

Fast Intraframe Coding for High Efficiency Video Coding

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Abstract

The High Efficiency Video Coding (HEVC) is a new video coding standard that can provide much better compression efficiency than its predecessor H.264/AVC. However, it is computationally more intensive due to the use of flexible quadtree coding unit structure and more choices of prediction modes. In this paper, a fast intraframe coding scheme is proposed for HEVC. Firstly, a fast bottom-up pruning algorithm is designed to skip the mode decision process or reduce the candidate modes at larger block size coding unit. Then, a low complexity rough mode decision process is adopted to choose a small candidate set, followed by early DC and Planar mode decision and mode filtering to further reduce the number of candidate modes. The proposed method is evaluated by the HEVC reference software HM8.2. Averaging over 5 classes of HEVC test sequences, 41.39% encoding time saving is achieved with only 0.77% bitrate increase.

Keywords: HEVC, fast mode decision, intraframe coding, intra coding

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1. Introduction

The High Efficiency Video Coding (HEVC) is a new video coding standard developed by the Joint Collaborative Team on Video Coding (JCT-VC) formed by the ITU-T Video Coding Experts Group (VCEG) and ISO/IEC Moving Picture Experts Group (MPEG). In comparison with its predecessor H.264/AVC, 50% bitrate reduction is achieved for equal perceptual quality [1]. While the same block-based hybrid coding structure as in H.264/AVC is adopted in HEVC, each coding tool is improved with new technical features and characteristics. As opposed to the fixed size macro-block (MB) in H.264/AVC, the coding tree unit (CTU) in HEVC is configurable and its size can be chosen from 64x64, 32x32 and 16x16. A CTU consists of one coding unit (CU) or can be recursively split into a quadtree of CUs. The largest size of a CU is equal to that of a CTU, and the smallest is 8x8. An example of CU splitting and its corresponding quadtree is shown in Fig. 1. The dotted lines with arrows represent the processing order of the CUs in the CTU, the notation “1” in the quadtree indicates further splitting and “0” indicates leaf node. A CU can be further split into multiple prediction units (PU) for inter or intra prediction. In intra coding, the PU partition type can be either PART_2Nx2N or PART_NxN, as shown in Fig. 2. However, PART_NxN is only allowed for the minimum CU size, otherwise it is similar as four equal-size sub-CUs.

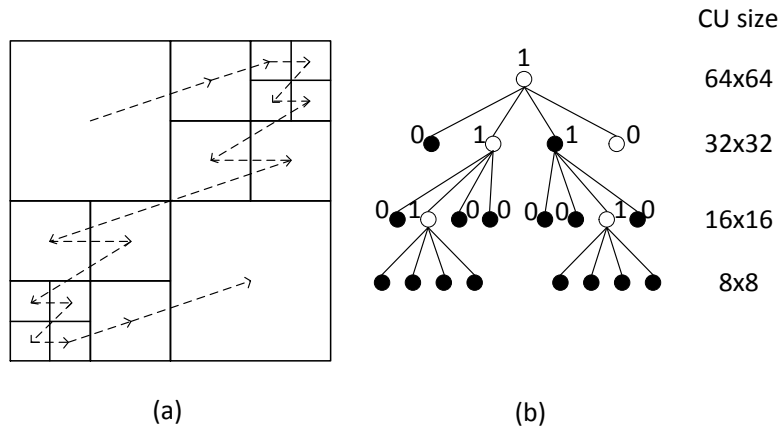


Fig. 1. Example of a 64x64 CTU and its CU partition and processing order. (a) CU partitions (b) quadtree structure

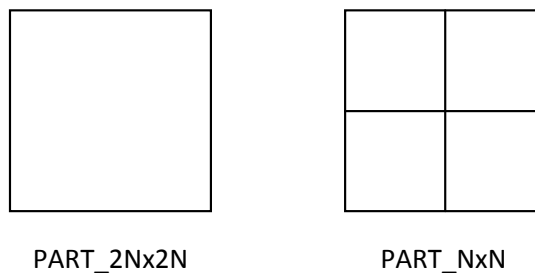


Fig. 2. PU types for intra prediction

During the transform and quantization process, a CU can also be recursively split into a quadtree of transform unit (TU). The intra prediction is applied for each TU sequentially instead of applying the intra prediction at the PU level [2]. In this way, the nearest neighboring reference samples from the already reconstructed TU are used for prediction. The HEVC defines 35 intra prediction modes, namely *Intra_DC*, *Intra_Planar* and 33 angular prediction modes denoted as *Intra_Angular*[k], $k = 2, \dots, 34$. In comparison with H.264/AVC, the intra prediction modes defined in HEVC are able to capture more directional structures.

In the HEVC test mode (HM), a rate-distortion (RD) optimized bottom-up pruning algorithm [3] is adopted to find the best CU partition of a CTU. Given a CU, the best PU partition type, prediction mode and TU partition are found by minimizing the Lagrangian cost. While the flexible block structure and more choices of prediction mode provide better coding performance, it dramatically increases the encoder complexity. Even for intraframe coding, it is still far away from real-time application [4]. The computational complexity mainly comes from two folds. First, an optimal CU partition within a CTU can consist of various sizes of CU ranging from 8×8 to 64×64 . Second, finding an optimal prediction mode requires a RD optimization process. Therefore, fast algorithms in both aspects are desirable. Research works regarding fast CU size decision include [5-8]; works targeting fast intra mode decision include [9-15]. In our previous work [16], a novel fast bottom-up pruning (FBUP) algorithm was proposed and proved to be efficient. In this paper, three techniques are proposed for fast intra mode decision and combined with the FBUP algorithm. Starting from the smallest CU size, a full quadtree is processed in a bottom-up manner. First, we check whether mode decision process is needed for a current CU node. If the mode decision process is performed, then a set of intra candidate modes are derived from the coding information obtained from its sub-blocks (sub-CUs or PART_NXN PUs), followed by a rough decision process to choose a smaller set of candidates. The number of candidates in the set is adaptively chosen based on the low complexity RD cost. In this way, we can either skip the mode decision process or reduce the number of candidate modes. Thus, the computational complexity is reduced.

In Section 2, the previous works in the literature are reviewed. Then the proposed method is described in Section 3. In Section 4, the experimental results are presented to prove the efficiency of the proposed algorithm. Compared to the original HM encoder, averaging over all the test sequences and rate points, 41.39% encoding time saving is achieved while the bitrate increase is only 0.77%. Finally, the conclusion is given in Section 5.

2. Related Works

2.1 Rate-Distortion Optimized Bottom-up Pruning

In HEVC, the CTU size is 64×64 and the maximum number of depth levels of the quadtree is $D = 4$. The HM encoder adopts the rate-distortion optimized bottom-up pruning algorithm to obtain the optimal CU quadtree partition. Consider the full quadtree as shown in Fig. 3, we locate a node by its depth level from top to bottom and its position from left to right. Let (i, j) be the index of j th node at depth level i , then $j < 4^i$. Denote $X_{i,j}$ as a CU at node (i, j) without further splitting and $C_{i,j}$ as the optimal tree after rate-distortion optimized pruning. Let $J(\cdot)$ be the operation to calculate the best RD cost. The bottom-up pruning algorithm

traverses the full quadtree in a depth-first order. The sub-CUs of node (i, j) is pruned if and

$$\text{only if } J(X_{i,j}) \leq \sum_{k=0}^3 J(C_{i+1,4j+k}).$$

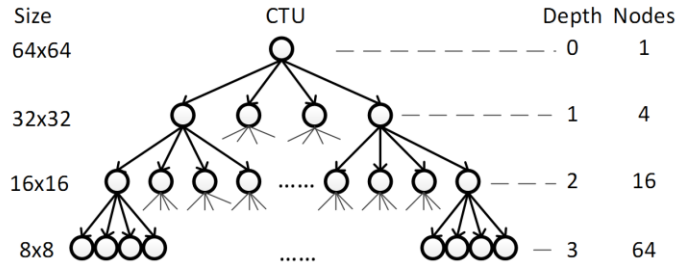


Fig. 3. Full quadtree

2.2 Fast Intra Mode Decision Algorithm in HM

Full RD optimized search in the 35 intra prediction modes is computational complex. To reduce the encoder complexity, the HM encoder adopts a fast intra mode decision algorithm, which consists of two steps described as follows.

1. Rough mode decision: choose the N best candidate modes by minimizing $J_{SATD} = D_{SATD} + \lambda R_{mode}$.

2. Given the N candidate modes in step 1 and the *most probable modes* (MPM) derived from neighboring PUs, do R-D optimized mode decision. The best intra mode is found by minimizing $J_{fullRD} = D_{rec} + \lambda R_{total}$.

D_{SATD} is the Sum of Absolute Transformed Difference (SATD) which calculates the sum of absolute value of hadamard transformed coefficients of the residual signal, R_{mode} is the number of bits to encode mode information, D_{rec} is the distortion of the reconstructed block, R_{total} is the total number of bits to encode current block and λ is the Lagrangian multiplier. Calculation of J_{SATD} doesn't require the DCT transform, quantization and entropy coding process, thus it's much simpler than calculation of the full RD cost J_{fullRD} . Therefore, the computational complexity can be reduced if N is set to a smaller value. In the HM encoder N is set to 3, 3, 3, 8 and 8 for the PU sizes of 64×64 , 32×32 , 16×16 , 8×8 and 4×4 respectively.

3. Proposed Methods

3.1 Fast bottom-up Pruning Algorithm

3.1.1 Analysis of Bottom-up Pruning Algorithm

The bottom-up pruning algorithm performs mode decision at each node of the full quadtree. Therefore, a total of $\sum_{i=0}^{D-1} 4^i$ mode decisions for each CTU. However, given a CU at

node (i, j) , the best partition and prediction modes of its sub-CUs $C_{i+1,4j+k}, k = 0,1,2,3$ are known. Thus, we can reuse the coding information in sub-CUs to check whether mode decision at current node is necessary.

Table 1. The probability $p_0 = P(J(X_{i,j}) > J(C_{i,j}) | \sum_{k=0}^3 Q(C_{i+1,4j+k}) = n)$

i	$n=0$	$n=1$	$n=2$	$n=3$	$n=4$
0	0.97	0.98	0.99	1.00	1.00
1	0.49	0.76	0.88	0.95	0.98
2	0.33	0.69	0.86	0.92	0.97

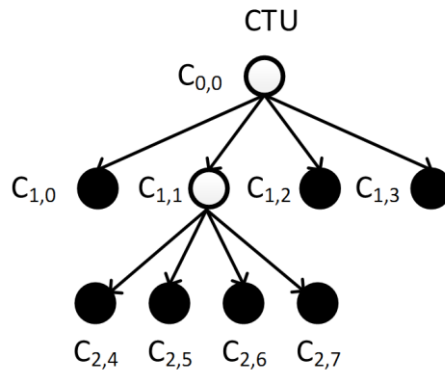


Fig. 4. Example of a pruned quadtree.

Let $Q(\cdot) = 0$ indicates a leaf node and $Q(\cdot) = 1$ denotes a tree. Then $Q(C_{i+1,4j+k}) = 1$ suggests that the structural information in the k th sub-CU is complex. Hence, the current node is likely to be split. In **Table 1**, it shows the probability p_0 of a node is split when $\sum_{k=0}^3 Q(C_{i+1,4j+k}) = n$, i.e. $p_0 = P(J(X_{i,j}) > J(C_{i,j}) | \sum_{k=0}^3 Q(C_{i+1,4j+k}) = n)$. The results are obtained by coding the first second (50 frames) of HEVC test sequence *BasketballDrill*. Similar statistics are found in coding the other sequences. Note that at level 3, it reaches the leaf node of the quadtree, thus the CU doesn't have any sub-CUs. However, HEVC allows PART_NxN type PU at the bottom level, in which the CU can also be considered as a tree.

3.1.2 Fast bottom-up Pruning Algorithm

Based on the above observations, we can conclude that there is a high probability that a CU remains split if its sub-CUs are sub-trees. In other words, lots of mode decision process in a large CU is unnecessary. Therefore, they could be avoided to decrease the computational complexity. In this paper, $\sum_{k=0}^3 Q(C_{i+1,4j+k}) \geq i + 1$ is set as the necessary condition to skip the intra mode decision process at node (i, j) . An example is shown in **Fig. 4**. If $C_{1,1}$ is a tree, then the sub-CUs of node $C_{0,0}$ are not pruned. Implementation details of the proposed fast bottom-up pruning algorithm is described by the pseudocode in **Algorithm 1**.

Algorithm 1 Fast bottom-up pruning algorithm	
Function ModeDecision($X_{i,j}, C_{i,j}$)	
if $i < D - 1$ then	
Generate sub-CUs $X_{i+1,4j+k}, k = 0,1,2,3$	
for $k = 0 \rightarrow 3$ do	
ModeDecision($X_{i+1,4j+k}, C_{i+1,4j+k}$)	
end for	
$C_{i,j} \leftarrow \bigcup_{k=0}^3 C_{i+1,4j+k}$	
$J(C_{i,j}) \leftarrow \sum_{k=0}^3 J(C_{i+1,4j+k})$	
end if	
if $i == D - 1$ or $\sum_{k=0}^3 Q(C_{i+1,4j+k}) < i + 1$ then	
Do intra mode decision and calculate $J(X_{i,j})$	
if $i == D - 1$ or $J(X_{i,j}) \leq J(C_{i,j})$ then	
$C_{i,j} \leftarrow X_{i,j}$	
$J(C_{i,j}) \leftarrow J(X_{i,j})$	
end if	
end if	
end function	

3.1.2 Analysis of the Performance of Fast Bottom-up Pruning Algorithm

To analyse the performance of the proposed FBUP algorithm, we can evaluate how often a node (i, j) is skipped by FBUP while its RD cost $J(X_{i,j})$ is actually less than $J(C_{i,j})$, denoted as $p_1 = P(J(X_{i,j}) < J(C_{i,j}) | \sum_{k=0}^3 Q(C_{i+1,4j+k}) = n)$, and use $\nabla J = \frac{J(C_{i,j}) - J(X_{i,j})}{J(X_{i,j})} \times 100\%$ as a measure of loss in RD performance. An example is

shown in **Table 2**, in which the results are obtained by encoding the HEVC test sequence *BasketballDrill*. We can see that generally the values of p_1 and ∇J are small. Similar results are observed when coding other HEVC test sequences. It indicates that the probability of the proposed FBUP algorithm fails to predict the result of RD optimized mode decision is quite small, and the loss in RD performance is also trivial.

Table 2. Analysis of the performance of proposed fast bottom-up pruning algorithm

QP	CU level 0		CU level 1		CU level 2	
	p_1 (%)	∇J (%)	p_1 (%)	∇J (%)	p_1 (%)	∇J (%)
22	0.00	0.22	1.98	2.20	8.87	3.17
27	0.06	0.50	7.09	2.97	9.17	4.14
32	0.26	0.78	7.69	3.62	6.39	4.54
37	3.00	3.52	5.82	4.87	6.24	3.68

3.2 Proposed Fast Intra Mode Decision Algorithm

In this paper, three techniques are proposed for fast intra mode decision, namely, *bottom-up prediction*, *adaptive intra mode filtering*, and *DC and Planar early decision*.

3.2.1 Bottom-up Prediction

In the proposed FBUP algorithm, mode decision at a CU node is selectively skipped based on the coding information of its sub-CUs. Similarly, we can also predict the intra mode of current CU node if it's not skipped. An example is shown in Fig. 5, in which the red arrows indicate the intra prediction directions. The intra prediction mode of the block is the same as the prediction modes of its two sub-blocks.

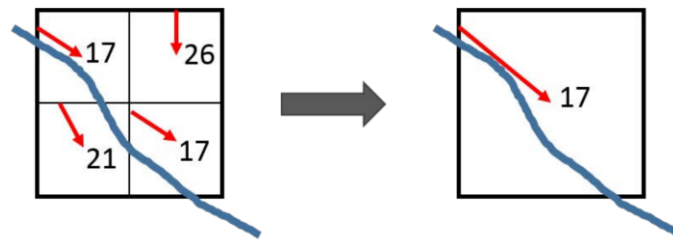


Fig. 5. Example of bottom-up prediction.

The straightforward way of bottom-up prediction is to use the chosen best modes of sub-CUs, instead of all 35 modes, as the candidate modes for the parent CU. Though the number of candidate modes can be largely reduced by such method, however, we find that the coding efficiency is decreased significantly. Therefore, a more robust scheme is required. In this paper, the rough mode decision results of sub-CUs are employed to select the candidate modes for parent CU. Let $\Omega_{i,j}$ be the set of candidate modes of a CU at node (i, j) and $\Phi_{i+1,4j+k}$ be the set of N modes chosen in the rough mode decision process of its k th sub-CU, then $\Omega_{i,j} = \bigcup_{k=0}^3 \Phi_{i+1,4j+k}$. By using the N modes that are chosen by rough mode decision instead of only one mode, prediction from sub-CUs becomes more robust. On the other hand, N is usually a small number, so it can achieve a good tradeoff between coding efficiency and encoder complexity.

3.2.2 Adaptive Intra Mode Filtering

In the fast intra mode decision algorithm in HM, the number N is set to a fixed value. In this paper, an adaptive method is proposed based on the J_{SATD} costs in the rough mode decision process.

1. For each mode in candidate set Ω , calculate its cost J_{SATD} , sort the candidate set in the ascending order of J_{SATD} .
2. Let $Cand_i, i = 0, 1, \dots, 7$ be the first 8 modes after sorting, calculate the mean value of their cost, denoted as $\mu = \frac{1}{8} \sum_{i=0}^7 J_{SATD}(Cand_i)$.
3. The new candidate set is obtained as $\Omega' = \{Cand_i | J_{SATD}(Cand_i) < \mu \ \& \ i < N - 1\}$.

3.2.3 DC and Planar Early Decision

The intra mode in HEVC can be categorized into two classes: one is DC and Planar modes, the other is directional intra prediction mode. The DC and Planar modes are designed for smooth area, and the directional modes are designed for coding blocks that have directional edges. It's assumed that the rough mode decision process can effectively distinguish these two classes. So, in this paper, if the best mode in rough mode decision process is Planar or DC mode, then the directional modes are removed from the candidate set.

3.2.4 The Overall Algorithm

The three techniques described in the previous subsections can be combined. Similar to the original intra mode decision algorithm in HM, the most probable modes (MPM) derived from neighboring coded blocks are also included in the final candidate set for RD optimized mode decision. The overall algorithm is as follows:

1. For a CU at node (i, j) , the set of candidate intra modes is $\Omega_{i,j} = \bigcup_{k=0}^3 \Phi_{i+1,4j+k}$
2. Calculate J_{SATD} for each candidate mode in $\Omega_{i,j}$, sort the candidate modes in the descending order of J_{SATD} and denoted as $Cand_i, i = 0, 1, \dots, M-1$
3. If $Cand_0$ equals to 0 or 1, i.e. Planar or DC mode, then $m = 1 + (Cand_1 < 2)$ and go to step 6, else $m = 8$
4. Calculate $\mu = \frac{1}{8} \sum_{i=0}^7 J_{SATD}(Cand_i)$
5. For $i = 7, \dots, 0$, if $J_{SATD}(Cand_i) < \mu$ then $m = m - 1$
6. $\Phi_{i,j} = \{Cand_i, i = 0, \dots, m-1\} \cup \{MPM\}$, search the best mode in $\Phi_{i,j}$ by RD optimized mode decision as described in section 2.2.

4. Experimental Results

The proposed algorithm was evaluated in the HEVC reference software HM8.2 [17]. The main profile intra-only encoder configuration in the common test condition [18] is used to code the HEVC test sequences in classes A to E. The maximum CU size (CTU size) is 64x64, the maximum number of CU depth levels is 4, and maximum number of TU levels is 3. Rate-distortion optimized quantization, sample adaptive offset, transform skipping, and fast transform skipping are on. Four quantization parameters (QP) {22, 27, 32, and 37} are used to encode each sequence.

To demonstrate the encoding time saving (ETS) of the proposed method, an isolated PC with Intel Core 2 3.0GHz CPU and 2.0GB RAM was used to encode the first second of each sequence. Compared with the original fast intra mode decision algorithm in HM8.2 encoder, the ETS, in percentages, and the corresponding BD-rate [19] for the proposed fast intra mode decision algorithm are shown in **Table 3**. Averaging over all test sequences, the ETS for different QP settings are around 25% and the Y BD-rate is only 0.40%. It's also observed that the ETS is consistent for different test sequences and the maximum Y BD-rate is 0.70%. Thus, we can conclude that the proposed fast intra mode decision algorithm can efficiently reduce the encoder complexity without significant loss in rate-distortion performance. When the proposed fast intra mode decision algorithm is combined with the FBUP algorithm, the results are shown in **Table 4**. It shows that the combined algorithm can further reduce the encoder complexity. Averaging over all test sequences, the ETS for different QP settings are around 40% and the Y BD-rate is 0.77%. The maximum average bitrate increase is only 1.05%. Thus, the overall algorithm also does not compromise the RD performance.

Table 3. Encoding time saving (%) and corresponding Y BD-rate (%) of the proposed fast intra mode decision algorithm.

Sequence		Encoding time saving (%)				Y BD-rate (%)
		QP=22	QP=27	QP=32	QP=37	
Class A 2560x1600	<i>Traffic</i>	23.88	24.29	25.81	27.46	0.40
	<i>PeopleOnStreet</i>	23.78	24.65	25.05	27.51	0.38
	<i>NebutaFestival</i>	23.61	24.39	25.79	25.02	0.10
	<i>SteamLocomotive</i>	26.65	26.85	27.91	29.04	0.07
	Average	24.23	25.05	26.14	27.26	0.24
Class B 1920x1080	<i>Kimono</i>	24.86	24.54	26.08	28.08	0.13
	<i>ParkScene</i>	23.89	24.80	26.98	30.49	0.28
	<i>Cactus</i>	24.25	23.32	25.33	25.95	0.42
	<i>BQTerrace</i>	23.10	24.25	24.69	25.57	0.34
	<i>BasketballDrive</i>	24.91	23.20	26.12	29.67	0.30
	Average	24.20	24.02	25.84	27.95	0.29
Class C 832x480	<i>RaceHorses</i>	21.76	25.49	25.06	26.02	0.33
	<i>BQMall</i>	24.62	24.30	24.58	24.46	0.56
	<i>PartyScene</i>	21.11	22.59	25.77	25.18	0.68
	<i>BasketballDrill</i>	24.43	23.40	24.06	21.13	0.41
	Average	22.73	23.95	24.87	24.25	0.50
Class D 416x240	<i>RaceHorses</i>	23.17	22.10	22.15	26.70	0.48
	<i>BQSquare</i>	21.91	23.25	23.02	22.49	0.70
	<i>BlowingBubbles</i>	28.30	23.12	23.91	24.58	0.58
	<i>BaseketballPass</i>	24.48	23.60	24.57	25.84	0.55
	Average	24.46	23.02	23.41	24.90	0.58
Class E 1280x720	<i>FourPeople</i>	23.74	24.48	25.70	26.02	0.41
	<i>Johnny</i>	25.29	28.23	26.89	30.55	0.45
	<i>KristenAndSara</i>	24.32	25.55	26.56	27.39	0.44
	Average	24.45	26.09	26.38	27.99	0.44
Total Average		24.00	24.32	25.30	26.47	0.40

Table 4. Encoding time saving (%) and corresponding Y BD-rate (%) of the proposed fast intra mode decision algorithm combined with the FBUP algorithm.

Sequence		Encoding time saving (%)				Y BD-rate (%)
		QP=22	QP=27	QP=32	QP=37	
Class A 2560x1600	<i>Traffic</i>	43.57	41.83	38.55	38.92	0.87
	<i>PeopleOnStreet</i>	44.61	42.54	41.66	39.86	0.74
	<i>NebutaFestival</i>	31.27	31.32	35.56	36.19	0.45
	<i>SteamLocomotive</i>	35.51	33.31	36.59	37.61	1.01
	Average	38.74	37.25	38.04	38.14	0.77
Class B 1920x1080	<i>Kimono</i>	33.61	30.44	30.75	31.29	0.55
	<i>ParkScene</i>	45.92	42.65	40.17	39.44	0.91
	<i>Cactus</i>	45.07	42.48	40.08	36.79	0.88
	<i>BQTerrace</i>	45.10	43.07	42.76	39.66	0.63
	<i>BasketballDrive</i>	37.65	35.74	32.27	36.58	0.71
	Average	41.47	38.87	37.21	36.75	0.74
Class C 832x480	<i>RaceHorses</i>	45.89	45.71	42.42	41.86	0.71
	<i>BQMall</i>	49.50	46.60	43.86	39.83	0.81
	<i>PartyScene</i>	53.78	52.56	49.56	47.51	0.75
	<i>BasketballDrill</i>	50.00	46.60	42.87	39.38	0.84

	Average	49.79	47.87	44.68	42.14	0.78
Class D 416x240	<i>RaceHorses</i>	46.97	45.09	43.89	43.45	0.71
	<i>BQSquare</i>	54.46	52.69	50.98	48.47	0.74
	<i>BlowingBubbles</i>	53.81	46.75	43.36	38.90	0.71
	<i>BaseketballPass</i>	45.57	40.33	39.53	35.76	0.94
	Average	50.20	46.22	44.44	41.65	0.77
Class E 1280x720	<i>FourPeople</i>	42.84	41.19	40.17	38.07	0.76
	<i>Johnny</i>	39.68	37.95	36.36	38.17	1.05
	<i>KristenAndSara</i>	38.60	36.45	37.09	36.45	0.71
	Average	40.37	38.53	37.88	37.57	0.84
Total Average		44.17	41.76	40.41	39.21	0.77

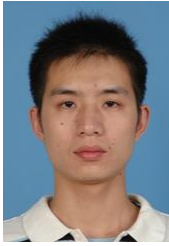
5. Conclusion

In this paper, a fast intra mode decision algorithm is proposed for HEVC intraframe coding. The proposed algorithm consists of three techniques to reduce the number of candidate modes for RD optimized mode decision. Compared to the original fast intra mode decision algorithm in HM encoder, the proposed algorithm can achieve about 25% encoding time saving with only 0.40% bitrate increase. Also, the proposed fast intra mode decision algorithm can be well combined with the proposed fast bottom-up pruning algorithm. The encoder complexity is further reduced, about 41% encoding time savings are achieved, and the average bitrate increase is only 0.77%.

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