A Complexity Reduction Method for Intra Prediction Method in HEVC Standard

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ABSTRACT:
High Efficiency Video Coding (HEVC) is considered the last standard for video compression with about 50% additional compression compared to the previous standard i.e. H264/AVC, while maintaining image quality. The significant increase in performance of this standard has been achieved with high computational complexity. In this standard, the intra prediction unit is one of the parts that although it greatly improves performance, it significantly increases its computational complexity due to the increase in the number of prediction modes. In this paper, a method has been proposed to reduce the number of intra prediction modes in HEVC by which the computational complexity of compression at this stage can be reduced as much as possible. The proposed method determines the predominant mode of 4 × 4 blocks, and the details in each larger block, and accordingly, by applying the appropriate filters and selecting the most likely mode, the number of candidate modes to select the best mode is reduced. The simulation results showed that on average the proposed method can reduce the compression time by 45% while increasing the bit rate by 0.69%.

KEYWORDS: HEVC, Intra Prediction, Computational Complexity, Prediction Block.

1. INTRODUCTION

With the advance of digital communication, the need for visual exchange of data is increasing. As to date, video data transmission accounts for more than half of all existing network traffic, and it is expected that video transmission through various networks increases even faster. Therefore, techniques that make it possible to make image data compression more effective have become important.

HEVC, as a new standard for video compression, has a large contribution to research in this field. This standard has many differences to increase the compression of video images with other standards. The quality of the images is better protected by the methods provided in this standard than other standards. However, it should be noted that this increase in compression is provided using more sophisticated algorithms. For this purpose, research has been conducted to provide methods for optimizing different parts of this standard [1].

The prediction stage is one of the most important stages of compressing video images. The large number of intra prediction modes and operations that should be performed for each of these modes significantly increases the computational complexity of HEVC [2]. Therefore, reducing computational complexity has become an important issue in this standard. Reducing computational complexity will be possible by applying preprocessors that speed up the decision-making stage of block size selection, and going through low-probability modes and only trying out high-probability prediction modes for selection.

In this paper, we extend the fast intra mode decision method in H.264/AVC [22] for intra prediction of HEVC to reduce both the number of prediction modes and CU sizes. The proposed method differs with the proposed method in [22] in two aspects. On one hand, we determine the predominant mode of 4 × 4 blocks, and the details in each larger block. On the other hand, in our method we apply the appropriate filters and select the most likely mode, the number of candidate modes to select the best mode is reduced. Thus, the speed of selecting the block size can be increased and consequently the speed of the intra prediction.

2. LITERATURE REVIEW

HEVC has a number of new features. One of these new features introduced in this standard is the intra

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prediction by block mode selection. The function of this standard is to find the direction of spatial correlation using adjacent blocks. This correlation is used for intra prediction. With these new features of internal compression, HEVC improves compression performance significantly compared to other compression standards. But using the Rate Distortion Optimization (RDO) algorithm, the computational complexity increases significantly [3]. In order to reduce the computational complexity of the intra prediction unit, various methods have been proposed that can be divided into three categories. The first category reduces the various sizes of the predicted block assessed. The second category reduces the number of intra prediction modes for a CU and selects fewer modes for RDO. The third category uses a combination of two methods to reduce both the number of blocks assessed and the number of prediction modes.

Papers [4-8] are among the works provided in the first category. Shen and Yu used the learning machine to speed up the CU size selection process [4]. Image texture uniformity and data of coded blocks adjacent to the current block in [5] are used to speed up decisions about CU dimensions. A gradient-based method has also been proposed by Ting and Chang that reduces the number of CUs assessed [6]. Kim et al. [7] introduced the conditions under which a decision was made to divide a block into smaller blocks. If the block cost was less than a threshold value that depends on the value of QP and the block size, the block division process stopped. Li et al. [8] used the current block data in the previous frame to determine the maximum and minimum current block size and reduce the number of prediction blocks. This method reduces coding time by about 16% while increasing the bit rate by 0.18%.

Papers [9-16] are among the works provided to reduce the number of intra prediction modes for RDO. Zhao et al. [9] suggested the use of RMD to reduce the number of modes for RDO. In their proposed method, first for RMD, a number of available modes that have the lowest cost are selected, then together with the most probable modes, which are obtained from the modes of adjacent blocks, participate in RDO. The most probable modes are added to the number of modes obtained from RMD, provided that those modes do not exist among the previously selected modes. For RMD, Hadamard transform is used instead of DCT to reduce computational complexity. In the result report of this method, a reduction by 20% in coding time has been announced. This method has been also used in HEVC reference software from version 4 onwards.

In [10], Najafabadi and Ramezanpour presented a two-stage method to select the prediction mode in HEVC, which reduces the number of predicted modes assessed so that only 19 modes are used instead of 35 modes for RMD and the number candidates running at RDO stage were also well reduced. As a result, RDO was performed on a smaller number of modes. The proposed methods for selecting the best prediction modes in [11] and [12] use gradient data to reduce the number of modes participating in RDO.

Jiang et al. [12] proposed a gradient-based method that first calculates the size and angle of the gradient for each prediction block, then selects the most probable modes based on the mode-gradient histogram and reduces the number of RDO modes. Image edge data is used by Silva et al. [13] to reduce the number of prediction modes to speed up the selection of the best prediction mode. Yan et al. [14] used a pixel-based edge detection algorithm to select the best prediction mode. Wang and Siu [15] used the variance of reference samples to investigate the smoothness of reference samples. If the variance is less than a certain threshold, only the planar mode will be used to predict the current block and there is no need to assess other modes, otherwise all modes will be assessed. In order to reduce the number of prediction modes, Motra et al. [16] used the best prediction mode of adjacent blocks and the best prediction mode of blocks that are in the same place in the previous frame.

Papers [17-19] can be in the third category, which reduces both the number of blocks assessed and prediction modes. Shen et al. [17] used the size of CUs adjacent to the current block to reduce the number of CUs assessed. Also, the costs of adjacent blocks and modes provided two conditions for terminating the prediction mode review. In the result report of this method, a reduction by 21% in encoding time versus a slight reduction in coding efficiency has been announced.

Zhao et al. [18] used a method similar to the paper [17] to stop the process of block division. In the process of dividing the block, if the cost of the offspring of a block is more than the father block, the process of division stops. They also reduce the number of modes for RDO due to the size of the prediction block. They reported a reduction by 37% in coding time, while image quality was slightly reduced. Using variance, Li et al. [19] investigated the uniformity of the block. If the variance is less than the threshold, the process of the block division stops. It also uses a tree structure to select a set of prediction modes. First, it selects a set of modes with a neighbor distance of 4. Then, it selects four of the best modes and adjacent modes that have a neighbor distance of 2. From the modes of the previous stage, the mode with the lowest cost, along with the neighbor modes with a distance of 1, are selected for RDO. A reduction by 40% in encoding time with an increase by 1.6% in bit rate has been reported for this method.

The authors in [20] presented the intra prediction algorithm based on the image texture. At the first stage, the number of blocks assessed is reduced based on the image texture uniformity. At the second stage, according to the direction of the dominant edge of the block, which is calculated at the first stage, a mode selection algorithm is proposed to reduce the number of prediction modes participating in RMD. Finally, a hardware architecture is proposed for the proposed method, which can be used in real-time applications due to its low cost and high speed. By implementing this, the encoding time will be reduced by an average of 46%, while maintaining the quality of the encoded video, the bit rate will be increased by 1.32%.

3. THE PROPOSED METHOD

The computational complexity of each stage of intra prediction in [21] are investigated and showed that about 75% of the total time of intra prediction was related to Rough Mode Decision (RMD) and RDO and the remaining 25% was related to the time spent for Residual Quad-Tree (RQT) (Fig. 1). Reducing the number of modes alone reduces RMD time, which is only 19% of the time complexity of the intra prediction algorithm.

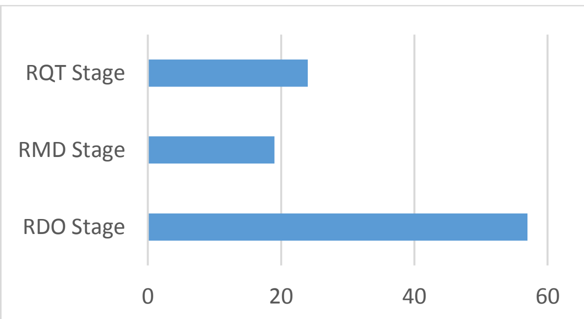

Fig. 1. Computational time of each stage of Intra prediction in HEVC.

In order to assess each block, all three stages of RMD, RDO, and RQT are required. If a method can be provided to assess the number of less predictive blocks, a significant improvement can be achieved in reducing the intra coding time because by reducing the number of blocks assessed, all three of the above stages will be excluded. Hence, in this paper, a method is proposed to reduce the number of RMD modes so that it requires less calculations than conventional methods.

In the proposed method, first 64 × 64 blocks are divided into 4 × 4 blocks with 35 modes in 9 groups (Table 1) and for each 4 × 4 block using filters, the possibility of selecting modes in 4 main horizontal, vertical, 45 and 135 ° directions are measured.

DC and Planar modes had the highest probability of being selected as the best mode out of all 35 predictive modes. Therefore, in the proposed method, these two modes are always tested before the other modes.

If X_{orig} is a 4 × 4 block of the original image, P_{mn} is an element of this block located in the m[th] row and n[th] column. H_{10} is the output of the filter applied to the original image matrix and is calculated by Equation (1) [22]. This spatial filter applied to the X_{orig} matrix is shown in Fig. 2a.

Table 1. dividing 35 HEVC intra modes to 9 groups.

#Group	Group Name	#Modes
1	M0	24,25,26,27,28
2	M1	8,9,10,11,12
3	M2	DC, Planar
4	M3	32,33,34
5	M4	16,17,18,19,20
6	M5	21,22,23
7	M6	13,14,15
8	M7	29,30,31
9	M8	2,3,4,5,6,7

x	x	x	x
y	y	y	y
-y	-y	-y	-y
-x	-x	-x	-x

(a)

y	y	y	y
-y	-y	-y	-y
-y	-y	-y	-y
y	y	y	y

(b)

y	y	y	y
-x	-x	-x	-x
x	x	x	x
-y	-y	-y	-y

(c)

Fig. 2. Spatial filters for M1 group Modes (x=2; y=1).

$$H_{10} = 2 \times (p_{00} + p_{01} + p_{02} + p_{03}) + (p_{10} + p_{11} + p_{12} + p_{13}) - (p_{20} + p_{21} + p_{22} + p_{23}) - 2 \times (p_{30} + p_{31} + p_{32} + p_{33}) \quad (1)$$

If the original image X_{orig} matrix has a vertical texture, the value of H_{10} will be very small, and conversely if the original image X_{orig} matrix contains more horizontal texture, the value of H_{10} will be very large. So, if the value of H_{10} is large, it can be concluded that the horizontal mode (mode No. 10 or M_{10}), is very likely to be selected as the best mode. It should also be noted that H_{20} and H_{30} can also be used to decide on mode selection. These two values can also be calculated using Equations (2) and (3) [22].

Figs. 2b and c shows a similar spatial filter for calculating H_{20} and H_{30}. The proposed algorithm, by combining this component H_{10}, H_{20} and H_{30}, uses the following values to determine how likely it is that horizontal mode will be selected as the best mode.

$$H_{20} = (p_{00} + p_{01} + p_{02} + p_{03}) - (p_{10} + p_{11} + p_{12} + p_{13}) - (p_{20} + p_{21} + p_{22} + p_{23}) + (p_{30} + p_{31} + p_{32} + p_{33}) \quad (2)$$

$$H_{30} = (p_{00} + p_{01} + p_{02} + p_{03}) - 2 \times (p_{10} + p_{11} + p_{12} + p_{13}) + 2 \times (p_{20} + p_{21} + p_{22} + p_{23}) - (p_{30} + p_{31} + p_{32} + p_{33}) \quad (3)$$

$$DH = |H10|/24 + |H20|/16 + |H30|/24 \quad (4)$$

The values 24 and 16 are used to normalize the value of D in Equation (4). These values are based on the sum of the absolute values of the filter matrix element values shown in Fig. 2.

A method similar to that described for the probability of horizontality can also be used to estimate the appropriateness of the vertical mode for decision-making in 4 × 4 blocks. Therefore, the matrices shown in Fig. 3 can be used as a filter applied to the original image.

x	y	-y	-x
x	y	-y	-x
x	y	-y	-x
x	y	-y	-x

(a)

y	-y	-y	y
y	-y	-y	y
y	-y	-y	y
y	-y	-y	y

(b)

y	-x	x	-y
y	-x	x	-y
y	-x	x	-y
y	-x	x	-y

(c)

Fig. 3. spatial filters for M0 group Modes (x=2; y=1)

As explained to find an estimate of the probability of selecting the horizontal mode, if the values of H01, H02 and H03 are large, it can be concluded that the vertical mode (mode No. 26 or m_{26}) is more likely to be selected as the best mode. These values can also be calculated using Equations (5), (6) and (7) [22].

$$H_{01} = 2 \times (p_{00} + p_{10} + p_{20} + p_{30}) + (p_{01} + p_{11} + p_{21} + p_{31}) - (p_{02} + p_{12} + p_{22} + p_{32}) - 2 \times (p_{03} + p_{13} + p_{23} + p_{33}) \quad (5)$$

$$H_{02} = (p_{00} + p_{10} + p_{20} + p_{30}) - (p_{01} + p_{11} + p_{21} + p_{31}) - (p_{02} + p_{12} + p_{22} + p_{32}) + (p_{03} + p_{13} + p_{23} + p_{33}) \quad (6)$$

$$H_{03} = (p_{00} + p_{10} + p_{20} + p_{30}) - 2 \times (p_{01} + p_{11} + p_{21} + p_{31}) + 2 \times (p_{02} + p_{12} + p_{22} + p_{32}) - (p_{03} + p_{13} + p_{23} + p_{33}) \quad (7)$$

$$DV = |H01|/24 + |H02|/16 + |H03|/24 \quad (8)$$

In order to determine the probability that some other modes are best, a combination of the values obtained from Equations (2), (3), (4), (6), (7) and (8) can be used. The value of H_{10} - H_{01}, calculated by Equation (9), is an example of this combination [22].

$$H_{10} - H_{01} = (p_{01} + 3p_{02} + 4p_{03}) + (-p_{10} + 2p_{12} + 3p_{13}) + (-3p_{20} - 2p_{21} + p_{23}) - (4p_{30} + 3p_{31} + p_{32}) \quad (9)$$

Fig. 4(a) shows the spatial filter such as Equation (9). As shown in this Fig.4, this combination can be used to determine whether the angular mode m_{18} (45 °) can be selected as the best predictive mode. The compounds (H_{21} −H_{12}) and (H_{32} - H_{23}) defined in the following equations can also be used for this purpose.

Spatial filters equivalent to Equations (10) and (11) are shown in Fig. 4 (b) and (c).

m	y	z	w
-y	m	x	Z
-z	-x	m	Y
-w	-z	-y	M

(a)

m	z	y	-w
-z	m	x	y
-y	-x	m	z
w	-y	-z	m

(b)

m	y	-z	x
-y	m	w	-z
z	-w	m	Y
-x	z	-y	m

(c)

Fig. 4. spatial filters for M4 group Modes (m=0;x=2; y=1;z=3;w=4)

$$H_{21} - H_{12} = (3p_{01} + p_{02} - 4p_{03}) + (-3p_{10} + 2p_{12} + p_{13}) + (-p_{20} - 2p_{21} + 3p_{23}) + (4p_{30} - p_{31} - 3p_{32}) \quad (10)$$

$$H_{32} - H_{23} = (p_{01} - 3p_{02} + 2p_{03}) + (-p_{10} + 4p_{12} - 3p_{13}) + (3p_{20} - 4p_{21} + p_{23}) + (-2p_{30} + 3p_{31} - p_{32}) \quad (11)$$

The proposed algorithm in this paper uses this value obtained from Equation (12) by the combined components mentioned in Equations (9), (10) and (11) to determine the probability of selecting a 45° directional mode as the best intra prediction mode [22].

$$DR = |H10 - H01|/28 + |H21 - H12|/28 + |H32 - H23|/28 = (|H10 - H01| + |H21 - H12| + |H32 - H23|)/28 \quad (12)$$

As mentioned earlier for the previous equations, the number 28 in Equation (12) is used to normalize the value of D, which is the sum of the absolute values of the values of the filter matrices shown in Fig. 4. Combinations, equations, and matrices of spatial filters such as what was found to be best for the right mode can also be defined and used for the best left mode (135 °). Fig. 5 shows the matrices used as the location filter applied to the X_{orig} matrix.

In other words, the appropriateness of the left directional mode is calculated using the combinations ($H_{10} + H_{01}$), ($H_{21} + H_{12}$) and ($H_{32} + H_{23}$) whose spatial filters are shown in Fig. 6. Using the above combinations of the H components, the probability of selecting mode 34 as the best intra prediction mode is calculated by Equation (13).

w	z	y	m
z	x	m	-y
y	m	-x	-z
m	-y	-z	-w

(a)

-w	y	z	m
y	x	m	-z
z	m	-x	-y
m	-z	-y	w

(b)

x	-z	y	m
-z	w	m	-y
y	m	-w	z
m	-y	z	-x

(c)

Fig. 5. spatial filters for M8 group Modes (m=0;x=2; y=1;z=3;w=4).

$$DL = (|H10 + H01| + |H21 + H12| + |H32 + H23|)/28 \quad (13)$$

After calculating the probability of selecting each of these four modes (horizontal, vertical, right and left direction), these values are sorted in descending order. In this way, the largest value of these values is D_1 and the second largest value is D_2, and so on until the end. Then, these values are mentioned as D_i, where i indicates the rank of this value in descending order of these values. So, if we assume that D_R is the largest value, we call it D_1, and if D_V is the second largest value, we call it D_2, and so on until the fourth value.

The mode associated with each D_i is called M_{D_i}. For example, if D_L is the largest and D_V is the second largest, the modes m_{34} and m_{26} are called m_{D1} and m_{D2}, respectively. If the direction of the two is perpendicular to each other, we call them orthogonal modes. For example, the modes m_{26} (vertical mode) and m_{10} (horizontal mode) are orthogonal. The modes m_{34} (left directional mode) and m_{18} (right directional mode) are also orthogonal.

The proposed algorithm tests M_{Di} mode and its neighbor modes to find the best prediction mode. For example, D_H has the largest value, which is equivalent to mode No. 10. In this algorithm, if this mode is orthogonal with a dimensional mode (the second largest value), 35 modes should be tested. But if it is not orthogonal with the next mode because m_{10} is in the category M_1, then the category M_1 with its two neighbor categories, M_6 and M_8, along with the two DC and Planar modes, should all be assessed. In this case, the algorithm tests 16 modes to decide on the best mode for the given 4 × 4 block.

In order to increase the compression performance and improve the quality of the decoded video image, in this method, spatial correlation between adjacent blocks is also used. Therefore, the best modes of 4 × 4 blocks that are on the left, top and top left are also tested. These modes are called m_L, m_U, and m_{UL}, respectively. It should be noted that these modes may be DC mode, or one of the modes tested in the previous step. So, the number of modes tested varies. The proposed algorithm is summarized as follows.

Proposed algorithm

```
CTU size←64×64
for all 4×4 blocks in CTU do
  Calculate DV, DH, DL, DR
   If Di⊥Dj then
     Select Di modes
   else
     Select a group of modes based on Table 1
   end if
end for
```

4. SIMULATION RESULTS

In order to assess the efficiency of the proposed method, reference software HM18.6 was used. In order to assess the coding efficiency and computational complexity of the proposed method, 10 videos including Class A to E with different QPs 22, 27, 32 and 37 presented by JCT-VC group have been used.

The test conditions are based on the conditions mentioned in the reference [23]. Further details of the structure used are shown in Table 2.

Table 2. Test conditions.

QP	22-27-32-37
Coding	I-Frame
Maximum CU	64×64
#Frame	50
Maximum Depth	4

Peak Signal-to-Noise Ratio (PSNR) parameter is one of the most common methods for measuring image quality, in which the second power of 255 is the maximum pixel value in the image.

The higher the PSNR, which is the maximum signal-to-noise ratio, the better the image reconstruction.

$$PSNR = 10log_{10}^{(\frac{255^2}{MSE})} \quad (14)$$

where

$$MSE = \frac{4 \times MSE_Y + MSE_U + MSE_V}{6} \quad (15)$$

Coding time is also used to compare the computational complexity of the proposed method with the reference software. Coding time, bit rate and PSNR difference were measured by Equations (16), (17) and (18).

$$DT = \frac{Time_{proposed} - Time_{HM18.6}}{Time_{HM18.6}} \times 100\% \quad (16)$$

Where $Time_{proposed}$ is the execution time by the proposed method and Time $HM_{18.6}$ is the time of video encoding by $HM_{18.6}$ software.

$$\Delta Bitrate = \frac{Bitrate_{proposed} - Bitrate_{HM18.6}}{Bitrate_{HM18.6}} \times 100\% \quad (17)$$

Where $Bitrate_{proposed}$ is bit rate by the proposed method and $Bitrate_{HM18.6}$ is the bit rate of video by $HM_{18.6}$ software.

$$\Delta PSNR = PSNR_{proposed} - PSNR_{HM18.6} \times 100\% \quad (18)$$

Where $PSNR_{proposed}$ is encoded video quality by the proposed method and $PSNR_{HM18.6}$ is encoded video quality by $HM_{18.6}$ software. Coding efficiency with coding time changes compared to reference software that is shown in Table 3. Negative signs in the Table indicate a reduction in the measurement parameter. A positive sign indicates an increase in the measurement parameter. According to the results of simulation, it can be concluded that the proposed method reduces the encoding time by about 45% while the average bit rate increases by 0.69%.

Table 3. Coding performance with coding time changes compared to reference software.

Test sequences	**ΔBitrate (%)**	**ΔPSNR (db)**	**ΔT(%)**
Basketballpass	1.17	-0.02	-47.3
Blowingbubbles	0.91	-0.05	-45.7
RaceHorses	0.82	-0.07	-40.1
Partyscene	0.72	-0.12	-46.8
Basketballdrill	0.74	-0.07	-44.5
Fourpeople	0.83	-0.02	-46.6
Kimono1	0.17	-0.04	-48.2
Parkscene	0.03	-0.04	-43.7
Peopleonstreet	0.79	-0.05	-39.6
Traffic	0.69	-0.06	-46.2
Average	0.69	-0.05	-45

The maximum reduction by 48% in encoding time is related to *Kimono1* video, while the minimum reduction by 40% in encoding time is related to video of *peopleonthestreet*. Table 4 shows the efficiency of the proposed method compared to the method presented by Yao et al. [24] and Shen et al. [17]. The proposed method reduces coding time by 9% compared to the method of Yao et al. [24] while achieving a better bit rate.

5. CONCLUSION

In this paper, a fast method has been proposed for intra prediction in HEVC. The proposed method determines the details in each larger block by determining the predominant mode of the 4 × 4 blocks and decides accordingly. For each 4 × 4 block, the mode in horizontal, vertical and diagonal directions of 45 and 135 was calculated and the minimum value was determined as the dominant mode. For blocks larger than 4 × 4, the mode direction of the 4 × 4 blocks in that block was used to determine the dominant mode direction for that block. Then, according to the prevailing mode direction, a group of predictive modes was selected, which includes a mode in the same direction as the dominant mode and adjacent modes assessed for RMD. The simulation results showed that the proposed method can reduce the encoding time by an average of 45% while increasing the bit rate by 0.69%.

Table 4. Comparison of the results of the proposed method with several other methods.

Test sequences	ΔBitrate (%)	ΔPSNR (db)	ΔT(%)
Yao et al.[24]	0.57	-0.07	-36
Shen et al.[17]	--	--	-21
Proposed method	0.69	-0.05	-45

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