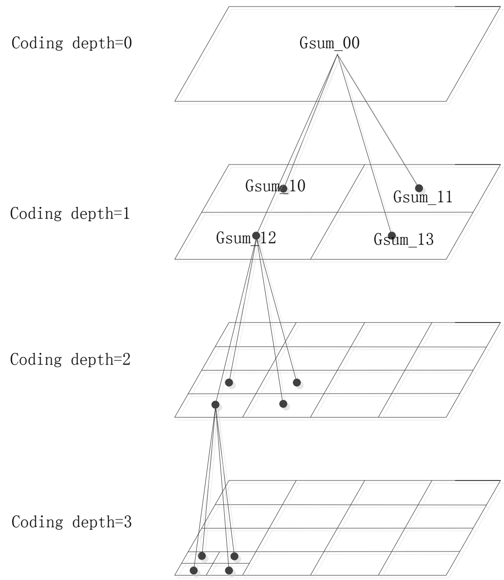

Fig. 3. The sobel value corresponding to each scale based on quad-tree partition

Firstly, G_{sum_00} of CU size with 64×64 shall be calculated when the current coding depth is 0. Then, when the coding depth is 1, G_{sum_10}, G_{sum_11}, G_{sum_12}, G_{sum_13} can be obtained by using the method of quad-tree partition.

Due to standard derivation, as measurement on the degree of statistical distribution most commonly used in probability statistics, which can better reflect the dispersion degree between individuals in the group. The formula of standard derivation is as shown in (4)

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \frac{1}{N}\sum_{j=1}^{N}x_j)^2} \quad (4)$$

By imitating this thought we have defined (5)

$$Th = \sqrt{\frac{1}{4}\sum_{i=1}^{4}(G_{sum\_ai} - \frac{1}{4}\sum_{j=1}^{4}G_{sum\_aj})^2} \quad (5)$$

In order to calculate reasonable Th values, we have carried out a number of experimental statistics, employed different resolutions including the first 100 frames of nine video sequences in total for statistical. Finally, the Th value is set to 15. When $Th \geq 15$, it means that the detailed textures in this region are relatively more which calls for the needs of further partition. So repeat operations of similar step (1) and add 1 to the coding depth. When $Th < 15$, it means that this region is relatively flat and there is no need for further partition .The specific steps are shown in Fig. 4.

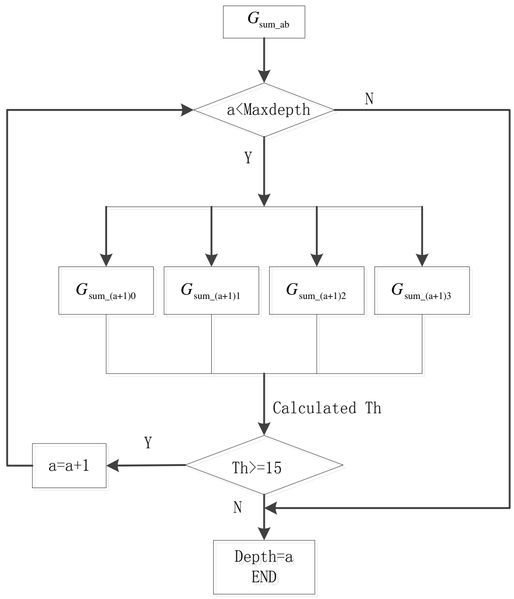

Fig. 4. The flowchart of determing the final block by sobel operator

C. *Algorithm Improvement*

Although Sobel operator has a smoothing effect on noise, the subject of image is not strictly separated from the background. Thus, the positional accuracy of edge is not very high. Taking this into account, in order to make the accuracy of compressed encoding higher, after finishing LCU partition based on Sobel operator and at the start of the predictive coding of LCU, corresponding improvement are made so as to prevent derivation caused by algorithm.

Firstly, we conducted relevant experimental statistics for different video sequence under different resolutions carrying out final statistics of CU partition. The experiment result is as shown in Fig. 5. In the sequence of smaller resolutions, the probability of best CU size being 16×16 or 8×8 is higher that can be seen from Fig. 5. However, for sequence of higher resolutions, the probability of best CU size being 64×64 or 32×32 is higher. For this discipline, 832×480 is taken as the demarcation point, for video sequence of resolution being the same with or smaller than it, when taking predictive coding of LCU, not only PU prediction mode of coding depth determined by Sobel operator shall be traversed, but the next layer of this coding depth shall be taken into consideration, too. While sequence video with resolution being higher than 832×480 takes LCU predictive coding, not only PU prediction mode of coding depth determined by Sobel operator shall be traversed, but the previous layer of this coding depth shall be considered. The improvement strategy is as shown in Table Ⅱ.

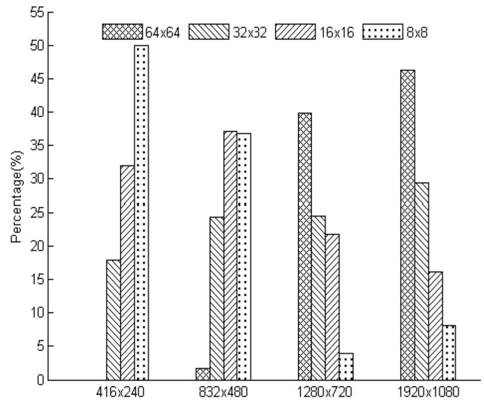

Fig. 5. The percentage of different encoding size of the final block at different resolutions

TABLE II: THE FINAL NUMBER OF CODING LAYERS AT DIFFERENT RESOLUTIONS

Resolution	The number of layers ultimately need to be encoded
416×240	The present layer and the next layer determined by the Sobel operator
832×480	The present layer and the next layer determined by the Sobel operator
1280×720	The present layer and the upper layer determined by the Sobel operator
1920×1080	The present layer and the upper layer determined by the Sobel operator

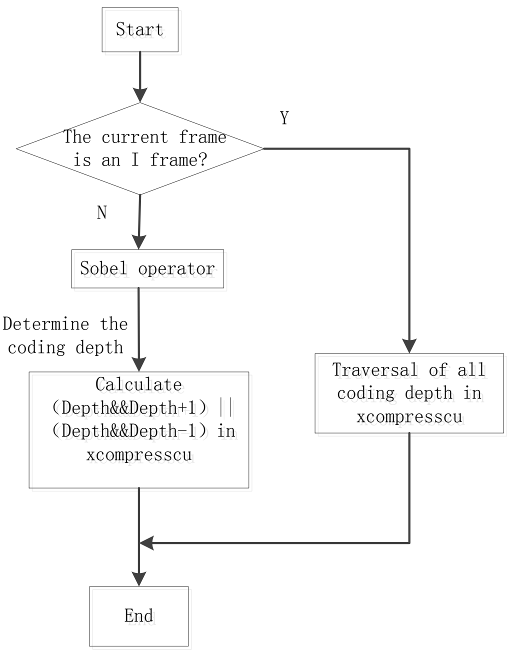

Fig. 6. The flowchart the proposed algorithm

D. *Specific procedures of the algorithm*

Specific processes of the algorithm as shown in Fig 6:

1) Judge whether the current coding frame is I frame, if so, skip the following steps and directly enter into Xcompresscu (kernel function of predictive coding to CU) which employs quad-tree recursive call to code, if not, conduct step 2);

2) A function calculating Sobel operator shall be added before Xcompresscu. Set CU depths as 0, and G_{sum_00} is obtained from Sobel operator;

3) The depth plus 1, four Sobel values under current depth shall be obtained by quad-tree partition;

4) Using judgment conditions of Formula 5, when and the current CU depth < the largest coding depth, jumping to (3); when and the current CU depth =the largest coding depth, final CU depth shall be determined to be equal to current depth; if , final CU depth shall be determined to be equal to current depth -1;

5) After entering into Xcompresscu, coding depth determined by Sobel operator and PU prediction mode under this depth +1 or PU prediction mode under this depth -1 shall be traversed in accordance with video resolution.

TABLE III: THE EXPERIMENTAL STATISTICAL RESULTS

Sequence	QP	Comparison of the proposed algorithm with HM9.0			Comparison of the proposed algorithm + literature [15-16] and literature [15-16]		
		$\Delta PSNR$(Y)(dB)	$\Delta BR(\%)$	$\Delta T(\%)$	$\Delta PSNR$(Y)(dB)	$\Delta BR(\%)$	$\Delta T(\%)$
BQ Square (416×240)	22	-0.001	0.22	-31.59	-0.01	-0.04	-32.65
	27	0.009	0.78	-31.05	0.00	0.29	-32.79
	32	0.003	1.51	-27.22	0.01	1.35	-30.14
	37	-0.039	2.52	-25.51	-0.03	2.29	-29.74
Blowing Bubbles (416×240)	22	-0.003	0.58	-31.03	-0.01	0.46	-29.78
	27	0.005	0.82	-32.28	0.00	0.97	-31.38
	32	-0.013	1.49	-31.68	-0.02	1.08	-31.28
	37	-0.048	2.43	-30.06	-0.06	2.47	-32.43
Party Scene (832×480)	22	-0.013	1.4	-34.88	-0.02	1.34	-33.30
	27	0.017	1.62	-34.08	-0.01	1.70	-35.37
	32	-0.031	1.81	-35.99	-0.03	1.61	-35.69
	37	-0.051	1.58	-35.24	-0.05	1.55	-35.45
Race Horses (832×480)	22	-0.002	0.93	-34.5	0.00	1.03	-31.82
	27	0.001	1.24	-37.28	0.00	1.33	-34.35
	32	-0.015	1.85	-38.96	-0.02	1.61	-38.20
	37	-0.02	2.76	-39.57	-0.03	2.58	-41.33
Kristen and Sara (1280×720)	22	-0.044	1.02	-57.82	-0.05	0.58	-49.78
	27	-0.04	0.91	-59.03	-0.05	0.65	-47.44
	32	-0.025	1.00	-60.03	-0.05	0.64	-47.56
	37	0.028	1.31	-60.1	-0.04	1.23	-47.57
Johnny (1280×720)	22	-0.057	0.22	-55.13	-0.06	-0.13	-49.55
	27	-0.033	0.18	-56.02	-0.05	0.10	-46.50
	32	-0.047	0.28	-57.42	-0.05	0.31	-49.52
	37	-0.036	1.72	-61.28	-0.06	0.94	-49.90
BQ Terrace (1920×1080)	22	-0.061	1.47	-49.11	-0.06	1.53	-46.02
	27	-0.085	0.14	-48.12	-0.09	0.03	-41.57
	32	-0.045	0.01	-50.1	-0.06	0.01	-39.96
	37	-0.032	0.34	-51.33	-0.03	0.38	-39.96
Cactus (1920×1080)	22	-0.06	1.86	-52.94	-0.06	2.00	-47.63
	27	-0.048	2.07	-50.7	-0.07	2.03	-43.09
	32	-0.046	1.37	-54.62	-0.07	1.23	-40.58
	37	-0.031	0.86	-53.59	-0.06	0.62	-40.19
Party Scene (1920×1080)	22	-0.18	2.9	-66.05	-0.11	2.64	-45.48
	27	-0.083	1.67	-50.71	-0.10	1.63	-42.82
	32	-0.07	0.53	-52.11	-0.08	0.58	-42.45
	37	-0.03	0.9	-55.24	-0.06	0.60	-45.49
Average Value		-0.03	1.23	-45.34	-0.04	1.09	-39.96

IV. EXPERIMENT RESULT AND RELEVANT ANALYSIS

All experiments in this paper employ encoder_lowdelay_P_main.cfg of low-latency coding structure, in this configuration document, except from the first frame being I frame (Intra-Coded Picture), others are P frame (Prediction-Coded Picture). Inter-mode prediction employs inter-mode temporal correlation of video image, so in order to prevent the error diffusion, this paper employ HEVC standard coding frame instead of encoding I frame by using Sobel operator. Meanwhile, Intra Period shall be set as 8 in configuration document, and the final coding series shall be IPPPPPPPIP… This improvement has little effect on time but it can lower bitrate better.

Experiments in this paper select HM9.0 as test model. Testing environment of experiments complies with HM9.0 test standard, which uses configuration document of lowdelay_P_main and selects the first 100 frames of nine video sequence of different resolutions to test in the case of quantization parameter QP=22, 27, 32, 37, respectively. In order to adequately testify the superiority of this paper's algorithm, experiment shall be carried out in the condition of closing and opening these two accelerating tools (ESD and CFM) of HM9.0.

Experimental results are as shown in Table Ⅱ, $\Delta PSNR(\mathrm{Y})$, ΔBR and ΔT respectively means the increase and decrease between algorithm in this paper and HM9.0 algorithm on three values , i.e. *PSNR* (peak signal to noise ratio), code rate and coding time, the calculation formula is:

$$\Delta PSNR(\mathrm{Y}) = PSNR(\mathrm{Y})_s - PSNR(\mathrm{Y})_{hm9.0} \tag{6}$$

$$\Delta BR = \frac{BR_s - BR_{hm9.0}}{BR_{hm9.0}} \times 100\% \tag{7}$$

$$\Delta T = \frac{T_s - T_{hm9.0}}{T_{hm9.0}} \times 100\% \tag{8}$$

where $PSNR(\mathrm{Y})_s$, BR_s and T_s receptively represent $PSNR$, bit rate and final coding time obtained from coding by algorithm referred in this paper. It is seen from Table Ⅲ that, comparing algorithm in this paper with fast inter-frame perdition algorithm of HEVC standard, the time is averagely saved by 45.35%, at the same time, there is little fluctuation of code rate and $PSNR$. Even if in the condition of taking part in the fast algorithm of ref. [15-16], this paper's algorithm still can reduce the coding time by 39.96% with little fluctuation of code rate and $PSNR$.

Through the observation of experimental data, it can be found that for many sequences ΔBR will increase by the increasing QP value. This is because, with the increase of QP, pixel textures of image frame tend to be flat so the probability of CU employing large size is relatively higher. But the threshold value of this paper is fixed; therefore, a very good adaptive process is not achieved. But, through the observation of overall data, this paper's algorithm still has a very obvious effect on saving coding time.

V. Conclusion

An algorithm of fast CU size decision based on Sobel operator is proposed in this paper, before taking LCU coding in HM code, by using textural features between video images, this algorithm determines the coding depth of final CU so as to reach the goal of reducing traversed coding layers and lowering computational complexity. Though the value of ΔBR will change with the increasing QP value for the sequence of different resolutions as the original coding features of HM, and with the increasing of sequence resolution and QP values, the probability of CU employing large size is relatively higher, it can be easily solved by employing adaptive threshold and using more and more precise way in CU division in the late work. What is the most important is its time saving of this algorithm. It can be found from the experiment data that the algorithm in this paper can save time of 45.34% averagely with little change of bit rate and $\Delta PSNR$. Even if in the condition of taking part in the fast algorithm of ref. [15], [16], this paper's algorithm still can reduce the coding time by 39.96%. This is because, at present, most of HEVC inter-mode fast algorithms reduce to traverse PU prediction mode to lower the computational complexity by using the temporal and spatial correlation. It is before taking LCU coding in HM code that algorithm used in this paper is to reduce traversed layers. So the combination with fast HEVC inter-mode algorithm of reducing PU prediction mode can be conducted.

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