Fast Intra Mode Decision Algorithm Based on Refinement in HEVC

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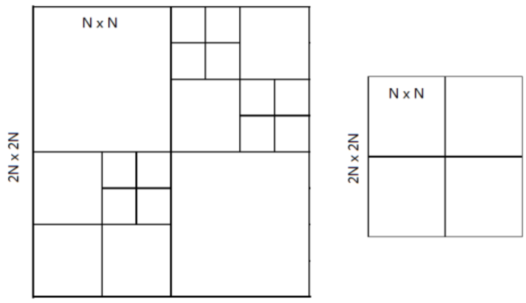
***Abstract*— High Efficiency Video Coding (HEVC) is the next generation video compression standard providing significant coding performance. It adopts 35 intra prediction modes with larger CU size to improve the intra encoding efficiency, so that cause a high computational complexity. In this paper, two fast intra-prediction algorithms are proposed to reduce the number of candidate modes for rate-distortion (RD) optimization. We obtain an optimal adjacent modes (OAM) list consisting of dominant directions through the analysis of costs of several general direction modes. Furthermore, we improve the most probable mode (MPM) algorithm to make full use of the spatial correlation between neighbour prediction blocks instead of simply merging the prediction modes of neighbour prediction blocks into the candidate list. Experimental results show that the proposed algorithms can reduce about 27.3% of the encoding time compared to the HEVC test model 14.0, while the decrease of coding quality is negligible.**

Keywords*—HEVC; Fast mode decision; Intra prediction; General directions; OAM

I. Introduction

Recently, along with the increasing requirements for higher resolution and better quality video beyond high definition, the H.264/AVC standard cannot satisfy the compression performance demand for the devices and applications to display ultra-high definition videos. High Efficiency Video Coding (HEVC) [1] is jointly developed by the ISO/IEC Moving Picture Experts Group (MPEG) and ITU-T Video Coding Experts Group (VCEG) which aims to achieve a better performance in coding and compression efficiency than the H.264/AVC standard [2].

The intra prediction is a procedure to obtain the pixel values based on spatial correlation with neighbour samples. To improve the coding efficiency in this procedure, HEVC has adopted conventional block-based hybrid coding architecture and many more prediction modes with larger coding unit. The coding architecture brings in three block concepts: Coding Unit (CU), Prediction Unit (PU) and Transform Unit (TU). This scheme enables the efficient process with flexible block sizes to code, predict and transform. In intra prediction [3], as shown in Fig. 1, the CU concept allows recursive splitting into 4 square shaped block, whose size ranges from 8*8 (smallest coding unit, SCU) to 64*64 (largest coding unit, LCU). PU, whose size is 2N*2N as large as the current CU, can be splitted into PART_N*N if CU is SCU. Furthermore, compared with 9 prediction modes in H.264/AVC, HEVC provides at most 35 possible prediction modes for PUs, including 33 angular direction modes and 2 non-directional modes. The predictions in intra prediction have the angles of +/- {0, 2, 5, 9, 13, 17, 21, 26, 32}/32 as shown in Fig. 2. Planar mode and DC mode are the two non-directional modes usually selected when the content of the block is smooth. For the current CU, the rate-distortion (RD) cost of every possible prediction mode should be calculated, and the mode with the minimum RD cost is selected as the best prediction mode. If the current CU is larger than the SCU, it will be splitted into four equal-size sub-CUs. A cost comparison between the current CU and the sum of four sub-CUs is then conducted to determine the CU size and prediction mode.



(a) CU structure (b) PU structure

Fig. 1. Partition structure of CU and PU

However, the computational complexity increases markedly, as the intra prediction process becomes more meticulous and accurate. The recursive block partitions together with increased number of prediction modes make the encoding time of HEVC about 4 times over that of H.264/AVC.

In this paper, two fast intra prediction mode decision algorithms are proposed and implemented in HEVC Test Model (HM) 14.0. On the one hand, we choose some general direction modes in HEVC to calculate sum of absolute transformed difference (SATD) cost instead of all the 35 modes. By analysing the results, we obtain an optimal adjacent

This project was supported by the grant from Shenzhen municipal government for basic research on Information Technologies (No. J-CYJ20130331144751105), and by Shenzhen Peacock Plan.

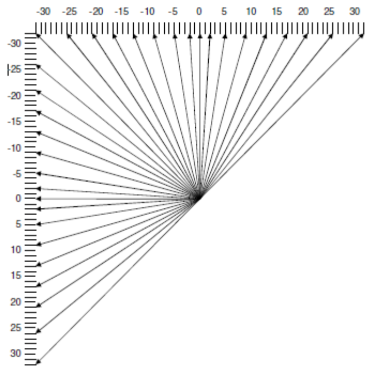


Fig. 2. Angular direction of Intra Prediction modes

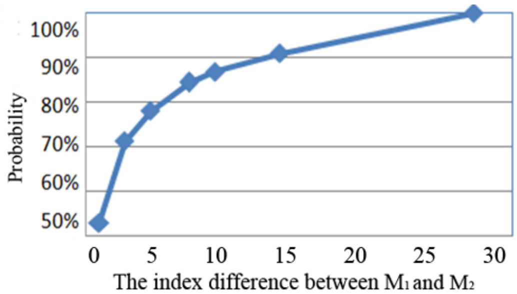


Fig. 3. Probability distribution of the two best modes' index difference

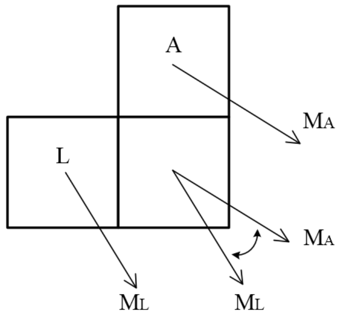


Fig. 4. Case of M_A and M_L have little difference

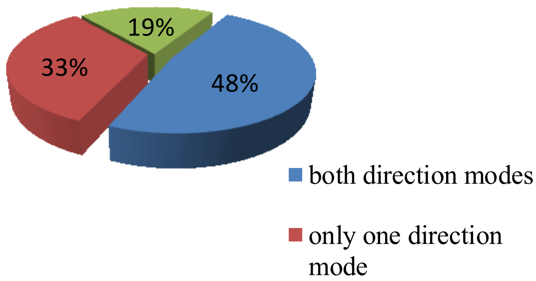


Fig. 5. Probability distribution of neighbour mode types

mode calculation. On the other hand, we utilize the correlation of the adjacent direction modes between the neighbour prediction blocks to improve the former algorithm. Therefore, both the candidate modes to do SATD calculation and RD optimization decrease considerably.

The remainder of this paper is organized as follows. The current related work on intra prediction in HEVC is introduced in Section II. Section III describes the proposed fast mode decision algorithms. Experiment results are shown in Section IV, and overall conclusions are discussed in Section V.

II. Related Work

Today, JCY-VC (Joint Collaborative Team on Video Coding, established by MPEG and VCEG) has released HM software which has integrated some remarkably improved tools and new technologies to achieve the goal of HEVC. To reduce the computational complexity, a fast intra mode decision algorithm combining Rough Mode Design (RMD) algorithm and Most Possible Mode (MPM) algorithm is presented in the current HEVC test model. The RMD algorithm is proposed by Y. Piao et al. [4], calculating the trade-off between mode coding bits and distortion (SATD) to produce a candidates list for RD optimization. This algorithm reduced the number of intra prediction modes (IPM). Zhao et al. [5] introduced the conception of MPM, which is derivedfrom the mode of neighbour blocks. This scheme provides 20% and 28% time saving in intra high efficiency and low complexity cases on average compared to the default encoding scheme.

Apart from these algorithms adopted by HM in intra prediction, there are several effective approaches presented to reduce the encoding complexity. Jiang et al. [6] proposed a fast mode decision algorithm based on gradient calculated which achieved 20% encoding time saving in all intra low complexity cases on average with negligible loss of coding efficiency. Silva et al. [7] studied the current CU's edge direction information and proposed a fast HEVC intra prediction mode decision. This method provides a decrease of up to 32% in prediction time, and an increase of 0.9% in bit-rate. Yan et al. [8] merged the adjacent modes generated by RMD into groups and used a pixel-edge detection method to reduce candidates. Their algorithm obtained 23.5% time saving on average. Zhang et al. [9] presented an early termination scheme to terminate current CU mode decision and lead to a 32% encoding time reduction with a BD-BR increase of 1.1%.

III. Proposed Fast Intra Mode Decision Algorithm

A. Motivation Observations

The modes generated after the RMD process are usually adjacent to each other. We test different classes of sequences and select two best direction modes with the least cost in current block. The absolute difference between the two modes and the probability distribution for different cases are shown in Fig. 3. We find it happens almost half of the cases for the differences between the two modes are only 1, and more than three quarters of the cases for the difference is less than 5.

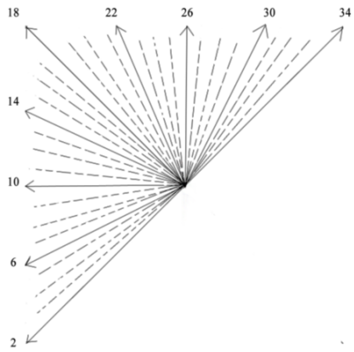


Fig. 6. The 9 general direction modes and their indices

Considering the strong correlation in the candidate list, a fast algorithm based on analysing the general direction modes to obtain OAMs is valuable.

The adjacent prediction blocks also have a strong correlation. We test several sequences in all-intra mode and find the prediction modes of the above block and the left block often have a little difference if both of them are direction modes shown in Fig.4, where M_A represents the mode of block above and M_L represents the mode of block left. The probability distribution of neighbour mode types is shown in Fig. 5, and 78% of the absolute differences between M_A and M_L are less than or equal to 3 if they are both direction modes. Therefore, we can obtain a more accurate dominate direction by analysing the correlation between the neighbour blocks' modes.

From the above, it can be inferred that calculating SATD for all the 35 prediction modes is not necessary in the HM14.0 RMD process, and the MPM algorithm can also be improved.

B. *The fast algorithm based on the refinement of general directions*

We defined an optimal adjacent mode (OAM) list with fewer mode candidates to do RD optimization. It will reduce the complexity of intra prediction obviously utilizing the method of stepwise refinement.

We calculated the SATD of 9 general directions instead of every possible mode in HEVC. The coefficients of these general directions are {2, 6, 10, 14, 18, 22, 26, 30 and 34} as shown in Fig.6. These general directions are similar to the prediction directions in H.264/AVC and they can dominantly reflect the gradient direction of the current PU.

$$\mathrm{OAM} = \begin{cases} \{M_1-2, M_1-1 \dots M_2\}, & \text{if } M_1 - M_2 = 4 \\ \{M_2-2, M_2-1 \dots M_2\}, & \text{if } M_2 - M_1 = 4 \\ \{M_1-2, M_1-1 \dots M_1+2, \\ \quad M_2-1, M_2, M_2+1\}, & \text{else} \end{cases} \qquad (1)$$

Then, we obtained the minimum cost mode M_1 and the second minimum cost mode M_2. The OAM list can be generated by analysing the position of M_1 and M_2.The M_1 and M_2 are adjacent when the absolute difference between them is equal to 4, and the OAM list is built up by modes between M_1 and M_2. When the M_1 and M_2 are not adjacent, we obtained the OAM list consisting of the direction modes mainly around the M_1 and M_2. The OAM generation algorithm is shown as the Equation 1.

C. *The improved algorithm based on MPM*

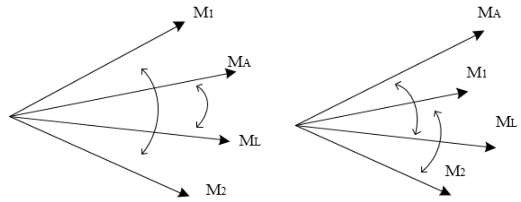


Fig. 7. Improved MPM algorithm combining with the former algorithm

The MPM process makes use of the correlation between modes of co-located neighbour blocks. However, the process merged the neighbour blocks' modes into the candidates without any analysis. In many cases, the left and above neighbour blocks' modes M_L and M_A have little difference.

We improved the MPM process and proposed an algorithm combined with the algorithm stated in B of Sec.III. The detail of the analysis process is shown in Fig. 7. M_1 and M_2 are the best and second best general modes. M_A and M_L are modes of above and left blocks. If M_A and M_L are both direction modes with a difference between them less than or equal to 3, and they are around M_1 and M_2 as shown in Fig. 7, we will modify the OAM list as $\{M_A\text{-}1, M_A \dots, M_L, M_L\text{+}1\}$. Otherwise, if only one of the two modes is a direction mode and it is in the range between M_1 and M_2, we will adjust the OAM list as $\{M_{AorB}\text{-}2, M_{AorB}\text{-}1 \dots M_{AorB}\text{+}2\}$. In the rest cases we just merge M_A and M_L into OAM list like the original MPM algorithm.

D. *supplements of non-directional modes and block size*

After the two steps above, we take into account the block size and non-directional modes including the DC mode and the Planar mode. Compare each cost of the two non-directional modes with M_2. If its cost is less than M_2, or it appears in the neighbour CUs modes, merge the mode into the OAM list. If neither of the cost of DC mode and Planar mode is less than the mode M_2, we infer the non-directional modes may produce large distortion and abandon the two modes.

Now, we obtained the OAM list which contains 5-8 direction prediction modes and 0-2 non-directional prediction modes. If the block size is larger than 8*8, we calculate the SATD for the OAM list, reserve the two minimum cost modes and abandon the rest modes in the list.

At last, the OAM list is the final result to do RD optimization. By implementing our fast algorithm, we don't need to calculate each penalty of possible mode and test their RD performance. As a consequence, huge encoding time of intra prediction process in HM will be saved.

IV. EXPERIMENT RESULT

We implemented the fast intra mode decision algorithms in HEVC test model HM14.0 to verify its performance. The test platform is Intel Xeon CPU E5-2643 3.50 GHz with 4 cores, 32.0 GB RAM. We tested the recommended sequences from Class A to Class E with quantization parameters 22, 27, 32, and 37 with 100 frames in All-Intra case specified by [10].

Table 1 is the average performance comparison between our proposed algorithms and default algorithm adopted in

HM14.0. The BD-Rate (BDR) and BD-PSNR (BDP) in the table, which are calculated from the Bjontegaard metrics [11], present the average differences in rate distortion performance. The Time-Saving (TS) is defined as the Equation 2.

$$TS=\frac{1}{4}\sum_{i=1}^{4}\frac{Time_{HM14.0}(QP_i)\text{-}Time_{proposed}(QP_i)}{Time_{HM14.0}(QP_i)}\times 100\% \qquad (2)$$

The ΔPSNR is calculated using the Equation 3. And the ΔPSNR-Y, ΔPSNR-U, ΔPSNR-V represent the performance of three components respectively.

$$\Delta PSNR = \frac{1}{4}\sum_{i=1}^{4}(PSNR_{proposed}(QP_i) - PSNR_{HM14.0}(QP_i)) \qquad (3)$$

TABLE I. CODING QUALITY AND COMPLEXITY REDUCTION COMPARED WITH ORIGINAL HM14.0

Class	Sequence	ΔPSNR-Y (dB)	ΔPSNR-U (dB)	ΔPSNR-V (dB)	BDBR (%)	BDP (dB)	TS (%)
A	Traffic	-0.030	-0.006	-0.001	0.9	-0.05	27.3
	PeopleOnStreet	-0.029	-0.004	-0.004	0.9	-0.05	24.7
B	Cactus	-0.026	-0.004	-0.003	1.0	-0.03	24.2
	ParkScene	0.029	-0.013	-0.001	0.7	-0.06	26.1
	Kimono	-0.024	-0.012	-0.014	1.3	-0.04	24.1
C	BQMall	-0.032	-0.004	-0.004	0.9	-0.08	34.2
	PartyScene	-0.045	-0.005	-0.004	0.7	-0.05	27.3
	BasketballDrill	-0.034	-0.010	-0.004	1.2	-0.05	28.6
D	RaceHorses	-0.038	-0.013	-0.008	1.0	-0.06	29.3
	BasketballPass	-0.034	-0.010	-0.004	1.2	-0.08	33.5
	BQSquare	-0.044	-0.006	-0.009	1.1	-0.08	26.7
E	Johnny	-0.020	0.009	0.002	1.3	0.06	29.7
	Vodyo3	-0.020	-0.005	-0.003	0.9	-0.04	24.8
	FourPeople	-0.033	-0.007	-0.005	1.1	-0.06	22.3
Average		-0.027	-0.006	-0.005	1.0	-0.05	27.3

It can be observed from the table that our algorithm provides a time reduction ranging from 22% to 35% depending on different video content. And the BD-Rate performance is favourable with only 1.0% gain and BD-PSNR 0.05 loss, which is negligible.

The graphical representation of RD curves is provided in Fig.8. Observed from the figures, the proposed algorithms give R-D performances similar to the algorithm in HM14.0.

V. CONCLUSION

In this paper, we proposed fast intra algorithms based on the refinement of general directions and the correlation between neighbour blocks in HEVC. By improving the RMD and MPM process, the number of candidate modes to do SATD calculation and RDO calculation is reduced considerably, so that the computational complexity can be reduced significantly. Experimental results show that our algorithms could save about 27.3% of encoding time with negligible performance loss compared to HM14.0. Along with the development of encoding technology, the number of directions in intra prediction will keep increasing. And the refinement idea of general directions in our algorithm will be favourable in the further standard.

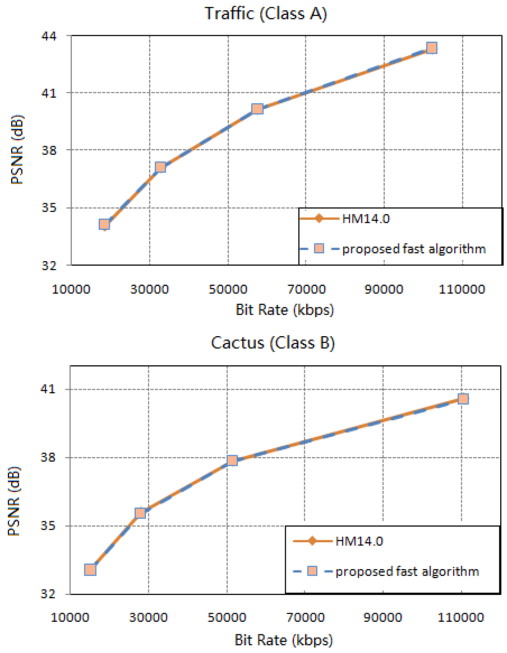


Fig. 8. RD curves of proposed algorithms and original algorithm

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